A COMPUTER SIMULATION OF A PACKAGING LINE

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

JAMES RANDOLPH STONEMAN

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Dr. Wayne H. Clifford
Major professor

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ABSTRACT

A COMPUTER SIMULATION OF A PACKAGING LINE

By

James Randolph Stoneman

This thesis and its computer program are designed to simulate the operation of a high speed beverage canning line such as a beer or soft drink line. The packaging line chosen for this study is composed of five machines and a connecting conveyor system. Through detailed time studies, accurate data has been collected on the speeds and relevant downtimes of these machines and programmed into the simulation procedure. Treating these as constants, the lengths of the interconnecting conveyor lines can be altered and their effect on total line production can be examined. An optimum conveyor length, matching capital investment against production, can be arrived at without having to spend the money or take the risk of actually making a physical change in the line.

A COMPUTER SIMULATION OF A PACKAGING LINE

By

James Randolph Stoneman

A THESIS

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CHAPTER I

INTRODUCTION

The purpose of this thesis is to duplicate the operation of a high speed beer or soft drink canning line. The typical beverage line is comprised of five machines and a connecting conveyor system. These machines include:

1. Depalletizer - to remove the bottomless empty cans from the incoming pallets.
2. Filler - to fill the empty cans with product.
3. Seamer - to attach the bottoms in an air tight double seam.
4. Packer - to place the containers in convenient packs of six and eight.
5. Traymaker - to place the packs in corrugated trays for easy loading and shipment.

The interaction of these machines becomes very complex as each operates at different speeds, has different capacities, and different patterns of breakdown. Consequently, direct analytical techniques are inadequate in reproducing such a system. The computer, then, is necessary to simulate the operation of various designs of such a high speed line.

A computer model is simply defined as a mathematical model expressed or written according to a particular set of rules so that the model may be processed by the computer.[1]

Simulation is defined as dynamic representation achieved by building a model and moving it through time.[2]

Simulation models have been used to date for purposes of experimentation or evaluation, that is, in trying to predict the consequences of changes in conditions, or methods without having to spend the money or take the risk of actually making the change in real life.[3] Models cannot replace the real world; at best they reduce a complex system to manageable proportions or serve to crystallize our thinking and perception.[4]

Soft drink and beer canning lines lend themselves well to the modern mass-production system of high speed assembly lines in meeting the large demands of the consuming public. However, mistakes in assembly line design can be costly in terms of idle time, lost production, and

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[1]McMillan and Gonzalez, Systems Analysis - A Computer Approach to Decision Models (Homewood, Ill.: R. D. Irwin, 1968), p. 12.

[2]William Arthur, "To Simulate or Not to Simulate: That Is The Question," Educational Data Processing Newsletter, XII, No. 4 (1968), 9

[3]Dimetris N. Chorafas, Systems and Simulation (New York: Academic Press, 1965), p. 17.

[4]McMillan and Gonzalez, p. 9.

excess capital investment. Computer simulation can be used in predicting the performance of a proposed line design, and can, therefore, be useful in avoiding costly mistakes in the installation and operation of an inadequate assembly line.[5]

The packaging line chosen for this study is composed of five machines and a connecting conveyor system. Each machine or station contributes to the work of the previous station, resulting in the production of the finished product at the end of the assembly line. The main program PKGLINE simulates the principle of this high speed line with packages entering and exiting at each operating station. Through exacting time studies the speeds and breakdown frequencies of these machines have been recorded and incorporated into the simulation program through the use of the subroutine DOWN.

These processing machines include (1) depalletizer, (2) filler, (3) seamer, (4) packer, and (5) traymaker. They will be examined in detail.

Depalletizer

Nine foot high pallet loads of bottomless empty cans are unloaded from semitrailers. The pallets are

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[5] Janis Church, Simulation as a Tool in Assembly Line Design (Dearborn, Michigan: Society of Manufacturing Engineers, 1971), p. 10.

pushed on a set of rollers built into the truck beds directly onto another set of rollers that feed into the depalletizing machine. A hoist raises the pallet into position and a sweep arm automatically pushes each layer of cans onto an accumulation table. This procedure is repeated for each layer of cans until the pallet is emptied. It is then automatically moved into a bin with other empty pallets and is replaced in the hoist by a full one. The accumulation table can hold a full pallet width of cans. These cans are then fed into circular discs which send them singly onto a cable-driven conveyor line. The modern day depalletizer used in high speed beverage lines is capable of handling 1500 cans per minute (cpm) and costs about $18,000 on today's market.

While moving on the conveyor the cans are turned upside-down and rinsed with water to free them from any extraneous matter, such as fragments of fiber or other loose material.[6] This process does not require a machine but simply a twist in the conveyor line. Consequently it has not been included in the operation of the simulation program.

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[6]Morris B. Jacobs, Manufacture and Analysis of Carbonated Beverages (New York: Chemical Publishing Co. Inc., 1959).

Filler

The cans proceed directly to the filler, a large circular-pyramid shaped machine. It rotates automatically, slowing down when there are gaps in the line of cans on the infeeding conveyor and speeding up to top rotation velocity when the maximum number of cans are being received from the depalletizer. Filler speed is approximately 1300 cpm. This is the slowest machine in a high speed canning or bottling line. The cost of a large high speed filler is $150,000. Production and output efficiency of the packaging line is gauged on this machine.

Seamer

The seamer is usually situated very close to the filler because the loss of carbon dioxide between the time the cans are filled until they are sealed directly affects the shelf life of the product. The greater the loss of CO_2 the sooner the product loses its drinkability.

An operator hand feeds a tube of 408 closures (bottoms) at a time into this machine which seals the filled containers in an airtight double seam created by interlocking the curl of the lid and the flange of the can.[7] The seamer runs at the same speed and capacity as the filler. It costs about $90,000.

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[7]National Canners Association, The Canning Industry (Washington, D.C.: Communications Services, 1971), pp. 21-27.

At this point, the filled and closed cans must be warmed to room temperature and preferably higher to aid drying and to prevent sweating after casing. When dealing with beer lines this is not a problem as the cans are pasteurized, or cooked in steam ovens. As far as soft drink beverage lines are concerned, however, the product and metal container must be treated. Cans that are cased while they are wet, or which sweat after they are cased, are more subject to external rusting and may damage the cases. Such warming may be accomplished by warm water sprays. This serves the double purpose of washing away any of the beverage that may have spilled on the outside of the cans.[8]

Packer

Cans are brought via conveyor into the packing and cartoning area. The packer divides the cans into groups of six or eight and places a set of clear plastic rings around the top of each pack, separating them permanently into six or eight packs for further processing. The packer runs at about 1500 cpm and costs in the neighborhood of $150,000 not installed.

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[8] Jacobs, p. 6.

Traymaker

The six and eight packs are grouped together in fours and threes respectively and die cut corrugated board is folded and glued with hot melt adhesive to form a tray around the containers. Filled trays are transported on conveyors to the dock area to be loaded onto pallets and into semitrailer trucks. A traymaker costs $130,000 and can handle 1700 cpm. This is the fastest machine on the line from the standpoint of cans handled per minute.

The costs of these five machines are for the capital investment only and do not take into account the charges for installing them in running position on the line. We can assume at least a 50% increase for installation.

Conveyors today cost $100.00 per running foot. These cost figures and capacities are current as of the first six months of 1975.

CHAPTER II

PROBLEM STATEMENT

When applying simulation the following steps are taken. The first is to isolate, define, and quantify the important features of the system to be simulated. Then these features are represented in terms of a model which is programmed for the computer. The model is then tested to make sure it is functioning correctly by making it reproduce known conditions. This validation stage enables the model-builder to check that all relevant factors have been included in the model and that the laws of behavior have been correctly represented therein. The last stage consists of running the model to simulate the effects of various proposed system configurations, so as to assess relative costs and benefits.[9]

The packaging line chosen for this study is a complex system with many components. It involves several machines and a variety of transfer equipment that is arranged and laid out to form a complete high speed beverage canning line. Because of this complexity and because

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[9] John Smith, Computer Simulation Models (London: Griffin, 1968), p. 3.

the elements can have a random or variable nature, direct analytical techniques are inadequate in selecting or designing the optimum packaging line. Simulation is chosen when the overall performance of a system cannot be estimated analytically and observation of the actual system is not practical. Trial-and-error changes to an operating packaging line can be expensive. With simulation, the performance of a proposed line, or changes to an existing line, are estimated without installing and operating the line.[10]

The computer is used to simulate the operation of various designs of such a high speed line. The machines interact with one another through their capacities, expressed in containers per minute (cpm), and downtimes thus affecting the production of other machines as well as total line output. By studying an actual high speed line pertinent data was gathered concerning machine capacities and relevant downtimes. Treating these as constants, the lengths of the interconnecting conveyor lines can be altered and their effect on total line production can be examined.

For purposes of this paper we assume:

1. A continuous infeed of cans into the first machine, the depalletizer.

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[10]Church, p. 5.

2. An infinite amount of storage space capable of accepting all the output of the last machine, the traymaker.
3. No downtime due to conveyor malfunctions. All downtime is attributed to the machines in the line.

Without being redundant it should again be mentioned that capital costs of the various machines in a high speed beverage line are substantial. With this computer program, line production efficiency can be set against conveyor cost to design the most efficient line at the lowest net cost.

The program, written in FORTRAN, uses variable names to describe the machines (stations), downtimes, and conveyors (buffers). It is relatively easy to change the number and locations of the stations, the number, location, and size of the buffers, the distribution of operating time, and the probabilities of rejects and jams to simulate other assembly lines.

CHAPTER III

SIMULATION MODELING

The problem and an abstract model of the theory behind the simulation program have been examined in previous sections. Now the simulation model will be examined in detail.

Figure 3.1 isolates a machine and its entering and exiting conveyor mechanisms. The variables are defined:

$C_{(I)}$:	entering conveyor to machine I.
$M_{(I)}$:	machine I.
$C_{(1+1)}$:	exiting conveyor from machine I carrying units to machine I+1.
$ICM_{(I)}$:	maximum number of units conveyor I can hold. This is a holdup on the line.
$ICP_{(I)}$:	actual number on conveyor I from previous cycle $0 \leq ICP \leq ICM$.
$NMM_{(I)}$	maximum number of units machine I can hold. This is the quantity Q(I) multiplied by the change in time and is also a holdup on the packaging line.
$NMP_{(I)}$:	actual number in machine I. These will exit if exit conveyor I+1 is open. $0 \leq NMP \leq NMM$
$MD_{(I)}$:	machine downtime if $MD \geq 1$ machine I is down if $MD \equiv 0$ machine I is operating.

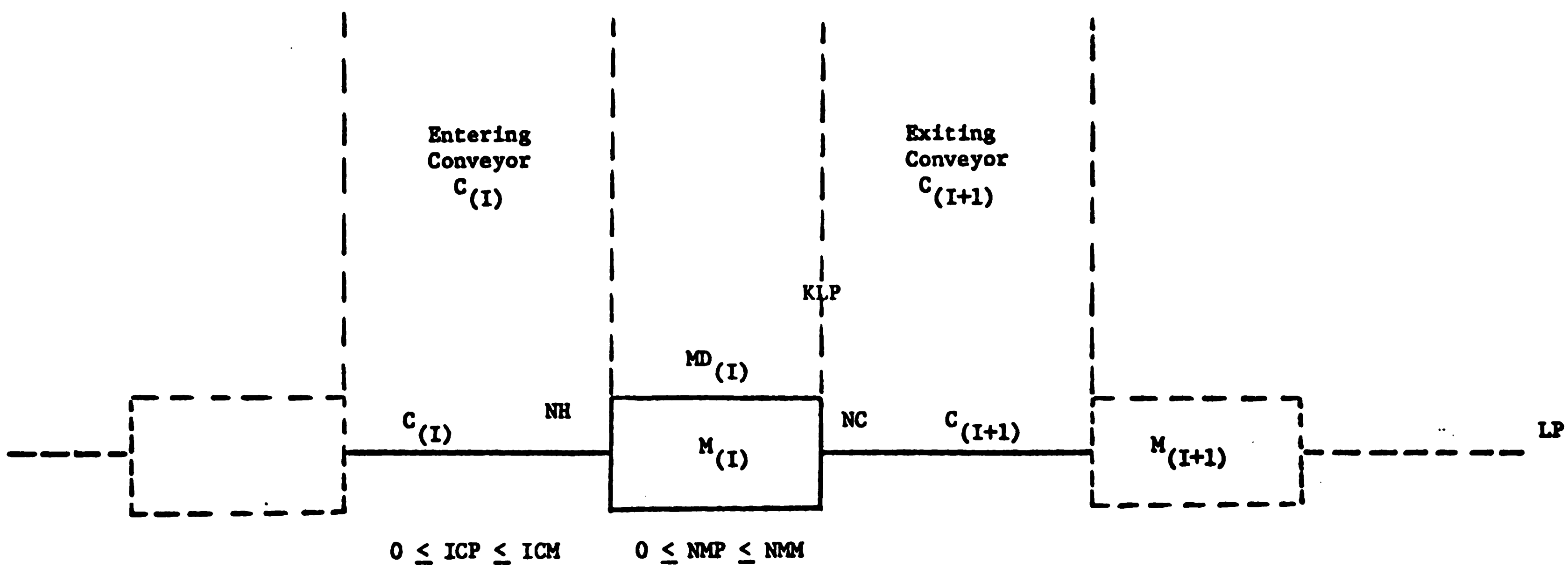


Figure 3.1.—Block Diagram for Simulation Model.

$KLP_{(I)}$: the production for machine I.

$NH_{(I)}$: the number of packages to leave conveyor I to enter machine I. It is the smaller of the machine capacity and the conveyor content.

$NC_{(I)}$: the number of packages to leave machine I to enter conveyor I+1. It is the smaller of the conveyor capacity and the machine content.

The simulation program can be divided into two parts: (Figure 3.2):

I. the exiting packages from $M_{(I)}$

II. the entering packages to $M_{(I)}$

I. The exiting packages

A. A check is run on the station machine $M_{(I)}$ to see if it is down.

1. If yes: no units will exit, output = 0

2. If no: the machine is operating. The number of packages (units) in this machine from the previous cycle will exit on this cycle if the exit conveyor $C_{(I+1)}$ is open.

B. A check is made to see if the empty space on the conveyor $C_{(I+1)}$ is capable of holding all the packages exiting from the maching $M_{(I)}$.

1. If no: the number on the conveyor is incremented by the number of packages it can accept (denoted by NC) and the number in the machine is lessened by a similar amount, or

$$ICP_{(I+1)} = ICP_{(I+1)} + NC$$

$$NMP_{(I)} = NMP_{(I)} - NC$$

2. If yes: the number on the conveyor is incremented by the entire quantity in the machine and the machine is left empty. Equations

$$ICP_{(I+1)} = ICP_{(I+1)} + NMP_{(I)}$$

$$NC = NMP_{(I)}$$

$$NMP_{(I)} = 0$$

show this operation.

Machine I can now accept packages from conveyor I.

II. The entering packages

A. A check is run to see if the empty space in the machine $M_{(I)}$ is capable of holding all the packages exiting from the conveyor $C_{(I)}$.

1. If no: the number in the machine is incremented by the number of packages it can accept (denoted by NH) and the number on the conveyor is lessened by a similar amount, or,

$$ICP_{(I)} = ICP_{(I)} - NH$$

$$NMP_{(I)} = NMP_{(I)} + NH$$

2. If yes: the number in the machine is incremented by the entire quantity on the conveyor and the conveyor is left empty. Equations

$$NMP_{(I)} =_{(I)} + ICP_{(I)}$$

$$NH = ICP_{(I)}$$

$$ICP_{(I)} = 0$$

show this operation.

The following are mathematical equations for the simulation model.

1. $0 \leq ICP \leq ICM$

2. $0 \leq NMP \leq NMM$

3. MD = 0 if the machine is operating.

   = 1,2,3,...7 if the machine is down. The whole number indicates the length of time in minutes the machine is not running.

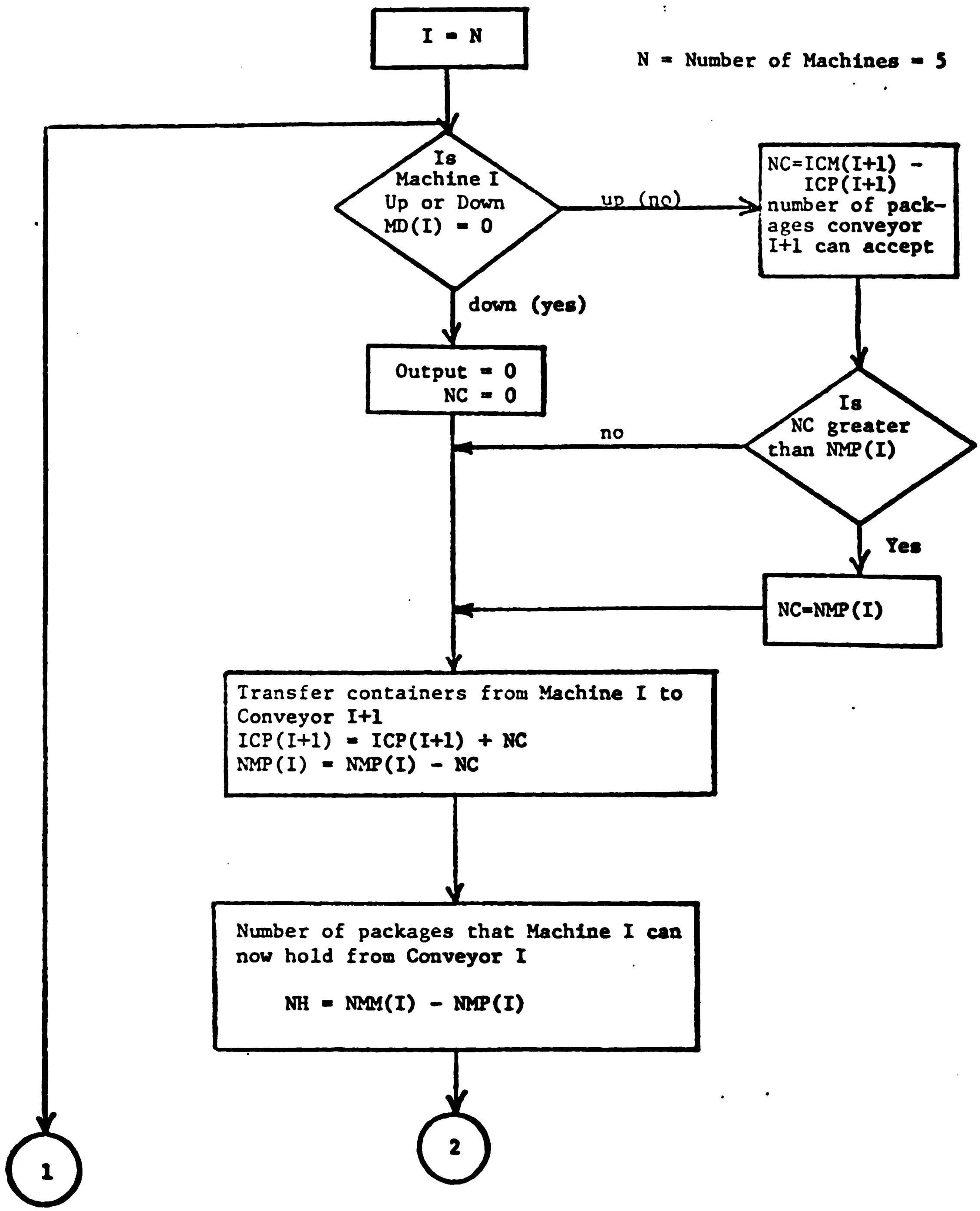


Figure 3.2.—Flow Chart for the Simulation Model, Part I

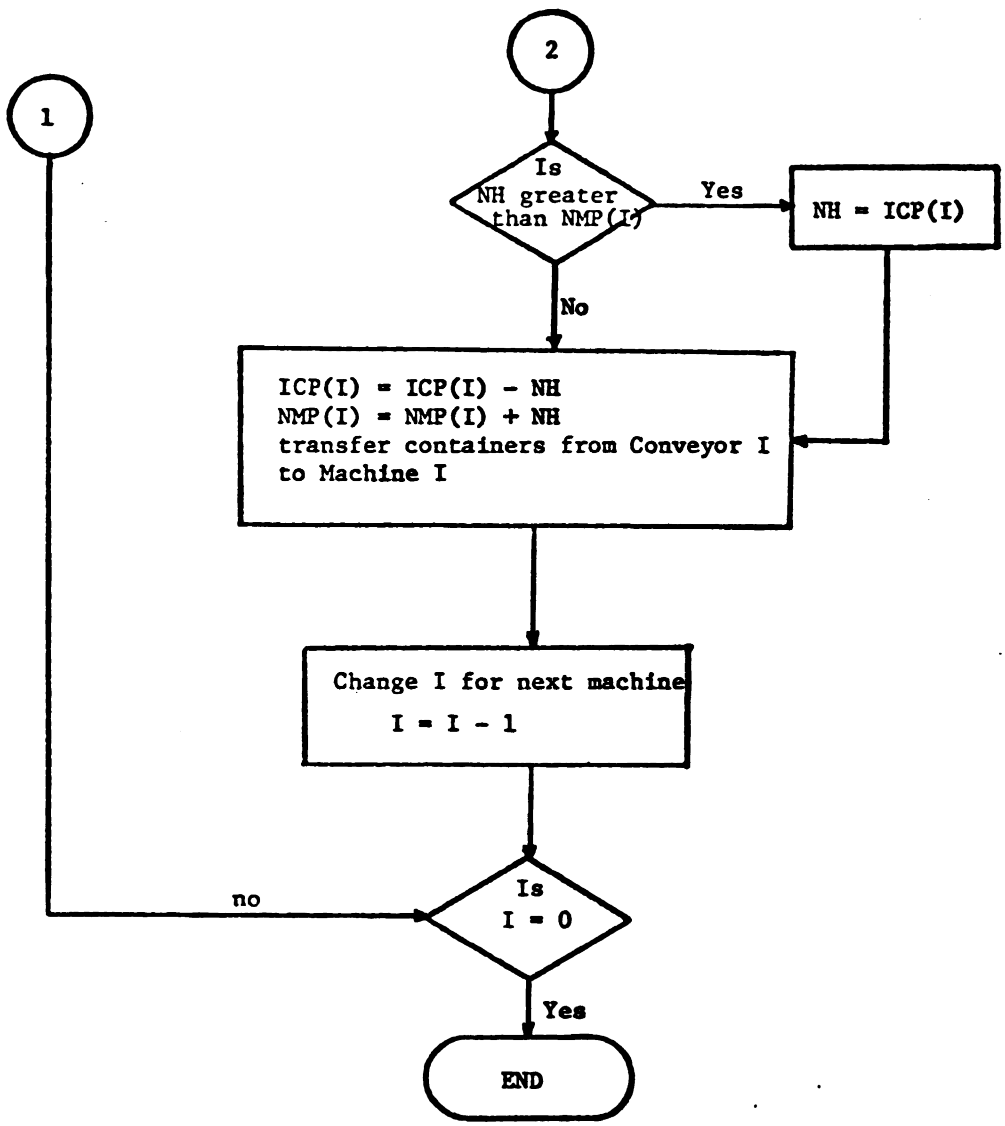


Figure 3.2.--Flow Chart for the Simulation Model, Part II

CHAPTER IV

DOWNTIME VALIDATION

Data for the subroutine evaluating the frequency and size of the downtimes occurring in the packaging line was gathered from detailed time studies made in a high speed beverage canning plant over a period of three weeks. This entailed 90 hours of actual observation. The operation times were observed and for each station the distributions of those times were determined from a stopwatch study. The actual data and the appropriate bar graphs are presented for the depalletizer, filler, and seamer in the line. Downtime data and bar graphs for the packer and traymaker were estimated by Bill Weatherston, Superintendent of Canning for a large Great Lakes brewery.

Depalletizer Downtime Data

Time	Reason
7"	trouble with pallet infeed
1' 21"	broken pallet
2'	pallet caught on edge of hoist
2' 22"	something caught under pallet at hoist
3' 54"	broken pallet

17"	slow infeed
54"	hoist not raise pallet
1' 6"	edge of pallet caught on hoist
36"	hoist not raise pallet
14"	pallet change
8"	pallet change
1' 16"	inspection of equipment
3' 2"	switch lines
1' 41"	personnel switch
1' 23"	personnel switch
2' 29"	personnel switch
14"	pallet not lock into place
54"	personnel switch
8"	personnel switch
22"	personnel switch
56"	personnel switch
47"	pallet change
54"	pallet change
29"	pallet change
50"	pallet change
1' 56"	chip board jam
10"	jammed caps
42"	grip fingers missed chipboard
14"	grip fingers missed chipboard
12"	grip fingers missed chipboard
21"	grip fingers missed chipboard

10"	grip fingers missed chipboard
10"	grip fingers missed chipboard
43"	grip fingers missed chipboard
12"	grip fingers missed chipboard
12"	grip fingers missed chipboard
1' 4"	grip fingers missed chipboard
8"	grip fingers missed chipboard
18"	chipboard jam
56"	chipboard jam
54"	chipboard jam
2' 54"	chipboard jam
55"	chipboard jam
1'	chipboard jam
48"	grip fingers missed chipboard
36"	grip fingers missed chipboard
32"	grip fingers missed chipboard
18"	grip fingers missed chipboard
1' 3"	grip fingers missed chipboard
2' 16"	grip fingers missed chipboard
1' 14"	grip fingers missed chipboard
1' 49"	grip fingers missed chipboard
3' 8"	grip fingers missed chipboard
34"	grip fingers missed chipboard
44"	grip fingers missed chipboard
28"	grip fingers missed chipboard

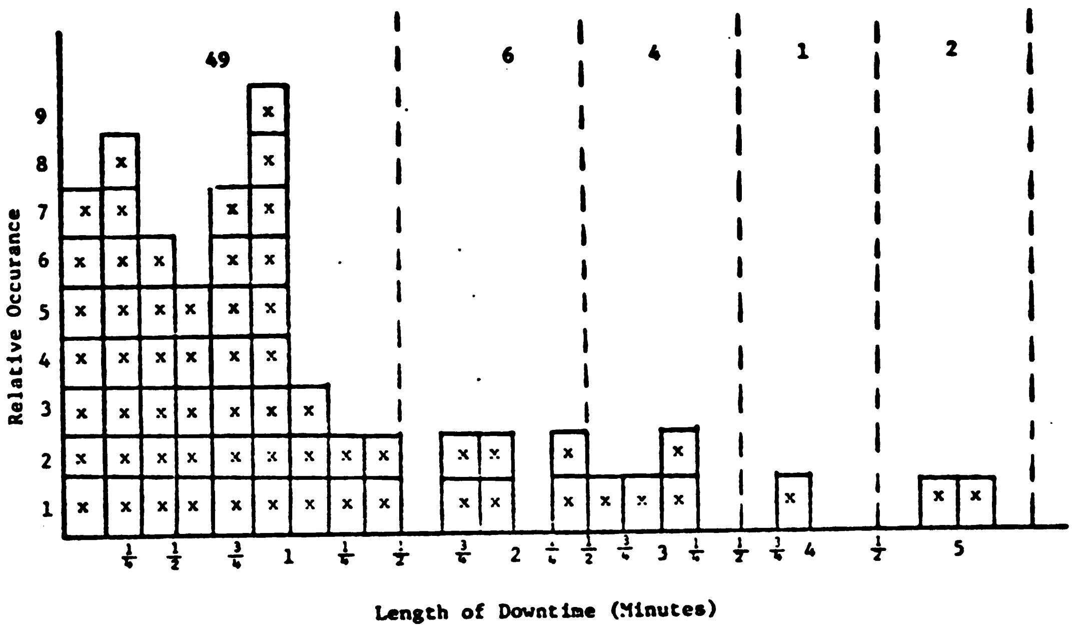


Figure 4.1.--Depalletizer Downtime.

4'45"	chip jam in hopper
4"	suction cup malfunction
26"	jam at disc outfeed
30"	loose chip - not lower
50"	jam at disc outfeed
1'	inspector
40"	jam at disc output

<u>Filler Downtime Data</u>

3'	jam in exiting tunnel
15"	jam in exiting tunnel
41"	jam in exiting tunnel
12"	high can switch malfunction
4"	high can switch malfunction
7' 24"	low level oil
10"	tipped can at filler output
24"	jam at filler infeed
2'	jam in tunnel
19"	bent can
41"	jam in tunnel
2' 24"	bent can in worm gear
7"	output-one can gap
57"	jam in tunnel
16"	can partially filled
28"	can partially filled
30"	can partially filled

1' 12"	can partially filled
1' 2"	can partially filled
22"	no grease - one hour-light
2' 34"	no CO_2 light
1' 10"	clean filler with water
6' 20"	can partially filled
4"	jam in tunnel
1'	bent can at high can limit
1' 2"	jam in tunnel
8"	no CO_2 gas
7' 4"	low oil level
2'	jam in tunnel
2' 12"	jam in tunnel
1' 30"	jam in tunnel
54"	jam in tunnel
1' 35"	jam in tunnel
50"	jam in tunnel
42"	jam in tunnel
1'	jam in tunnel
1' 26"	jam in tunnel
56"	jam in tunnel
50"	no grease one hour-light
40"	no grease one hour-light
2'	can jam at infeed
1'	no grease one minute-light
1'	bent can at high can limit

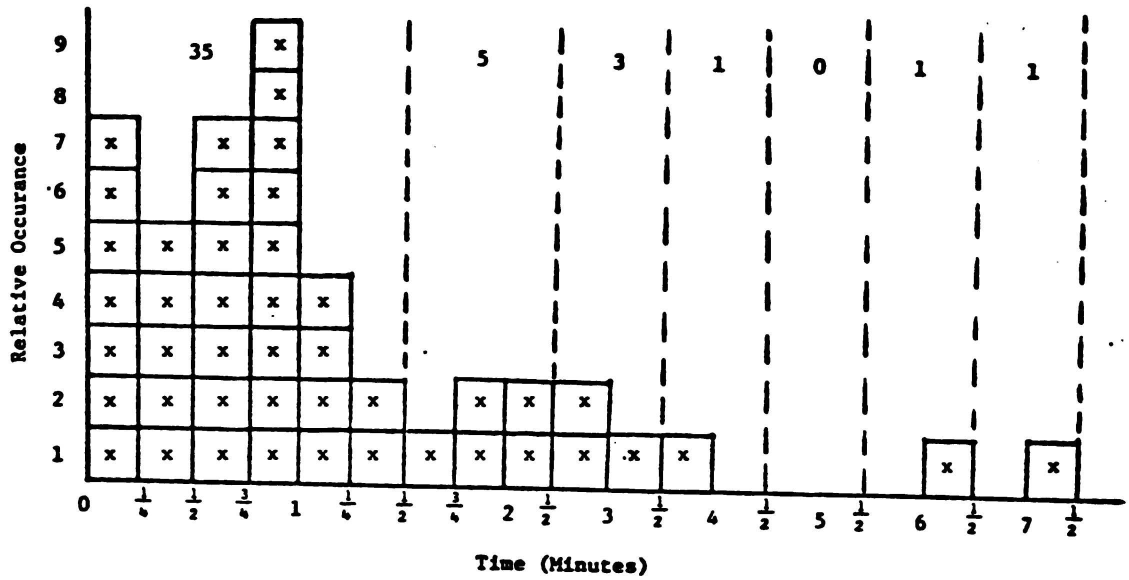


Figure 4.2.--Filler Downtime.

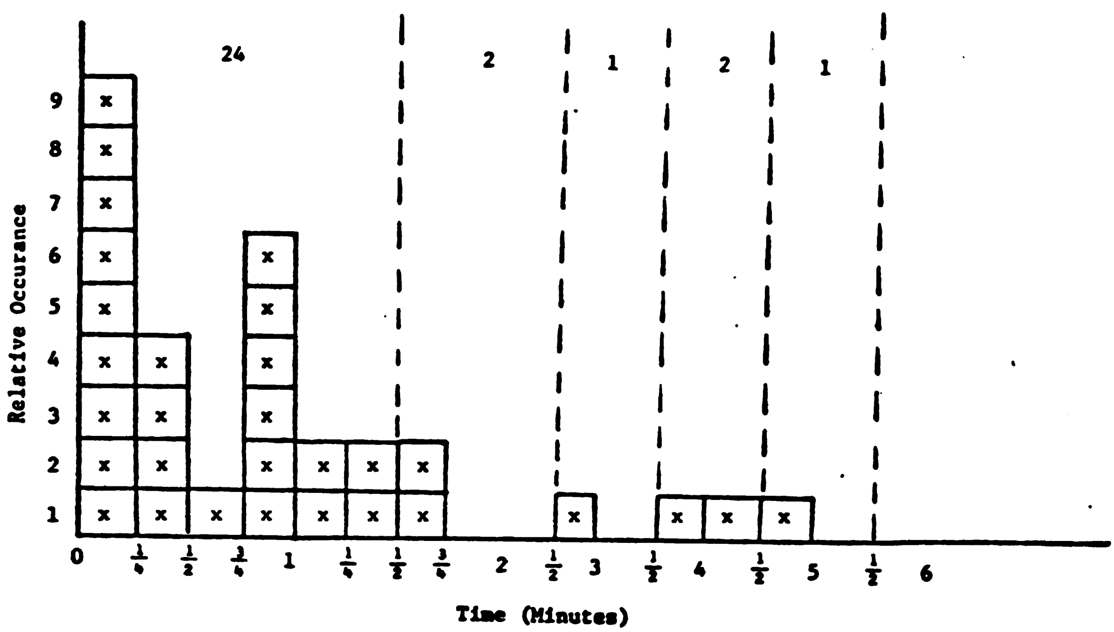


Figure 4.3.--Seamer Downtime.

1'	no grease one minute-light
4"	jam in tunnel
1'	no grease one minute-light
1'	bent can
1'	bent can
3'	jam at rinser

<u>Seamer Downtime Data</u>

32"	jam at discharge rail
3' 38"	bent lid in seamer head
1' 32"	bent can in seamer
1'	can jam in seamer output
3"	seamer missed lid
30"	seamer missed lid
11"	seamer missed lid
1' 17"	jam seamer output
2' 42"	seamer output-machinist
4"	missed lid
4"	missed lid
50"	seamer output jam
1'	seamer input jam
1'	seamer output jam
2'	can jam
5'	transfer chain jammed
1'	seamer output jam
8"	seamer missed lid

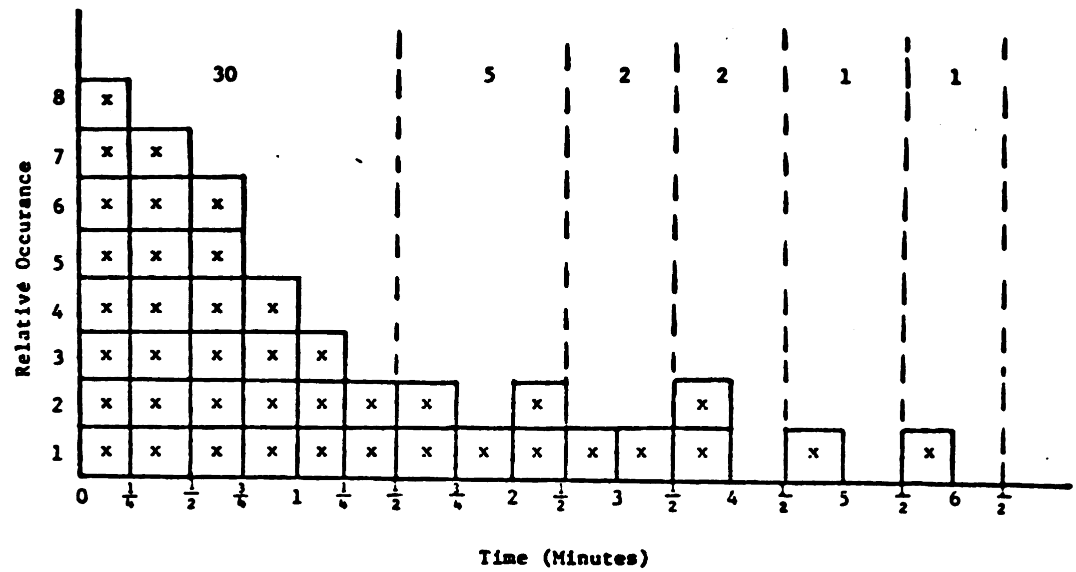


Figure 4.4.--Packer Downtime.

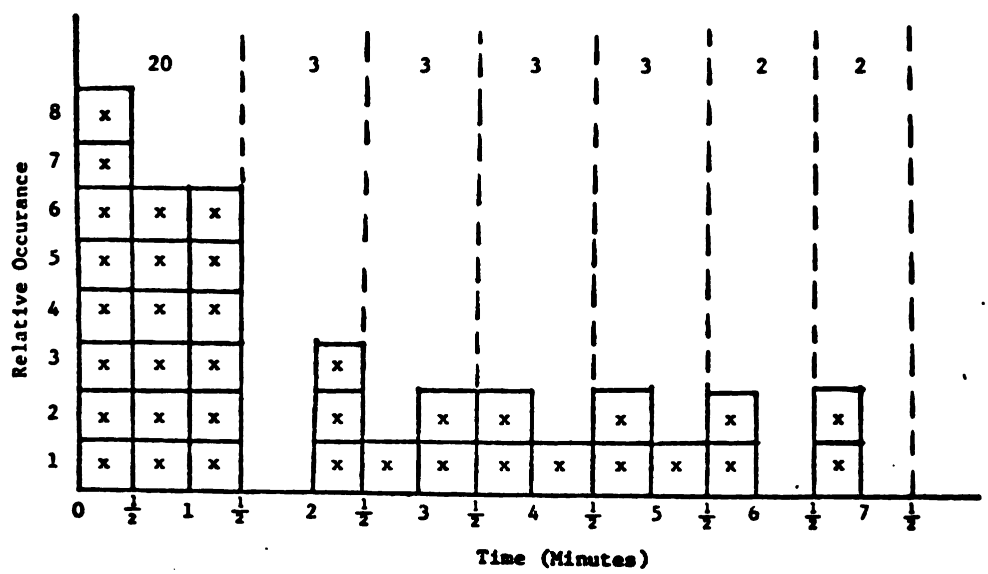


Figure 4.5.--Traymaker Downtime.

22"	jam seamer output
5"	seamer missed lid
10"	seamer missed lid
4"	seamer missed lid
24"	seamer missed lid
1' 34"	jam at output
4' 6"	output conveyor - air nozzle
1' 10"	output conveyor - air nozzle
24"	seamer input jam
15"	seamer input jam
1' 30"	seamer input jam
1' 10"	seamer input jam
1'	bent can at seamer

In order to use this data in a subroutine and make it applicable to this simulation program the number of occurrences of downtime in each minute time frame were counted and rounded to the nearest whole minute. The size of the breakdowns range from one to seven minutes. Each minute for all five machines is represented by one data card for a total of seven cards in all. The card representing the first minute is shown:

```
DATA (NX(1,K), K=1,5) / 49,35,24,30,20/
```

This translates to mean:

49 - one minute breakdowns for the depalletizer

35 - one minute breakdowns for the filler

24 - one minute breakdowns for the seamer

30 - one minute breakdowns for the packer

20 - one minute breakdowns for the traymaker

The depalletizer data for all seven minutes is broken down as follows:

1 minute -	49 occurrences	total time 49 minutes
2 minute -	6 occurrences	12 minutes
3 minute -	4 occurrences	12 minutes
4 minute -	1 occurrence	4 minutes
5 minute -	2 occurrences	10 minutes
6 minute -	0 occurrences	0 minutes
7 minute -	0 occurrences	0 minutes
		87 minutes

It was decided to operate this line at approximately 80% efficiency, therefore 87 minutes or 20% of the total running time, the depalletizer is down. This would signify a total simulation time of 87 ÷ .20 = 435 minutes. The total simulation run to insure 80% efficiency for all five machines is shown in an eighth data card:

DATA NTOT / 435,355,220,325,440 /

435 minutes is the total simulation run for the depalletizer
355 minutes is the total simulation run for the filler
220 minutes is the total simulation run for the seamer
325 minutes is the total simulation run for the packer
440 minutes is the total simulation run for the traymaker

At what point in time a machine breaks down and how long it remains down is determined by a random number generator (RANF(X)) subroutine in the computer that generates a number sequence between 0.0 and 0.99...9. This sequence is found to be randomly and uniformly distributed based on chi-squared testing.

An example of this downtime generation is shown for the depalletizer.

Equation: M = NTOT(K) * RANF(0.5) + 1.0
= 435 * (0.130...) + 1.0
= 57.6 ...

A different random number value for M is determined for the depalletizer as well as for each of the other machines at the beginning of each one minute time period. This value is then run through the first column of the seven data cards. Referring to the Subroutine DOWN in Appendix A, it is seen that 57.6 is greater than 55 but smaller than 59, thus denoting the depalletizer will go down for a period of three minutes. Should M be larger than 62, as it will be 80% of the time, the machine would remain in operation.

CHAPTER VI

COMPUTER PROGRAMMING

5.1 Flow Chart

The computation process consists of a main program and two subroutines.

The main program, PKGLINE, is concerned with simulating the movement of a high speed assembly line. Each station (machine) is handled individually with its entering and exiting conveyor systems. Checks are run on each station to see if it is operating and to see how many packages each machine is capable of accepting from the entering conveyor. Likewise a check is made to see how many packages the exiting conveyor is capable of accepting from its machine.

The subroutine DOWN analyzes and delegates down-time to the various line machines in accordance with observed data gathered from actual high speed assembly line observations and estimates.

The subroutine PLINE used in Proof Model 4 uses fields of symbols to present a unique visual "picture" of the units as they are processed through the line. It was written by Dr. Wayne Clifford, Assistant Professor at the School of Packaging for presentation at a brewery packaging technology seminar at Kellogg Center.

A complete simulation run is eight hours. The time increments are one minute each, totaling 480. The program computes the line status each six seconds and prints out the current standing of each machine and corresponding entering conveyor at the end of each minute. The subroutine PLINE prints its visual every six seconds.

Flow charts have been drawn to show both the main program PKGLINE, and the subroutine DOWN:

Figure 5.1.1 for PKGLINE and Figure 5.1.2 for DOWN.

The variable names used in the main program:

ICP:	number of packages on each conveyor.
ICM:	maximum capacity of each conveyor.
NMP:	number of packages being processed at each station.
NMM:	maximum capacity of each station.
MD:	machine down = 0 if machine is running. = 1,2,...7 if machine is down.
KLP:	production of each machine.
KPT:	distinguishes the individual machines (depalletizer, filler, seamer, packer traymaker)
UPD:	indicates if machine is operating or not by printing UP or DN.

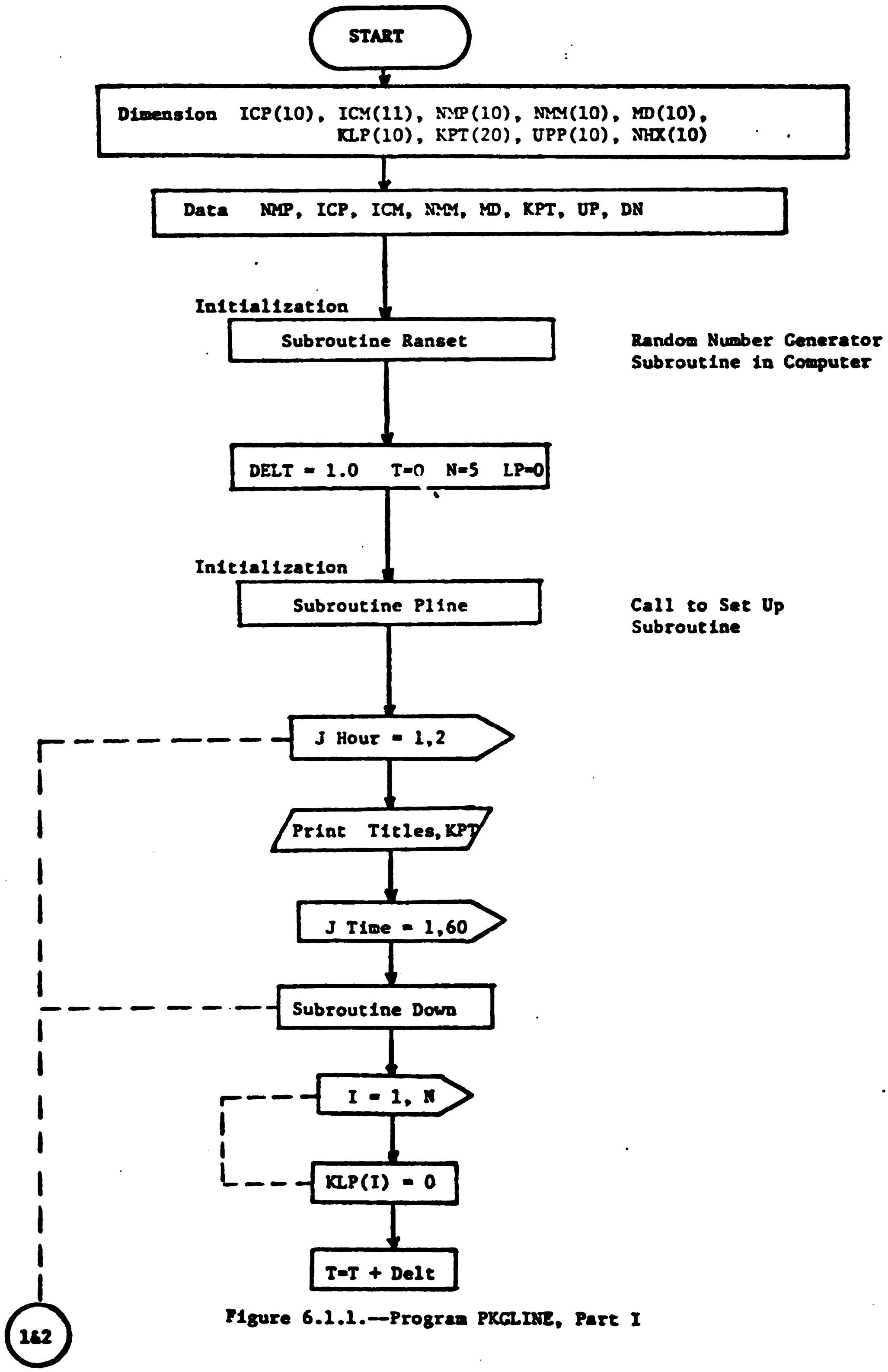


Figure 6.1.1.—Program PKGLINE, Part I

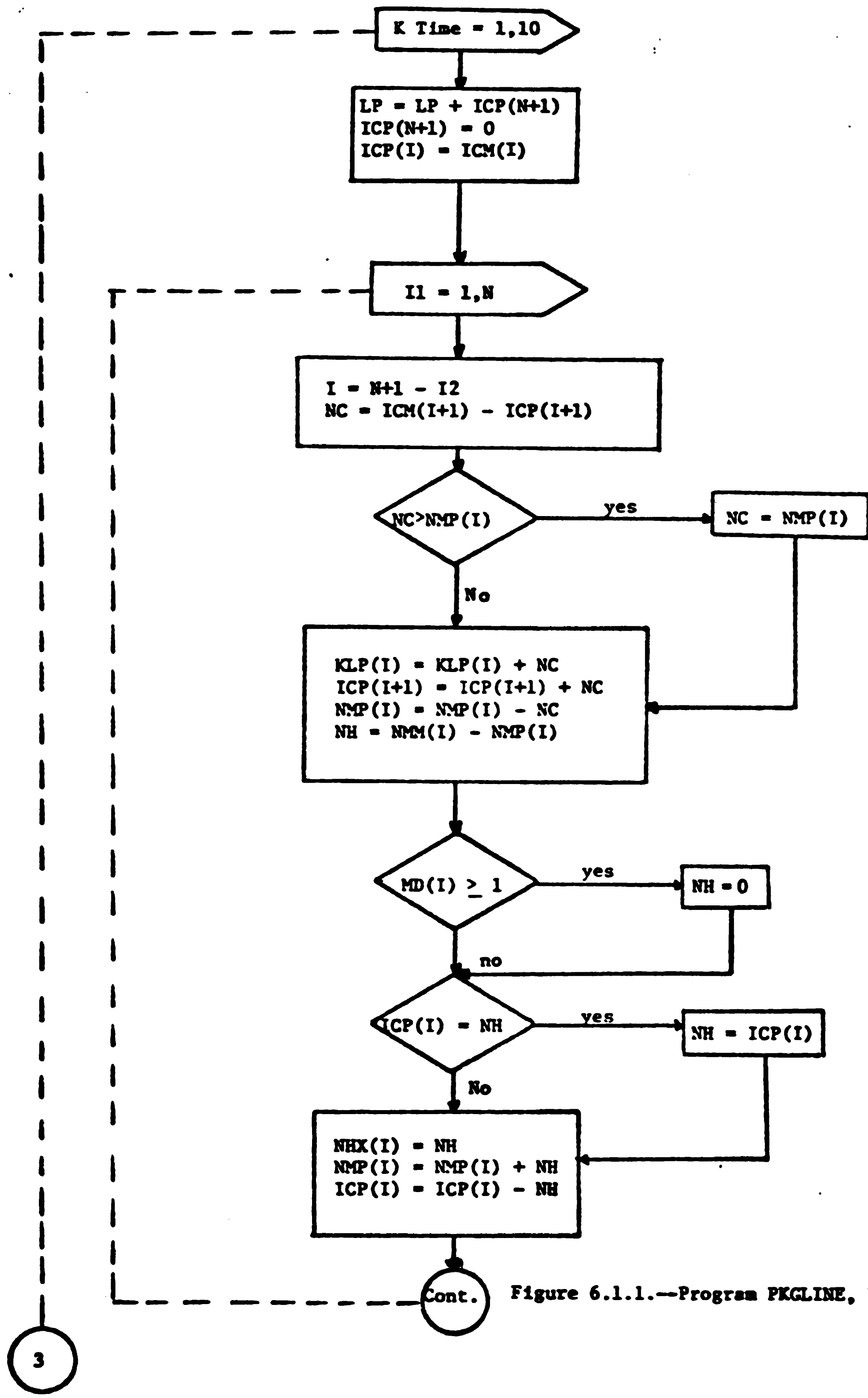


Figure 6.1.1.—Program PKGLINE, Part II

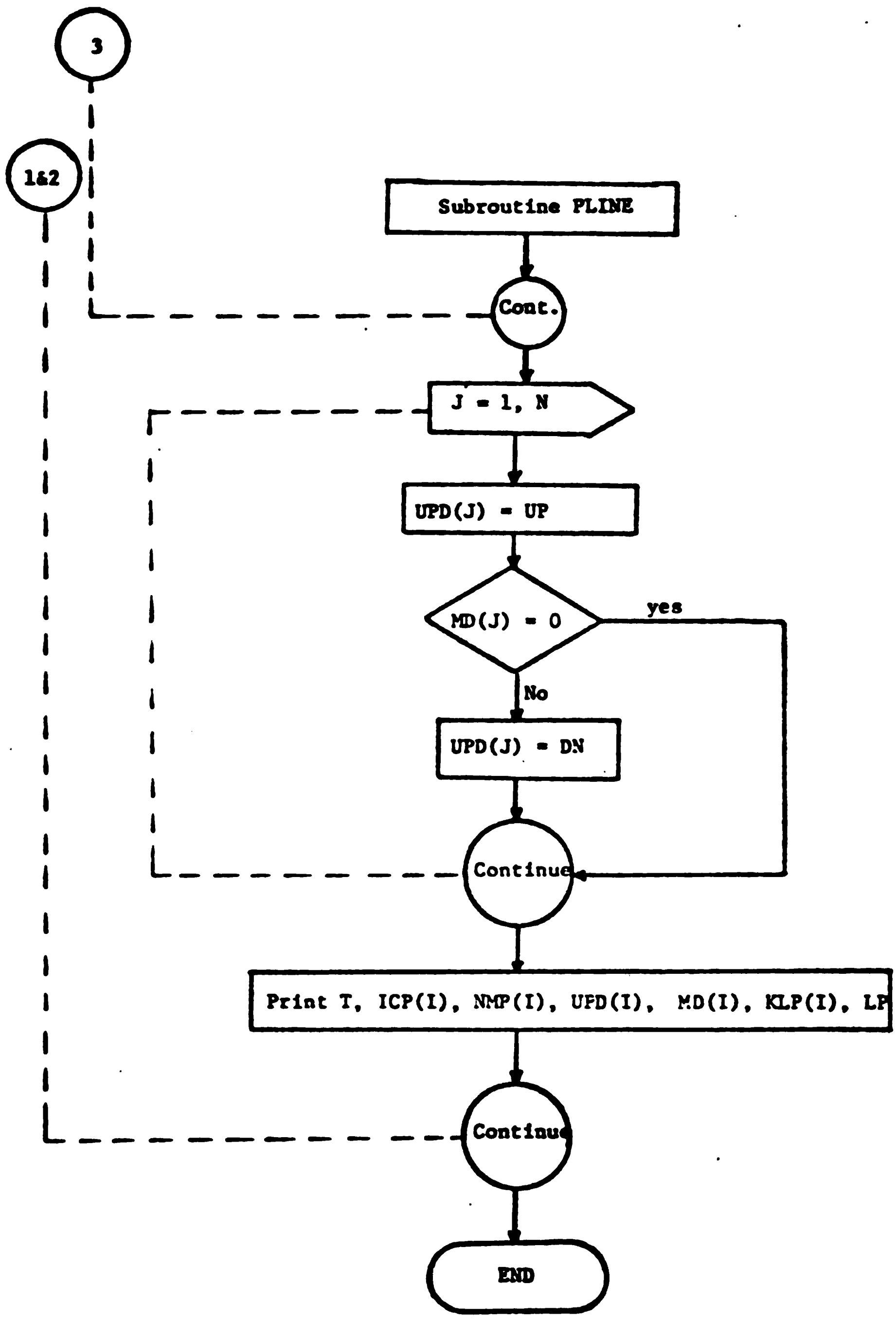


Figure 6.1.1.--Program PKGLINE, Part III

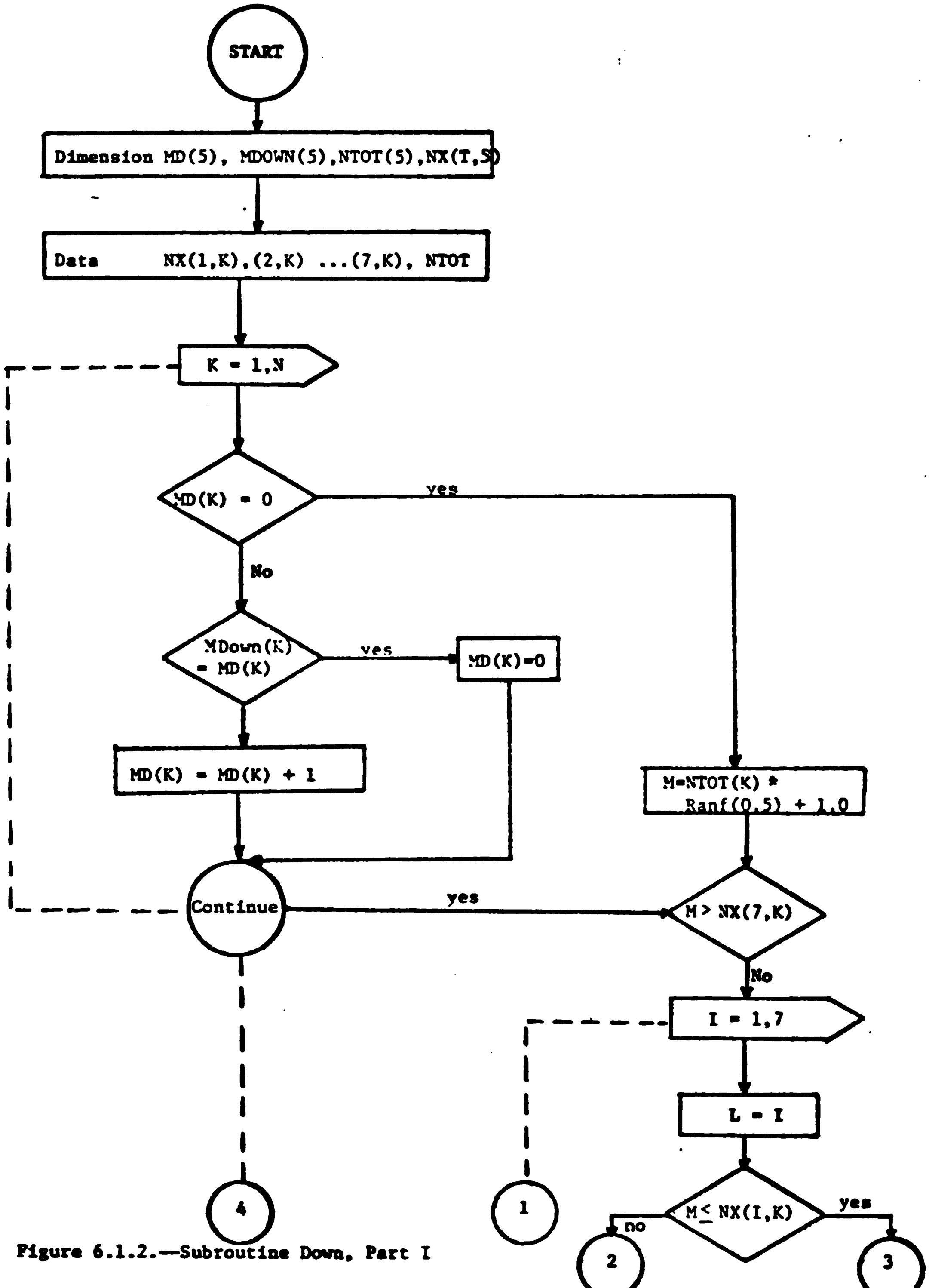


Figure 6.1.2.--Subroutine Down, Part I

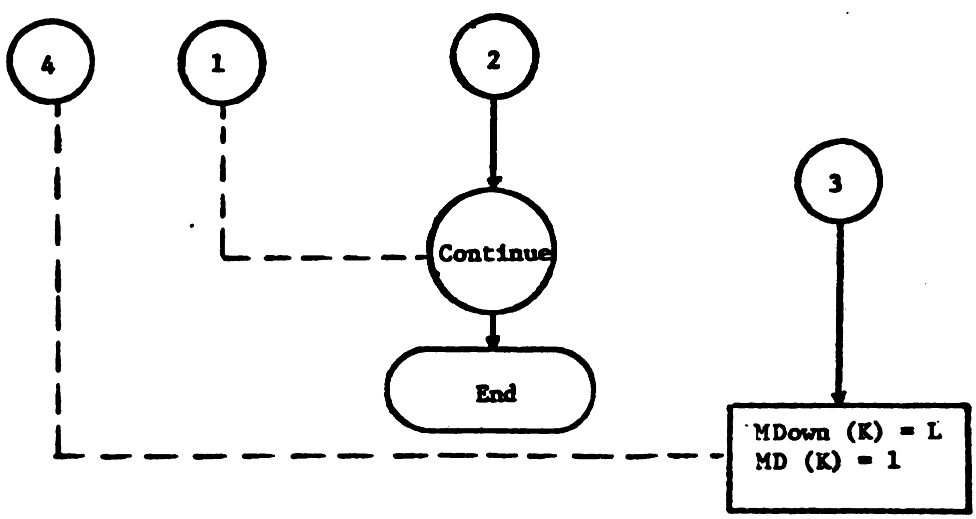


Figure 5.1.2.—Flow Chart for Subroutine DOWN, Part II

NHX: array necessary for PLINE subroutine

DELT & T: time in minutes

N: number of machines in the line (5)

LP: total line production

NC: number of packages to exit machine and enter conveyor

NH: number of packages to exit conveyor and enter machine

The variable names used in DOWN:

DOWN: stores the time in minutes the machine is down

NTOT: running time from which random selector picks downtime

NX: two dimensional array used in matching length of downtime to machine

In the computer numerous computations occur in a simulation run, the number of which depends on the length of the run. In this case when simulating a beverage line for a greater period of time than one eight hour shift, 20 minutes of downtime must be allowed for the entire line for lubrication.

Assumptions used in the program:

1. Perpetual infeed to the conveyor entering the depalletizer.

2. Infinite storage space available to accept all the output from the traymaker.

3. All downtime is attributable to the five stations. The conveyors are trouble free.

4. In the actual downtime data studies, large downtimes not characteristic with normal downtime problems were ignored.

5. The incremental revenue on a single unit is assumed to be $0.03. To simplify matters in this paper, the entire amount will be applied to the capital investment in the conveying mechanisms.

CHAPTER VI

PROOF OF THE COMPUTER PROGRAM

Four models are examined:

1. A model with infitied (500,000 units) conveyor lengths between the stations.
2. A model with very small (140,140,120,140, 160,160) conveyor lengths between the stations. These lengths correspond to the larger machine capacities at either end of each conveyor.
3. A model with different size conveyor lengths between the stations. It will try to optimize output production at the lowest cost of conveying mechanisms.
4. Similar to model three but with the addition of the subroutine PLINE.

In each model the cost versus production aspect will be examined.

The optimum conveyor capacities could be found with a sophisticated trail and error subroutine, such as Rosenbrock's HCLMB.[11] However, the routine requires numerous multiple runs and its cost makes it prohibitive for this exercise. If one were designing a real assembly

[11] H.H. Rosenbrock and C. Storey, Computational Techniques for Chemical Engineers (New York: Pergamon Press, 1966), pp. 64-68.

line for a company this subroutine would be vital to pinpointing the optimum conveyor lengths.

6.1 Proof Model 1

This model forms a coupling of the five machines in a series as shown in Figure 6.1. It is designed with very large (500,000 unit) conveyor lengths or reservoirs between the machines. Each reservoir is half full of units at the beginning of the simulation run.

Because of the very large reservoirs each machine operates independently of line capacities and downtimes of the others. There is no idling time due to the inability of the entering conveyor to transport units (cans) or the existing conveyor to accept them. Therefore, each machine is expected to yield its full catalog efficiency of operation and the line efficiency will equal that of the last machine.

The simulation result of the proof model is shown in Table 6.1. Each machine turns over its stock of units every six seconds or ten times every minute. At the end of each minute there is a summary of the current status of each entering conveyor and corresponding machine.

Example:

TIME C1 M1 D1 P1 .... C5 M5 D5 P5 TOTAL

TIME: the time in minutes.

C1...C5: indicates the number of units on the conveyor as it is about to enter the station (depalletizer, filler, seamer, packer, traymaker).

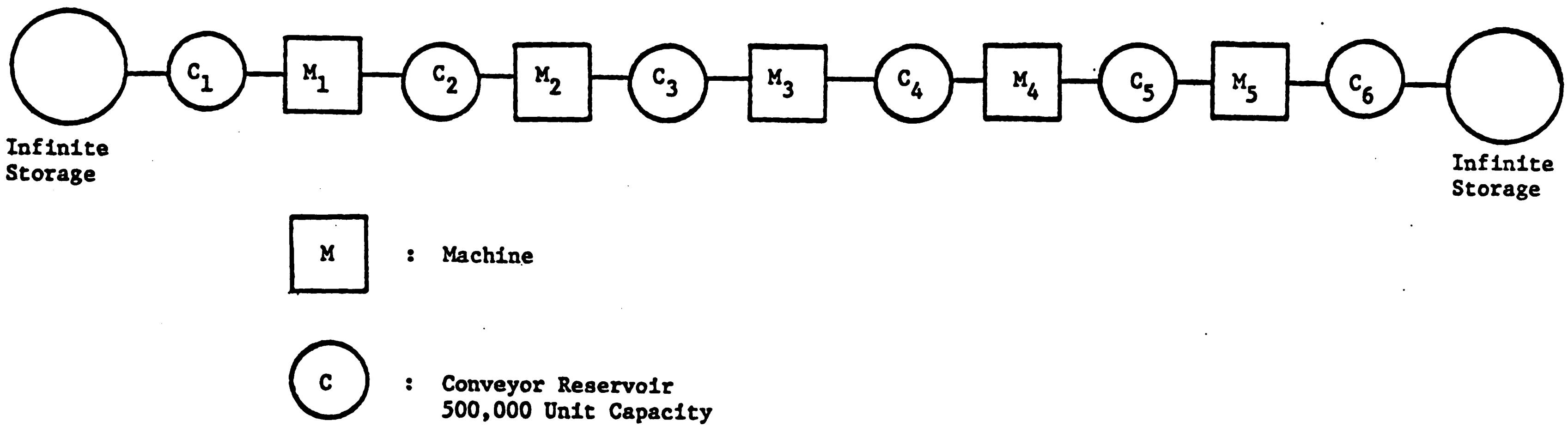


Figure 6.1.--Proof Model 1.

TIME	DEPALLETIZER					FILLER					SEAMER					PACKER					TRAYMAKER					
MIN	C1	M1	D1		P1	C2	M2	D2		P2	C3	M3	D3		P3	C4	M4	D4		P4	C5	M5	D5		P5	TOTAL
1.0	500000	0	DN	1	0	[illegible]	0	DN	1	0	[illegible]	120	UP	0	1080	251390	0	DN	1	0	248400	160	UP	0	1440	1280
2.0	499860	140	UP	0	1260	250060	120	UP	0	1080	249690	120	UP	0	1200	252290	0	DN	2	0	246800	160	UP	0	1600	2880
3.0	500000	0	DN	1	140	249000	120	UP	0	1200	249690	120	UP	0	1200	251490	0	DN	3	0	245200	160	UP	0	1600	4480
4.0	499860	140	UP	0	1260	249160	120	UP	0	1200	249690	120	UP	0	1200	254690	0	DN	4	0	243600	160	UP	0	1500	6080
5.0	500000	0	DN	1	140	249000	120	UP	0	1200	249940	0	DN	1	120	254930	0	DN	5	0	242030	160	UP	0	1600	7680
6.0	500000	0	DN	2	0	246800	120	UP	0	1200	249940	120	UP	0	1080	255930	0	DN	6	0	240400	160	UP	0	1600	9280
7.0	500000	0	DN	3	0	245600	120	UP	0	1200	249990	120	UP	0	1200	255690	140	UP	0	1260	240060	160	UP	0	1600	10880
8.0	499860	140	UP	0	1260	246660	120	UP	0	1200	251040	0	DN	1	120	254600	140	UP	0	1400	239860	160	UP	0	1600	12480
9.0	499860	140	UP	0	1400	246460	120	UP	0	1200	251040	120	UP	0	1040	254090	140	UP	0	1400	239660	160	UP	0	1600	14080
10.0	499860	140	UP	0	1400	246600	120	UP	0	1200	251040	120	UP	0	1200	253390	140	UP	0	1400	239460	160	UP	0	1600	15680
11.0	499860	140	UP	0	1400	246260	120	UP	0	1200	251040	120	UP	0	1200	251540	140	UP	0	1400	239260	160	UP	0	1600	17280
12.0	499860	140	UP	0	1400	246460	120	UP	0	1200	251090	120	UP	0	1200	251490	140	UP	0	1400	239060	160	UP	0	1600	18880
13.0	499860	140	UP	0	1400	247900	0	DN	1	120	252030	120	UP	0	1200	254490	0	DN	1	140	237600	160	UP	0	1500	20480
14.0	499860	140	UP	0	1400	244160	120	UP	0	1040	251040	0	DN	1	120	254930	0	DN	2	0	236000	160	UP	0	1600	22080
15.0	499860	140	UP	0	1400	244260	120	UP	0	1200	251040	120	UP	0	1040	254490	140	UP	0	1260	235660	160	UP	0	1600	23580
16.0	499860	140	UP	0	1400	244600	120	UP	0	1200	251090	120	UP	0	1200	254290	140	UP	0	1400	235460	160	UP	0	1600	25280
17.0	500000	0	DN	1	140	247460	120	UP	0	1200	252290	0	DN	1	120	253000	140	UP	0	1400	235260	160	UP	0	1600	26880
18.0	500000	0	DN	2	0	246200	120	UP	0	1200	252240	120	UP	0	1040	252040	140	UP	0	1400	235060	160	UP	0	1600	28480
19.0	500000	0	DN	3	0	245000	120	UP	0	1200	252240	120	UP	0	1200	252690	140	UP	0	1400	234860	160	UP	0	1500	30080
20.0	499860	140	UP	0	1260	246260	0	DN	1	120	251200	120	UP	0	1200	252290	140	UP	0	1400	236260	0	DN	1	160	30400
21.0	499860	140	UP	0	1400	246460	120	UP	0	1040	251090	120	UP	0	1200	252290	140	UP	0	1400	237660	0	DN	2	0	30400
22.0	499860	140	UP	0	1400	246660	120	UP	0	1200	251040	120	UP	0	1200	251940	140	UP	0	1400	239060	0	DN	3	0	30400
23.0	500000	0	DN	1	140	245500	120	UP	0	1200	251040	120	UP	0	1200	251640	140	UP	0	1400	240460	0	DN	4	0	30400
24.0	499860	140	UP	0	1260	246460	0	DN	1	120	251200	0	DN	1	120	253430	140	UP	0	1400	240260	160	UP	0	1440	31680
25.0	499860	140	UP	0	1400	247460	120	UP	0	1040	251040	120	UP	0	1040	253090	140	UP	0	1400	240060	160	UP	0	1600	33280
26.0	499860	140	UP	0	1400	247200	120	UP	0	1200	251040	120	UP	0	1200	254990	140	UP	0	1400	239860	160	UP	0	1600	34880
27.0	499860	140	UP	0	1400	247460	120	UP	0	1200	251040	120	UP	0	1200	254540	140	UP	0	1400	239660	160	UP	0	1600	36480
28.0	499860	140	UP	0	1400	247660	120	UP	0	1200	251040	120	UP	0	1200	249490	140	UP	0	1400	239460	160	UP	0	1600	38080
29.0	499860	140	UP	0	1400	247860	120	UP	0	1200	251040	120	UP	0	1200	249290	140	UP	0	1400	239260	160	UP	0	1600	39680
30.0	499860	140	UP	0	1400	249060	120	UP	0	1200	251040	120	UP	0	1200	253490	0	DN	1	140	237860	160	UP	0	1500	41280
31.0	499860	140	UP	0	1400	247260	120	UP	0	1200	251040	120	UP	0	1200	253240	140	UP	0	1260	237460	160	UP	0	1600	42880
32.0	500000	0	DN	1	140	247200	120	UP	0	1200	251040	120	UP	0	1200	253090	140	UP	0	1400	237260	160	UP	0	1500	44480
33.0	499860	140	UP	0	1260	247260	120	UP	0	1200	251040	120	UP	0	1200	251940	140	UP	0	1400	239660	0	DN	1	160	44500
34.0	499860	140	UP	0	1400	247460	120	UP	0	1200	251040	120	UP	0	1200	249540	140	UP	0	1400	238460	160	UP	0	1440	46080
35.0	499860	140	UP	0	1400	247060	120	UP	0	1200	251040	120	UP	0	1200	249940	140	UP	0	1400	239260	160	UP	0	1500	47580
36.0	499860	140	UP	0	1400	247560	120	UP	0	1200	251040	120	UP	0	1200	252690	0	DN	1	140	236860	160	UP	0	1600	49280
37.0	500000	0	DN	1	140	246800	120	UP	0	1200	252240	0	DN	1	120	249430	140	UP	0	1260	236460	160	UP	0	1600	50880
38.0	499860	140	UP	0	1260	246800	120	UP	0	1200	252240	120	UP	0	1080	247390	140	UP	0	1400	236260	160	UP	0	1600	52480
39.0	499860	140	UP	0	1400	247060	120	UP	0	1200	252240	120	UP	0	1200	244990	140	UP	0	1400	237660	0	DN	1	160	52800
40.0	499860	140	UP	0	1400	247260	120	UP	0	1200	252240	120	UP	0	1200	249640	140	UP	0	1400	239060	0	DN	2	0	52800
41.0	499860	140	UP	0	1400	247460	120	UP	0	1200	253490	0	DN	1	120	247400	140	UP	0	1400	240460	0	DN	3	0	52800
42.0	499860	140	UP	0	1400	247060	120	UP	0	1200	253490	120	UP	0	1080	248490	0	DN	1	140	239260	160	UP	0	1440	54080
43.0	499860	140	UP	0	1400	247860	120	UP	0	1200	253440	120	UP	0	1200	249290	140	UP	0	1260	239660	160	UP	0	1600	55680
44.0	499860	140	UP	0	1400	249060	120	UP	0	1200	253490	120	UP	0	1200	249340	140	UP	0	1400	238460	160	UP	0	1600	57280
45.0	499860	140	UP	0	1400	249460	0	DN	1	120	252420	120	UP	0	1200	247890	140	UP	0	1400	239260	160	UP	0	1600	58880
46.0	499860	140	UP	0	1400	249160	120	UP	0	1040	252240	120	UP	0	1200	247690	140	UP	0	1400	238060	160	UP	0	1500	60480
47.0	499860	140	UP	0	1400	249860	120	UP	0	1200	251490	0	DN	1	120	246400	140	UP	0	1400	239460	0	DN	1	160	60900
48.0	499860	140	UP	0	1400	251260	0	DN	1	120	252460	120	UP	0	1080	245540	140	UP	0	1400	240960	0	DN	2	0	60900
49.0	499860	140	UP	0	1400	250660	0	DN	2	0	[illegible]	120	UP	0	1200	245990	140	UP	0	1400	240660	160	UP	0	1440	62080
50.0	499860	140	UP	0	1400	250060	0	DN	3	0	[illegible]	120	UP	0	1200	247090	0	DN	1	140	240800	0	DN	1	160	62400
51.0	499860	140	UP	0	1400	254260	120	UP	0	1080	249440	120	UP	0	1200	249240	0	DN	2	0	240900	0	DN	2	0	62400
52.0	499860	140	UP	0	1400	254460	120	UP	0	1200	249440	120	UP	0	1260	249390	140	UP	0	1260	242060	0	DN	3	0	62400
53.0	499860	140	UP	0	1400	254660	120	UP	0	1200	249440	120	UP	0	1200	247490	140	UP	0	1400	241860	160	UP	0	1440	63680
54.0	499860	140	UP	0	1400	254960	120	UP	0	1200	249440	120	UP	0	1200	249390	0	DN	1	140	240400	160	UP	0	1600	65280
55.0	499860	140	UP	0	1400	256260	0	DN	1	120	249440	120	UP	0	1200	252290	0	DN	2	0	239800	160	UP	0	1600	66880
56.0	500000	0	DN	1	140	255200	120	UP	0	1080	249690	120	UP	0	1200	251490	0	DN	3	0	238800	0	DN	1	160	67200
57.0	499860	140	UP	0	1260	255260	120	UP	0	1200	249690	120	UP	0	1200	252590	0	DN	4	0	237200	160	UP	0	1440	68480
58.0	499860	140	UP	0	1400	255460	120	UP	0	1200	249540	120	UP	0	1200	252990	0	DN	5	0	235660	160	UP	0	1600	70080
59.0	499860	140	UP	0	1400	255660	120	UP	0	1200	249690	120	UP	0	1200	253690	140	UP	0	1260	235260	160	UP	0	1600	71580
60.0	499860	140	UP	0	1400	255860	120	UP	0	1200	249590	120	UP	0	1200	253490	140	UP	0	1400	235060	160	UP	0	1600	73280
61.0	499860	140	UP	0	1400	255460	120	UP	0	1200	249540	120	UP	0	1200	253240	140	UP	0	1400	234860	160	UP	0	1600	74880
62.0	499860	140	UP	0	1400	255260	120	UP	0	1200	249490	120	UP	0	1200	253090	140	UP	0	1400	234660	160	UP	0	1600	76480
63.0	499860	140	UP	0	1400	255460	120	UP	0	1200	249340	120	UP	0	1200	252990	140	UP	0	1400	234460	160	UP	0	1500	78080
64.0	499860	140	UP	0	1400	255660	120	UP	0	1200	249640	120	UP	0	1200	252590	140	UP	0	1400	234260	160	UP	0	1600	79580
65.0	499860	140	UP	0	1400	256960	120	UP	0	1200	249640	120	UP	0	1200	252480	140	UP	0	1400	234060	160	UP	0	1600	81280
66.0	499860	140	UP	0	1400	257060	120	UP	0	1200	249540	120	UP	0	1200	252280	140	UP	0	1400	233860	160	UP	0	1600	82880
67.0	500000	0	DN	1	140	256660	120	UP	0	1200	249640	120	UP	0	1200	252390	140	UP	0	1400	233660	160	UP	0	1500	84480
68.0	499860	140	UP	0	1260	256460	120	UP	0	1200	249640	120	UP	0	1200	251990	140	UP	0	1400	235060	0	DN	1	160	84900
69.0	499860	140	UP	0	1400	256260	120	UP	0	1200	249540	120	UP	0	1200	253090	0	DN	1	140	233600	160	UP	0	1440	86080
70.0	499860	140	UP	0	1400	255460	120	UP	0	1200	249490	120	UP	0	1200	254290	0	DN	2	0	232060	160	UP	0	1500	87580
71.0	500000	0	DN	1	140	256600	0	DN	1	120	249490	0	DN	1	120	253030	140	UP	0	1260	231660	160	UP	0	1600	89280
72.0	499860	140	UP	0	1260	256660	120	UP	0	1200	249590	120	UP	0	1080	252690	140	UP	0	1400	231460	160	UP	0	1500	90880
73.0	500000	0	DN	1	140	256960	0	DN	1	120	247500	120	UP	0	1200	251990	0	DN	1	140	230000	160	UP	0	1600	92480
74.0	499860	140	UP	0	1260	258600	0	DN	2	0	246400	120	UP	0	1200	255080	0	DN	2	0	228400	160	UP	0	1600	94080
75.0	500000	0	DN	1	140	258260	0	DN	3	0	245200	120	UP	0	1260	254940	140	UP	0	1260	228060	160	UP	0	1600	95680

TABLE 7.1.--Proof Model 1, Part I

TIME	DEPALLETIZER					FILLER					SEAMER					PACKER					TRAYMAKER					
MIN	C1	M1	D1		P1	C2	M2	D2		P2	C3	M3	D3		P3	C4	M4	D4		P4	C5	M5	D5		P5	TOTAL
76.0	499860	140	UP	0	1260	259460	0	DN	4	0	264600	120	UP	0	1200	254680	140	UP	0	1400	227860	160	UP	0	1600	97280
77.0	499860	140	UP	0	1400	262860	0	DN	5	0	262400	120	UP	0	1200	255890	0	DN	1	140	226400	160	UP	0	1500	98880
78.0	499860	140	UP	0	1400	262260	0	DN	6	0	261620	120	UP	0	1200	255690	140	UP	0	1260	226060	160	UP	0	1600	100480
79.0	499860	140	UP	0	1400	262460	120	UP	0	1080	261490	120	UP	0	1200	255680	140	UP	0	1400	225860	160	UP	0	1600	102080
80.0	499860	140	UP	0	1400	262660	120	UP	0	1200	261490	120	UP	0	1200	255290	140	UP	0	1400	225660	160	UP	0	1600	103680
81.0	499860	140	UP	0	1400	262860	120	UP	0	1200	261490	120	UP	0	1200	256690	0	DN	1	140	224260	160	UP	0	1600	105280
82.0	499860	140	UP	0	1400	263060	120	UP	0	1200	261490	120	UP	0	1200	257690	0	DN	2	0	222600	160	UP	0	1500	106880
83.0	499860	140	UP	0	1400	263260	120	UP	0	1200	261490	120	UP	0	1200	258990	0	DN	3	0	221000	160	UP	0	1600	108480
84.0	499860	140	UP	0	1400	263460	120	UP	0	1200	261490	120	UP	0	1200	260090	0	DN	4	0	219460	160	UP	0	1600	110080
85.0	499860	140	UP	0	1400	263660	120	UP	0	1200	261490	120	UP	0	1200	261290	0	DN	5	0	217830	160	UP	0	1600	111680
86.0	499860	140	UP	0	1400	263860	120	UP	0	1200	261490	120	UP	0	1200	262480	0	DN	6	0	216200	160	UP	0	1600	113280
87.0	499860	140	UP	0	1400	265260	0	DN	1	120	261600	0	DN	1	120	261200	140	UP	0	1260	215860	160	UP	0	1600	114880
88.0	499860	140	UP	0	1400	265460	120	UP	0	1080	261490	120	UP	0	1090	260990	140	UP	0	1400	215550	160	UP	0	1600	116480
89.0	500000	0	DN	1	140	264460	120	UP	0	1200	261490	120	UP	0	1200	262090	0	DN	1	140	214200	160	UP	0	1600	118080
90.0	499860	140	UP	0	1260	264460	120	UP	0	1200	262690	0	DN	1	120	263200	0	DN	2	0	212600	160	UP	0	1500	119680
91.0	499860	140	UP	0	1400	265460	0	DN	1	120	263900	0	DN	2	0	263200	0	DN	3	0	211000	160	UP	0	1500	121280
92.0	499860	140	UP	0	1400	266060	120	UP	0	1080	263490	0	DN	3	0	262900	140	UP	0	1260	210660	160	UP	0	1600	122880
93.0	499860	140	UP	0	1400	266260	120	UP	0	1200	263490	120	UP	0	1090	262490	140	UP	0	1400	210460	160	UP	0	1500	124480
94.0	499860	140	UP	0	1400	266460	120	UP	0	1200	263490	120	UP	0	1200	262290	140	UP	0	1400	210260	160	UP	0	1500	126080
95.0	499860	140	UP	0	1400	267460	0	DN	1	120	262400	120	UP	0	1200	260090	140	UP	0	1400	210060	160	UP	0	1600	127680
96.0	499860	140	UP	0	1400	267260	0	DN	2	0	262400	0	DN	1	120	259490	140	UP	0	1400	211460	0	DN	1	160	128000
97.0	499860	140	UP	0	1400	266460	120	UP	0	1080	261910	0	DN	2	0	257490	140	UP	0	1400	212970	0	DN	2	0	128000
98.0	499860	140	UP	0	1400	268860	120	UP	0	1200	263490	120	UP	0	1090	257390	140	UP	0	1400	214260	0	DN	3	0	128000
99.0	499860	140	UP	0	1400	269860	120	UP	0	1200	263490	120	UP	0	1200	255990	140	UP	0	1400	215660	0	DN	4	0	128000
100.0	499860	140	UP	0	1400	270660	120	UP	0	1200	263490	120	UP	0	1200	255690	140	UP	0	1400	215460	160	UP	0	1440	129280
101.0	499860	140	UP	0	1400	270260	120	UP	0	1200	263490	120	UP	0	1200	256490	140	UP	0	1400	215260	160	UP	0	1600	130880
102.0	499860	140	UP	0	1400	270460	120	UP	0	1200	263490	120	UP	0	1200	257590	0	DN	1	140	213800	160	UP	0	1600	132480
103.0	499860	140	UP	0	1400	270660	120	UP	0	1200	264600	0	DN	1	120	256600	140	UP	0	1260	213460	160	UP	0	1600	134080
104.0	500000	0	DN	1	140	264660	120	UP	0	1200	264640	120	UP	0	1090	256090	140	UP	0	1400	213260	160	UP	0	1600	135680
105.0	499860	140	UP	0	1260	270860	0	DN	1	120	264000	120	UP	0	1200	255990	140	UP	0	1400	213060	160	UP	0	1600	137280
106.0	499860	140	UP	0	1400	271060	120	UP	0	1090	263930	120	UP	0	1200	255680	140	UP	0	1400	212460	160	UP	0	1600	138880
107.0	499860	140	UP	0	1400	271260	120	UP	0	1200	263930	120	UP	0	1200	255490	140	UP	0	1400	214260	0	DN	1	160	139200
108.0	500000	0	DN	1	140	272260	120	UP	0	1200	263890	120	UP	0	1200	256690	0	DN	1	140	214400	0	DN	2	0	139200
109.0	499860	140	UP	0	1260	271460	0	DN	1	120	264600	0	DN	1	120	255900	140	UP	0	1260	215660	0	DN	3	0	139200
110.0	499860	140	UP	0	1400	271660	120	UP	0	1090	264330	120	UP	0	1090	255090	140	UP	0	1400	215460	160	UP	0	1440	140480
111.0	499860	140	UP	0	1400	271860	120	UP	0	1200	263890	120	UP	0	1200	254940	140	UP	0	1400	215260	160	UP	0	1600	142080
112.0	500000	0	DN	1	140	272800	120	UP	0	1200	263490	120	UP	0	1200	254690	140	UP	0	1400	215060	160	UP	0	1600	143680
113.0	500000	0	DN	2	0	264860	120	UP	0	1200	263490	120	UP	0	1200	254490	140	UP	0	1400	214860	160	UP	0	1600	145280
114.0	500000	0	DN	3	0	269460	120	UP	0	1200	263490	120	UP	0	1200	254290	140	UP	0	1400	214660	160	UP	0	1600	146880
115.0	499860	140	UP	0	1260	269660	0	DN	1	120	262400	120	UP	0	1200	254380	140	UP	0	1400	216060	0	DN	1	160	147200
116.0	500000	0	DN	1	140	261900	0	DN	2	0	261600	120	UP	0	1200	253990	140	UP	0	1400	215860	160	UP	0	1440	148480
117.0	499860	140	UP	0	1260	271060	0	DN	3	0	260400	120	UP	0	1200	253590	140	UP	0	1400	215660	160	UP	0	1600	150080
118.0	499860	140	UP	0	1400	272460	0	DN	4	0	[illegible]	120	UP	0	1200	254890	0	DN	1	140	214200	160	UP	0	1500	151680
119.0	499860	140	UP	0	1400	273860	0	DN	5	0	[illegible]	0	DN	1	120	253500	140	UP	0	1260	213460	160	UP	0	1600	153280
120.0	499860	140	UP	0	1400	275260	0	DN	6	0	[illegible]	0	DN	2	0	252290	140	UP	0	1400	213660	160	UP	0	1600	154880
121.0	499860	140	UP	0	1400	276660	0	DN	7	0	[illegible]	0	DN	3	0	250930	140	UP	0	1400	213450	160	UP	0	1500	156480
122.0	499860	140	UP	0	1400	270400	120	UP	0	1080	243240	0	DN	4	0	249400	140	UP	0	1400	213260	160	UP	0	1600	158080
123.0	500000	0	DN	1	140	275460	120	UP	0	1200	241640	0	DN	5	0	249000	140	UP	0	1400	213050	160	UP	0	1600	159680
124.0	499860	140	UP	0	1260	275460	120	UP	0	1200	241640	120	UP	0	1090	247690	140	UP	0	1400	212860	160	UP	0	1600	161280
125.0	499860	140	UP	0	1400	277060	120	UP	0	1200	[illegible]	0	DN	1	120	246400	140	UP	0	1400	212660	160	UP	0	1600	162880
126.0	500000	0	DN	1	140	275000	120	UP	0	1200	242640	120	UP	0	1090	246090	140	UP	0	1400	214060	0	DN	1	160	163200
127.0	499860	140	UP	0	1260	275000	120	UP	0	1200	242640	120	UP	0	1200	245990	140	UP	0	1400	215460	0	DN	2	0	163200
128.0	500000	0	DN	1	140	274000	120	UP	0	1200	242640	120	UP	0	1200	245690	140	UP	0	1400	216960	0	DN	3	0	163200
129.0	500000	0	DN	2	0	272800	120	UP	0	1200	242640	120	UP	0	1200	245490	140	UP	0	1400	219260	0	DN	4	0	163200
130.0	500000	0	DN	3	0	272800	0	DN	1	120	241620	120	UP	0	1200	245290	140	UP	0	1400	219660	0	DN	5	0	163200
131.0	500000	0	DN	4	0	271800	120	UP	0	1090	241640	120	UP	0	1200	246490	0	DN	1	140	219800	0	DN	6	0	163200
132.0	500000	0	DN	5	0	271600	0	DN	1	120	241610	120	UP	0	1200	246600	0	DN	2	0	219400	0	DN	7	0	163200
133.0	499860	140	UP	0	1260	271600	120	UP	0	1090	241640	120	UP	0	1090	247690	0	DN	3	0	219200	160	UP	0	1440	164480
134.0	499860	140	UP	0	1400	271560	120	UP	0	1200	241640	120	UP	0	1200	248890	0	DN	4	0	216600	160	UP	0	1600	166080
135.0	499860	140	UP	0	1400	272060	120	UP	0	1200	241640	120	UP	0	1200	249640	140	UP	0	1260	216260	160	UP	0	1600	167680
136.0	499860	140	UP	0	1400	272260	120	UP	0	1200	241640	120	UP	0	1200	248490	140	UP	0	1400	216060	160	UP	0	1500	169280
137.0	499860	140	UP	0	1400	273660	0	DN	1	120	240630	120	UP	0	1200	248290	140	UP	0	1400	215860	160	UP	0	1500	170880
138.0	499860	140	UP	0	1400	273860	120	UP	0	1090	240240	120	UP	0	1200	249090	140	UP	0	1400	217260	0	DN	1	160	171200
139.0	499860	140	UP	0	1400	274060	120	UP	0	1200	240290	120	UP	0	1200	247990	140	UP	0	1400	218650	0	DN	2	0	171200
140.0	499860	140	UP	0	1400	274260	120	UP	0	1200	240290	120	UP	0	1200	247690	140	UP	0	1400	220060	0	DN	3	0	171200
141.0	499860	140	UP	0	1400	274460	120	UP	0	1200	240290	120	UP	0	1200	247490	140	UP	0	1400	221460	0	DN	4	0	171200
142.0	499860	140	UP	0	1400	274660	120	UP	0	1200	240290	120	UP	0	1200	247290	140	UP	0	1400	221260	160	UP	0	1440	172480
143.0	499860	140	UP	0	1400	274860	120	UP	0	1200	240290	120	UP	0	1200	247090	140	UP	0	1400	221060	160	UP	0	1600	174080
144.0	499860	140	UP	0	1400	275260	0	DN	1	120	[illegible]	120	UP	0	1200	246890	140	UP	0	1400	220860	160	UP	0	1500	175680
145.0	499860	140	UP	0	1400	275460	120	UP	0	1080	[illegible]	120	UP	0	1200	246690	140	UP	0	1400	220660	160	UP	0	1500	177280
146.0	499860	140	UP	0	1400	276660	120	UP	0	1200	[illegible]	120	UP	0	1200	246490	140	UP	0	1400	220460	160	UP	0	1600	178880
147.0	499860	140	UP	0	1400	276860	120	UP	0	1200	[illegible]	120	UP	0	1200	246290	140	UP	0	1400	220260	160	UP	0	1500	180480
148.0	499860	140	UP	0	1400	277460	120	UP	0	1200	[illegible]	120	UP	0	1200	246090	140	UP	0	1400	220060	160	UP	0	1600	182080
149.0	499860	140	UP	0	1400	277260	120	UP	0	1200	[illegible]	120	UP	0	1200	245890	140	UP	0	1400	219860	160	UP	0	1600	183680
150.0	499860	140	UP	0	1400	278060	0	DN	1	120	241200	0	DN	1	120	244690	140	UP	0	1400	219060	160	UP	0	1500	185280

TABLE 7.1.--Proof Model 1, Part II

M1...M5: indicates the number of units currently in the machine.

D1...D5: shows whether the machine is operating or not. Example:
UP 0 indicates the machine is operating.
DN 1,2,...7 signifies the number of minutes the machine has been down.

P1...P5: indicates the total production of the station at the end of that particular minute.

TOTAL: total line production.

Only the first two pages of the simulation are presented here. It is felt these will show the results equally as well as the entire printout and much less space will be required.

Comments about Table 6.1:

1. The efficiency of the line is assumed to be approximately 80%.

2. The efficiency of each machine, excluding idling time can be found by adding the downtimes of each over the eight hour simulation run, subtracting each from eight hours and figuring the result as a percentage of the total shift.

Examples:

A. Depalletizer Total Downtime = 85 minutes

$$\frac{480 \text{ min} - 85 \text{ min}}{480 \text{ min}} \times 100 = 82.292\%$$

B. Filler Total Downtime = 101 minutes

$$\frac{480 - 101}{480} \times 100 = 78.958\%$$

C. Seamer Total Downtime = 94 minutes

$$\frac{480 - 94}{480} \times 100 = 81.875\%$$

D. Packer Total Downtime = 87 minutes

$$\frac{480 - 87}{480} \times 100 = 81.875\%$$

E. Traymaker Total Downtime = 118 minutes

$$\frac{480 - 118}{480} \times 100 = 75.417\%$$

The overall line efficiency, based on machine downtimes is

$$\frac{82.292 + 78.958 + \ldots\ldots\ldots\ldots + 75.417}{5} = 79.792\%$$

This figure is very close to the expected 80%.

Another way of showing line efficiency is based on the number of units produced over time. For this first model, efficiency is gauged on the last machine, the traymaker.

Total Production:	185,280 units
Length of Run:	150 minutes
Last Machine:	1600 cpm (cans per minute)

$$\frac{185{,}280 \text{ units}}{150 \text{ min} \times 1600 \text{ cpm}} \times 100\% = 77.2\%$$

3. Filler idling time is as small as possible. Idle time as a percent of total running time is:

$$\frac{19 \text{ min}}{150 \text{ min}} \times 100\% - 12.7\%$$

This idle time is due to the 6 second start-up time step of the filler while it is being loaded with cans.

4. Conveyor cost versus production:

Conveyor Capacity: 500,000 units/conveyor
Each Unit (can): 2.5 inches in diameter
Cost of Conveyor: \$100.00 per running foot

Capital Cost:

$$\frac{500{,}000 \text{ units}}{\text{conveyor}} \times 5 \text{ conveyors} \times \frac{2.5 \text{ in}}{\text{unit}} \times \frac{1 \text{ ft}}{12 \text{ in}} \times \frac{\$100.00}{\text{ft}} = \$52{,}083{,}333$$

Total Output: 185,280 units (cans)
Incremental Revenue per unit of Output: \$0.03
Length of Run: 150 minutes

Incremental Profit:

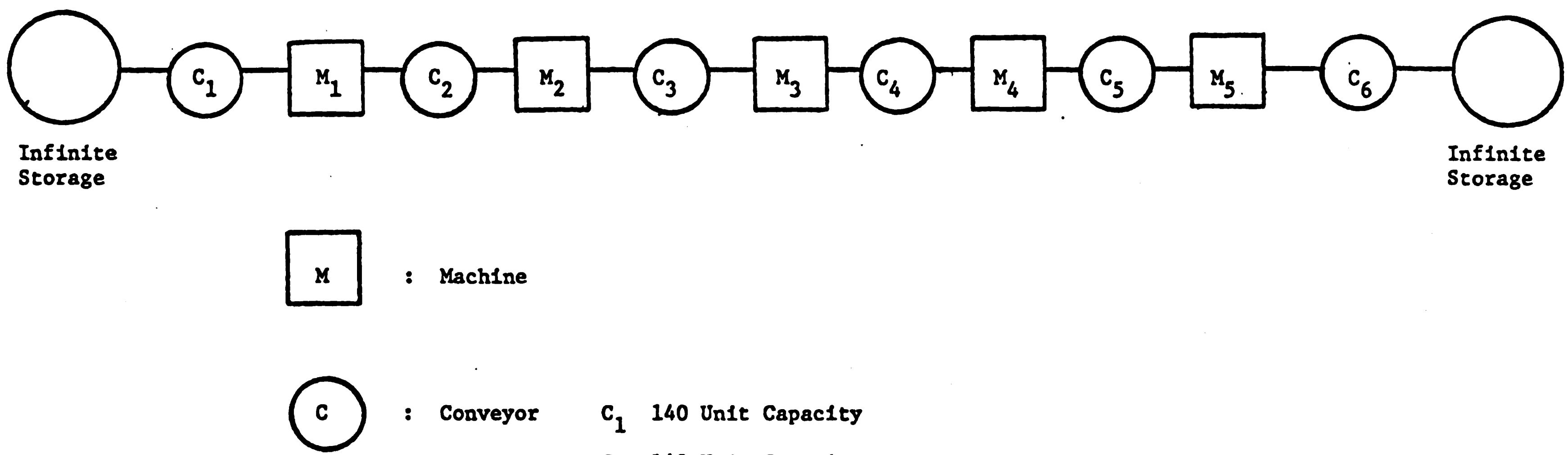
$$185{,}280 \text{ units} \times \frac{480 \text{ min}}{150 \text{ min}} \times \frac{\$.03}{\text{unit}} = \$16{,}786.88/\text{eight hour shift}$$

Necessary time to return investment with 3, eight hour shifts per day working five days per week:

$$\frac{\$52{,}083{,}333}{\$17{,}786.88} \times \frac{1 \text{ shift}}{3 \text{ shifts/day}} \times \frac{1 \text{ year}}{250 \text{ working days}} = 3.9 \sim 4 \text{ yrs.}$$

6.2 Proof Model 2

This proof model is the same as Model 1 except for the length of the transfer mechanisms between the machines. These very small conveyor lengths (140,140,120,140,160) correspond to the larger machine capacities at either end of each conveyor (Figure 6.2). The model run is started with each conveyor half full.



C_1 140 Unit Capacity

C_2 140 Unit Capacity

C_3 120 Unit Capacity

C_4 140 Unit Capacity

C_5 160 Unit Capacity

C_6 160 Unit Capacity

Figure 6.2.--Proof Model 2.

Interaction between the machines occurs almost 100% of the time which means every breakdown of a machine affects the operation of all the others. It is expected that the efficiency of each machine and the entire line will decrease markedly. The line efficiency for this model is based on the slowest machine, the filler.

Table 7.2 shows the computer printout. Some comments follow:

1. The efficiency of each machine, excluding idling time is the same as that discussed in comment (2) of Proof Model 1. The line efficiency based on the number of units produced is very low.

Total Production:	65,760 cans
Length of Run:	150 minutes
Slowest Machine:	$M_{(2)}$-Filler 1200 cpm

$$\frac{65,760 \text{ cans}}{150 \text{ min x } 1200 \text{ cpm}} \times 100 = 36.53\%$$

2. Machine idling time is large. Idle time as a percent of total running time for the filler is

$$\frac{68 \text{ min}}{150 \text{ min}} \times 100\% = 45.33\%$$

This compares to zero idle time for Proof Model 1. Idle time is defined as the number of minutes the filler did not produce its full machine capacity during the simulation run. Downtimes are ignored.

TIME	DEPALLETIZER				FILLER				SEAMER				PACKER				TRAYMAKER				
MIN	C1	M1	D1	P1	C2	M2	D2	P2	C3	M3	D3	P3	C4	M4	D4	P4	C5	M5	D5	P5	TOTAL
1.0	140	0	DN 1	0	70	0	DN 1	0	0	0	UP 0	60	130	0	DN 1	0	0	0	UP 0	80	80
2.0	140	140	UP 0	440	140	120	UP 0	250	120	120	UP 0	10	140	0	DN 2	0	0	0	UP 0	0	80
3.0	140	140	DN 1	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 3	0	0	0	UP 0	0	80
4.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 4	0	0	0	UP 0	0	80
5.0	140	140	DN 1	0	140	120	UP 0	0	120	120	DN 1	0	140	0	DN 5	0	0	0	UP 0	0	80
6.0	140	140	DN 2	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 6	0	0	0	UP 0	0	80
7.0	140	0	DN 3	140	0	0	UP 0	400	0	0	UP 0	640	0	0	UP 0	730	0	0	UP 0	780	820
8.0	140	140	UP 0	380	140	120	UP 0	120	120	0	DN 1	0	0	0	UP 0	0	0	0	UP 0	0	860
9.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1080	120	120	UP 0	840	120	120	UP 0	600	1340
10.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	2540
11.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	3740
12.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	4940
13.0	140	140	UP 0	0	140	100	DN 1	20	120	120	UP 0	20	140	0	DN 1	120	0	0	UP 0	360	5420
14.0	140	140	UP 0	20	140	120	UP 0	0	120	120	DN 1	0	140	0	DN 2	0	0	0	UP 0	0	5420
15.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1100	120	120	UP 0	860	6160
16.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	7360
17.0	140	140	DN 1	0	140	120	UP 0	0	120	0	DN 1	120	0	0	UP 0	350	0	0	UP 0	600	8080
18.0	140	0	DN 2	140	0	0	UP 0	400	0	0	UP 0	520	0	0	UP 0	520	0	0	UP 0	520	8560
19.0	140	0	DN 3	0	0	0	UP 0	0	0	0	UP 0	0	0	0	UP 0	0	0	0	UP 0	0	8600
20.0	140	140	UP 0	140	140	0	DN 1	0	0	0	UP 0	0	0	0	UP 0	0	0	0	DN 1	0	8600
21.0	140	140	UP 0	800	140	120	UP 0	680	120	120	UP 0	440	140	140	UP 0	150	160	0	DN 2	0	8600
22.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	140	UP 0	0	160	0	DN 3	0	8600
23.0	140	140	DN 1	0	140	120	UP 0	0	120	120	UP 0	0	140	140	UP 0	0	160	0	DN 4	0	8600
24.0	140	140	UP 0	0	140	120	DN 1	0	120	0	DN 1	120	0	0	UP 0	400	0	0	UP 0	560	9160
25.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1080	120	120	UP 0	840	120	120	UP 0	600	9640
26.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	10840
27.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	12040
28.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	13240
29.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	14440
30.0	140	140	UP 0	20	140	120	UP 0	20	120	120	UP 0	20	140	0	DN 1	120	0	0	UP 0	360	14920
31.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1100	120	120	UP 0	860	15660
32.0	140	0	DN 1	140	0	0	UP 0	400	0	0	UP 0	640	0	0	UP 0	830	0	0	UP 0	1120	16360
33.0	140	140	UP 0	940	140	120	UP 0	680	120	120	UP 0	440	140	140	UP 0	150	160	0	DN 1	0	16900
34.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1160	17940
35.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	19140
36.0	140	140	UP 0	20	140	120	UP 0	20	120	120	UP 0	20	140	0	DN 1	120	0	0	UP 0	360	19620
37.0	140	140	DN 1	0	140	120	UP 0	0	120	0	DN 1	120	0	0	UP 0	250	0	0	UP 0	260	19880
38.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1080	120	120	UP 0	840	120	120	UP 0	600	20360
39.0	140	140	UP 0	80	140	120	UP 0	80	120	120	UP 0	80	140	140	UP 0	40	160	0	DN 1	120	20600
40.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	140	UP 0	0	160	0	DN 2	0	20600
41.0	140	140	UP 0	0	140	120	UP 0	0	120	120	DN 1	0	140	140	UP 0	0	160	0	DN 3	0	20600
42.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 1	100	0	0	UP 0	300	20900
43.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1100	120	120	UP 0	860	21640
44.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	22840
45.0	140	140	UP 0	0	140	0	DN 1	120	0	0	UP 0	360	0	0	UP 0	600	0	0	UP 0	840	23800
46.0	20	140	UP 0	1200	140	120	UP 0	1080	120	120	UP 0	840	120	120	UP 0	600	120	120	UP 0	360	24040
47.0	140	140	UP 0	0	140	120	UP 0	0	120	40	DN 1	80	140	140	UP 0	40	160	0	DN 1	120	24280
48.0	140	140	UP 0	0	140	40	DN 1	80	120	120	UP 0	0	140	140	UP 0	0	160	0	DN 2	0	24280
49.0	140	140	UP 0	0	140	0	DN 2	40	0	0	UP 0	280	0	0	UP 0	530	0	0	UP 0	720	25000
50.0	140	140	UP 0	0	140	0	DN 3	0	0	0	UP 0	0	0	0	DN 1	0	0	0	DN 1	0	25000
51.0	140	140	UP 0	500	140	120	UP 0	340	120	120	UP 0	140	140	0	DN 2	0	0	0	DN 2	0	25000
52.0	140	140	UP 0	300	140	120	UP 0	300	120	120	UP 0	300	140	140	UP 0	160	160	0	DN 3	0	25000
53.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1160	26040
54.0	140	140	UP 0	20	140	120	UP 0	20	120	120	UP 0	20	140	0	DN 1	120	0	0	UP 0	360	26520
55.0	140	140	UP 0	0	140	120	DN 1	0	120	120	UP 0	0	140	0	DN 2	0	0	0	UP 0	0	26520
56.0	140	140	DN 1	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 3	0	0	0	DN 1	0	26520
57.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 4	0	0	0	UP 0	0	26520
58.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 5	0	0	0	UP 0	0	26520
59.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1100	120	120	UP 0	860	27260
60.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	28460
61.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	29660
62.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	30860
63.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	32060
64.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	33260
65.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	34460
66.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	35660
67.0	140	0	DN 1	140	0	0	UP 0	400	0	0	UP 0	640	0	0	UP 0	830	0	0	UP 0	1120	36860
68.0	140	140	UP 0	940	140	120	UP 0	680	120	120	UP 0	440	140	140	UP 0	150	160	0	DN 1	0	36900
69.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 1	100	0	0	UP 0	300	37200
70.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 2	0	0	0	UP 0	0	37200
71.0	140	140	DN 1	0	140	120	DN 1	0	120	0	DN 1	120	0	0	UP 0	250	0	0	UP 0	260	37460
72.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1080	120	120	UP 0	840	120	120	UP 0	600	37940
73.0	140	140	DN 1	0	140	100	DN 1	20	120	120	UP 0	20	140	0	DN 1	120	0	0	UP 0	360	38420
74.0	140	140	UP 0	0	140	100	DN 2	0	120	120	UP 0	0	140	0	DN 2	0	0	0	UP 0	0	38420
75.0	140	140	DN 1	0	140	0	DN 3	100	0	0	UP 0	340	0	0	UP 0	450	0	0	UP 0	480	38900

TABLE 7.2.--Proof Model 2, Part I

TIME	DEPALLETIZER				FILLER				SEAMER				PACKER				TRAYMAKER				
MIN	C1	M1	D1	P1	C2	M2	D2	P2	C3	M3	D3	P3	C4	M4	D4	P4	C5	M5	D5	P5	TOTAL
76.0	140	140	UP 0	0	140	0	DN 4	0	0	0	UP 0	0	0	0	UP 0	0	0	0	UP 0	0	38900
77.0	140	140	UP 0	0	140	0	DN 5	0	0	0	UP 0	0	0	0	DN 1	0	0	0	UP 0	0	38900
78.0	140	140	UP 0	0	140	0	DN 6	0	0	0	UP 0	0	0	0	UP 0	0	0	0	UP 0	0	38900
79.0	20	140	UP 0	1200	140	120	UP 0	1080	120	120	UP 0	840	120	120	UF 0	600	120	120	UP 0	360	39140
80.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	40340
81.0	140	140	UP 0	20	140	120	UP 0	20	120	120	UP 0	20	140	0	DN 1	120	0	0	UP 0	360	40820
82.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 2	0	0	0	UP 0	0	40820
83.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 3	0	0	0	UP 0	0	40820
84.0	140	140	UF 0	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 4	0	0	0	UP 0	0	40820
85.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 5	0	0	0	UP 0	0	40820
86.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 6	0	0	0	UF 0	0	40820
87.0	140	140	UP 0	0	140	120	DN 1	0	120	0	DN 1	120	0	0	UP 0	240	0	0	UP 0	260	41080
88.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1080	120	120	UP 0	840	120	120	UP 0	600	41560
89.0	140	120	DN 1	20	140	120	UP 0	20	120	120	UP 0	20	140	0	DN 1	120	0	0	UF 0	360	42040
90.0	140	140	UF 0	0	140	120	UP 0	0	120	120	DN 1	0	140	0	DN 2	0	0	0	UP 0	0	42040
91.0	140	140	UP 0	0	140	120	DN 1	0	120	120	DN 2	0	140	0	DN 3	0	0	0	UP 0	0	42040
92.0	140	140	UP 0	0	140	120	UP 0	0	120	0	DN 3	120	0	0	UP 0	240	0	0	UP 0	260	42300
93.0	20	140	UF 0	1200	140	120	UF 0	1200	120	120	UP 0	1080	120	120	UP 0	840	120	120	UP 0	600	42790
94.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	43990
95.0	140	140	UP 0	0	140	0	DN 1	120	0	0	UP 0	360	0	0	UF 0	600	0	0	UP 0	840	44940
96.0	140	140	UF 0	0	140	0	DN 2	0	0	0	DN 1	0	0	0	UF 0	0	0	0	DN 1	0	44940
97.0	140	140	UP 0	240	140	120	UP 0	120	120	0	DN 2	0	0	0	UP 0	0	0	0	DN 2	0	44940
98.0	140	140	UP 0	560	140	120	UP 0	560	120	120	UP 0	440	140	140	UP 0	150	160	0	DN 3	0	44940
99.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	140	UP 0	0	160	0	DN 4	0	44940
100.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1240	120	120	UP 0	1160	45980
101.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	47180
102.0	140	140	UP 0	20	140	120	UP 0	20	120	120	UP 0	20	140	0	DN 1	120	0	0	UP 0	360	47660
103.0	140	140	UP 0	0	140	120	UP 0	0	120	0	DN 1	120	0	0	UP 0	240	0	0	UF 0	260	47920
104.0	140	0	DN 1	140	0	0	UP 0	400	0	0	UP 0	520	0	0	UP 0	520	0	0	UP 0	520	48400
105.0	140	140	UP 0	140	140	0	DN 1	0	0	0	UP 0	0	0	0	UP 0	0	0	0	UP 0	0	48440
106.0	20	140	UP 0	1200	140	120	UP 0	1080	120	120	UF 0	840	120	120	UP 0	600	120	120	UP 0	360	48680
107.0	140	140	UP 0	80	140	120	UP 0	80	120	120	UP 0	80	140	140	UP 0	80	160	0	DN 1	120	48920
108.0	140	140	DN 1	0	140	120	UP 0	0	120	120	UP 0	0	140	140	DN 1	0	160	0	DN 2	0	48920
109.0	140	140	UP 0	0	140	120	DN 1	0	120	120	DN 1	0	140	140	UF 0	0	160	0	DN 3	0	48920
110.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1240	120	120	UP 0	1160	49960
111.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	51160
112.0	140	0	DN 1	140	0	0	UP 0	400	0	0	UP 0	640	0	0	UF 0	840	0	0	UF 0	1120	52360
113.0	140	0	DN 2	0	0	0	UP 0	0	0	0	UP 0	0	0	0	UP 0	0	0	0	UP 0	0	52400
114.0	140	0	DN 3	0	0	0	UP 0	0	0	0	UP 0	0	0	0	UP 0	0	0	0	UP 0	0	52400
115.0	140	140	UP 0	140	140	0	DN 1	0	0	0	UP 0	0	0	0	UP 0	0	0	0	DN 1	0	52400
116.0	140	140	DN 1	0	140	0	DN 2	0	0	0	UP 0	0	0	0	UP 0	0	0	0	UP 0	0	52400
117.0	140	140	UP 0	0	140	0	DN 3	0	0	0	UP 0	0	0	0	UP 0	0	0	0	UF 0	0	52400
118.0	140	140	UP 0	0	140	0	DN 4	0	0	0	UP 0	0	0	0	DN 1	0	0	0	UP 0	0	52400
119.0	140	140	UP 0	0	140	0	DN 5	0	0	0	DN 1	0	0	0	UP 0	0	0	0	UP 0	0	52400
120.0	140	140	UP 0	0	140	0	DN 6	0	0	0	DN 2	0	0	0	UF 0	0	0	0	UF 0	0	52400
121.0	140	140	UP 0	0	140	0	DN 7	0	0	0	DN 3	0	0	0	UF 0	0	0	0	UP 0	0	52400
122.0	140	140	UP 0	240	140	120	UP 0	120	120	0	DN 4	0	0	0	UP 0	0	0	0	UP 0	0	52400
123.0	140	140	DN 1	0	140	120	UP 0	0	120	0	DN 5	0	0	0	UP 0	0	0	0	UP 0	0	52400
124.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1080	120	120	UP 0	840	120	120	UP 0	600	52880
125.0	140	140	UP 0	0	140	120	UF 0	0	120	0	DN 1	120	0	0	UF 0	350	0	0	UF 0	600	53600
126.0	140	0	DN 1	140	0	0	UP 0	400	0	80	UP 0	440	140	140	UP 0	150	160	0	DN 1	0	53600
127.0	140	140	UP 0	420	140	120	UP 0	160	120	120	UP 0	0	140	140	UF 0	0	160	0	DN 2	0	53600
128.0	140	140	DN 1	0	140	120	UP 0	0	120	120	UP 0	0	160	140	UF 0	0	160	0	DN 3	0	53600
129.0	140	140	DN 2	0	140	120	UP 0	0	120	120	UP 0	0	140	140	UP 0	0	160	0	DN 4	0	53600
130.0	140	140	DN 3	0	140	120	DN 1	0	120	120	UP 0	0	140	140	UP 0	0	160	0	DN 5	0	53600
131.0	140	140	DN 4	0	140	120	UP 0	0	120	120	UP 0	0	140	140	DN 1	0	160	0	DN 6	0	53600
132.0	140	140	DN 5	0	140	120	DN 1	0	120	120	DN 1	0	140	140	DN 2	0	160	0	DN 7	0	53600
133.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 3	140	0	0	UP 0	300	53900
134.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	0	DN 4	0	0	0	UP 0	0	53900
135.0	20	140	UP 0	1200	140	120	UF 0	1200	120	120	UP 0	1200	120	120	UF 0	1100	120	120	UF 0	860	54640
136.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	55840
137.0	140	140	UP 0	0	140	0	DN 1	120	0	0	UP 0	360	0	0	UP 0	600	0	0	UP 0	840	56800
138.0	140	140	UP 0	800	140	120	UP 0	680	120	120	UF 0	440	140	140	UP 0	150	160	0	DN 1	0	56800
139.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	140	UP 0	0	160	0	DN 2	0	56800
140.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	140	UP 0	0	160	0	DN 3	0	56800
141.0	140	140	UP 0	0	140	120	UP 0	0	120	120	UP 0	0	140	140	UF 0	0	160	0	DN 4	0	56800
142.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1240	120	120	UP 0	1160	57840
143.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	59040
144.0	140	140	UP 0	0	140	0	DN 1	120	0	0	UP 0	360	0	0	UF 0	600	0	0	UF 0	840	60000
145.0	20	140	UF 0	1200	140	120	UP 0	1080	120	120	UP 0	960	120	120	UP 0	600	120	120	UP 0	360	60240
146.0	20	140	UF 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	61440
147.0	20	140	UF 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	62640
148.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	63840
149.0	20	140	UP 0	1200	140	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	120	120	UP 0	1200	65040
150.0	140	140	UP 0	0	140	120	DN 1	0	120	0	DN 1	120	0	0	UP 0	340	0	0	UP 0	600	65760

TABLE 7.2.--Proof Model 2, Part II

3. The assumption that no units will enter or exit a station if its corresponding entering or exiting conveyors are full is in evidence in this model. It can be seen that the capacities and downtimes of each machine materially affect the production of the machines before and after them. A maximum of 1400 and 1600 units per minute can be carried on the entering conveyors to machines 4 and 5, respectively. However, this quantity never rises this high when both machines are running because of the line bottleneck, the filler and seamer machines. Although the packer and traymaker are capable of producing 1400 and 1600 units respectively, it is of no consequence if the cans are not available.

4. From a cost versus production point of view:

Conveyor Capacity:	140+140+120+140+160 = 700 units
Each Unit (Can):	2.5 inches diameter
Cost of Conveyor:	$100.00 per running foot

Capital Cost:

$$700 \text{ units} \times \frac{2.5 \text{ in.}}{1 \text{ unit}} \times \frac{1 \text{ ft.}}{12 \text{ in.}} \times \frac{\$100.00}{1 \text{ ft.}} = \$14,583.33$$

Incremental Revenue:

Total Output:	65,760
Incremental Revenue per Unit of Output:	$0.03
Length of Run:	150 minutes

$$65,760 \text{ units} \times \frac{480 \text{ min}}{150 \text{ min}} \times \frac{\$0.03}{\text{unit}} = \$6,312.96/\text{eight hour shift}$$

Necessary time to recoup investment working 3, eight hour shifts per day, five days per week:

$$\frac{\$14,583.33}{\$6,312.96} \times \frac{1 \text{ shift}}{3 \text{ shifts/day}} = 77 \text{ working days.}$$

Models 1 and 2 were examined more to prove that the simulation model functions realistically as a high speed assembly line, given the stated assumptions in section six, rather than as a practical cost versus production example. However, there are important aspects to be noticed in this area. Model 1 produced more units but lost its profit in excessive capital investment in conveyor equipment. Model 2 spent too little on capital equipment and suffered from an inefficient line, loss of production and lost market position.

6.3 Proof Model 3

Proof Models 3 and 4 are designed in an effort to optimize production at the lowest capital investment in conveyor systems. Model 3 utilizes conveyor lengths of 10,000, 20,000, 15,000, 15,000, and 30,000 units (Figure 6.3). All four models are similar in that they are arranged in a coupling of five machines in a series and each simulation run is started with all conveyors half full.

Some comments follow concerning Table 6.3:

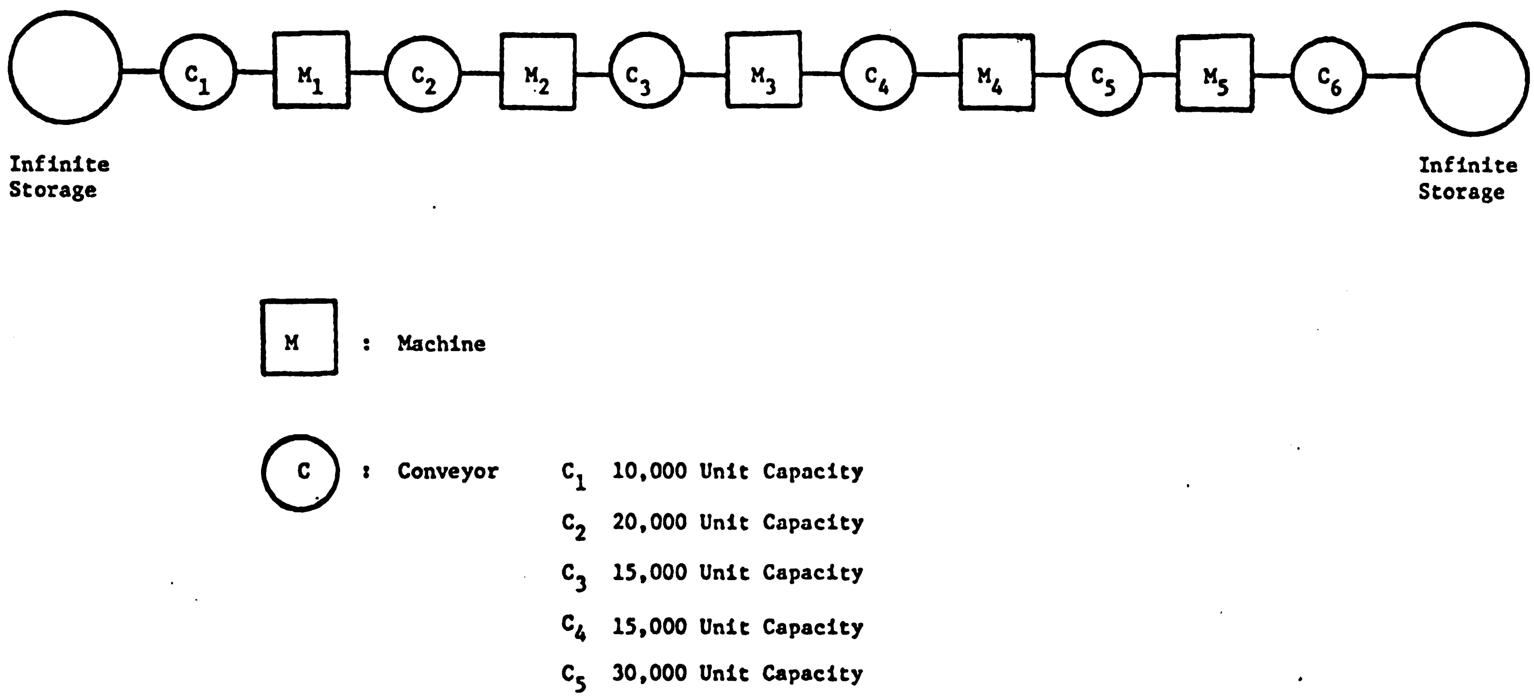


Figure 7.3.--Proof Model 3.

TIME MIN	DEPALLETIZER C1	M1	D1	P1	FILLER C2	M2	D2	P2	SEAMER C3	M3	D3	P3	PACKER C4	M4	D4	P4	TRAYMAKER C5	M5	D5	P5	TOTAL
1.0	10000	0	DN 1	0	10000	0	DN 1	0	6100	120	UP 0	1080	8580	0	DN 1	0	13600	160	UP 0	1440	1280
2.0	9860	140	UP 0	1260	10000	120	UP 0	1080	6140	120	UP 0	1200	9790	0	DN 2	0	11800	160	UP 0	1520	2880
3.0	10000	0	DN 1	140	9960	120	UP 0	1200	6190	120	UP 0	1200	10190	0	DN 3	0	10200	160	UP 0	1500	4490
4.0	9860	140	UP 0	1260	9860	120	UP 0	1200	6190	120	UP 0	1200	12190	0	DN 4	0	8600	160	UP 0	1600	6080
5.0	10000	0	DN 1	140	9600	120	UP 0	1200	7190	0	DN 1	120	12300	0	DN 5	0	7060	160	UP 0	1500	7590
6.0	10000	0	DN 2	0	6940	120	UP 0	1200	7390	120	UP 0	1080	13390	0	DN 6	0	5430	160	UP 0	1600	9280
7.0	10000	0	DN 3	0	5600	120	UP 0	1200	7190	120	UP 0	1200	13190	140	UP 0	1260	5060	160	UP 0	1600	10880
8.0	9860	140	UP 0	1260	5660	120	UP 0	1200	9590	0	DN 1	120	11100	140	UP 0	1400	4860	160	UP 0	1600	12480
9.0	9860	140	UP 0	1400	[illegible]	120	UP 0	1200	9590	120	UP 0	1080	11590	140	UP 0	1400	4660	160	UP 0	1500	14080
10.0	9860	140	UP 0	1400	6000	120	UP 0	1200	9590	120	UP 0	1200	11390	140	UP 0	1400	4460	160	UP 0	1600	15680
11.0	9860	140	UP 0	1400	6260	120	UP 0	1200	9540	120	UP 0	1200	11140	140	UP 0	1400	4260	160	UP 0	1600	17280
12.0	9860	140	UP 0	1400	6460	120	UP 0	1200	9590	120	UP 0	1200	11340	140	UP 0	1400	4060	160	UP 0	1500	18880
13.0	9860	140	UP 0	1400	7400	0	DN 1	120	7500	120	UP 0	1200	12140	0	DN 1	140	2600	160	UP 0	1600	20480
14.0	9860	140	UP 0	1400	9500	120	UP 0	1080	9590	0	DN 1	120	12300	0	DN 2	0	1000	160	UP 0	1500	22080
15.0	9860	140	UP 0	1400	9200	120	UP 0	1200	9590	120	UP 0	1080	11340	140	UP 0	1260	660	160	UP 0	1600	23680
16.0	9860	140	UP 0	1400	9460	120	UP 0	1200	9590	120	UP 0	1200	11790	140	UP 0	1400	460	160	UP 0	1500	25280
17.0	10000	0	DN 1	140	7400	120	UP 0	1200	9740	0	DN 1	120	10900	140	UP 0	1400	260	160	UP 0	1500	26880
18.0	10000	0	DN 2	0	7200	120	UP 0	1200	9740	120	UP 0	1080	10140	140	UP 0	1400	140	140	UP 0	1540	28440
19.0	10000	0	DN 3	0	5000	120	UP 0	1200	9790	120	UP 0	1200	9340	140	UP 0	1400	140	140	UP 0	1400	29840
20.0	9860	140	UP 0	1260	6200	120	UP 0	1200	9720	120	UP 0	1200	9740	140	UP 0	1400	1540	0	DN 1	140	31120
21.0	9860	140	UP 0	1400	6400	0	DN 1	120	9590	120	UP 0	1200	9390	140	UP 0	1400	2940	0	DN 2	0	31120
22.0	9860	140	UP 0	1400	6700	120	UP 0	1080	8590	120	UP 0	1200	9340	140	UP 0	1400	4340	0	DN 3	0	31120
23.0	10000	0	DN 1	140	5860	120	UP 0	1200	9590	120	UP 0	1200	9190	140	UP 0	1400	5740	0	DN 4	0	31120
24.0	9860	140	UP 0	1260	6800	0	DN 1	120	9700	0	DN 1	120	7900	140	UP 0	1400	5540	160	UP 0	1440	31600
25.0	9860	140	UP 0	1400	7000	120	UP 0	1080	9580	120	UP 0	1080	7590	140	UP 0	1400	5340	160	UP 0	1500	33000
26.0	9860	140	UP 0	1400	7260	120	UP 0	1200	9590	120	UP 0	1200	7340	140	UP 0	1400	5140	160	UP 0	1500	34500
27.0	9860	140	UP 0	1400	7460	120	UP 0	1200	9540	120	UP 0	1200	7190	140	UP 0	1400	4940	160	UP 0	1500	36200
28.0	9860	140	UP 0	1400	7660	120	UP 0	1200	9590	120	UP 0	1200	6390	140	UP 0	1400	4740	160	UP 0	1600	37800
29.0	9860	140	UP 0	1400	7860	120	UP 0	1200	9590	120	UP 0	1200	6740	140	UP 0	1400	4540	160	UP 0	1500	39400
30.0	9860	140	UP 0	1400	9060	120	UP 0	1200	9590	120	UP 0	1200	7390	0	DN 1	140	3040	160	UP 0	1600	41300
31.0	9860	140	UP 0	1400	9260	120	UP 0	1200	9590	120	UP 0	1200	7790	140	UP 0	1260	2740	160	UP 0	1500	42500
32.0	10000	0	DN 1	140	7260	120	UP 0	1200	8590	120	UP 0	1200	7590	140	UP 0	1400	2540	160	UP 0	1500	44200
33.0	9860	140	UP 0	1260	7260	120	UP 0	1200	9540	120	UP 0	1200	7390	140	UP 0	1400	3940	0	DN 1	160	44520
34.0	9860	140	UP 0	1400	7460	120	UP 0	1200	9540	120	UP 0	1200	7140	140	UP 0	1400	3740	160	UP 0	1440	45900
35.0	9860	140	UP 0	1400	7660	120	UP 0	1200	9590	120	UP 0	1200	6990	140	UP 0	1400	3540	160	UP 0	1600	47400
36.0	9860	140	UP 0	1400	7960	120	UP 0	1200	9590	120	UP 0	1200	8180	0	DN 1	140	2090	160	UP 0	1500	49300
37.0	10000	0	DN 1	140	6840	120	UP 0	1200	9740	0	DN 1	120	6390	140	UP 0	1260	1740	160	UP 0	1600	50500
38.0	9860	140	UP 0	1260	6960	120	UP 0	1200	9740	120	UP 0	1080	6540	140	UP 0	1400	1540	160	UP 0	1600	52200
39.0	9860	140	UP 0	1400	7060	120	UP 0	1200	9710	120	UP 0	1200	6190	140	UP 0	1400	2940	0	DN 1	160	52520
40.0	9860	140	UP 0	1400	7260	120	UP 0	1200	9790	120	UP 0	1200	6190	140	UP 0	1400	4340	0	DN 2	0	52520
41.0	9860	140	UP 0	1400	7460	120	UP 0	1200	10990	0	DN 1	120	6300	140	UP 0	1400	5740	0	DN 3	0	52520
42.0	9860	140	UP 0	1400	7660	120	UP 0	1200	10190	120	UP 0	1080	5190	0	DN 1	140	4280	160	UP 0	1440	53900
43.0	9860	140	UP 0	1400	7960	120	UP 0	1200	10790	120	UP 0	1200	5780	140	UP 0	1260	3940	160	UP 0	1600	55400
44.0	9860	140	UP 0	1400	9660	120	UP 0	1200	10290	120	UP 0	1200	5590	140	UP 0	1400	3740	160	UP 0	1600	57000
45.0	9860	140	UP 0	1400	9660	0	DN 1	120	9790	120	UP 0	1200	5190	140	UP 0	1400	3540	160	UP 0	1600	58600
46.0	9860	140	UP 0	1400	9660	120	UP 0	1080	9790	120	UP 0	1200	5140	140	UP 0	1400	3340	160	UP 0	1500	60200
47.0	9860	140	UP 0	1400	9960	120	UP 0	1200	10990	0	DN 1	120	3390	140	UP 0	1400	4740	0	DN 1	160	60520
48.0	9860	140	UP 0	1400	11260	0	DN 1	120	9130	120	UP 0	1080	3590	140	UP 0	1400	6140	0	DN 2	0	60520
49.0	9860	140	UP 0	1400	12660	0	DN 2	0	9790	120	UP 0	1200	3190	140	UP 0	1400	5340	160	UP 0	1440	61900
50.0	9860	140	UP 0	1400	14060	0	DN 3	0	7590	120	UP 0	1200	4590	0	DN 1	140	6030	0	DN 1	160	62120
51.0	9860	140	UP 0	1400	14200	120	UP 0	1080	7190	120	UP 0	1200	5790	0	DN 2	0	6090	0	DN 2	0	62120
52.0	9860	140	UP 0	1400	14460	120	UP 0	1200	7190	120	UP 0	1200	5590	140	UP 0	1260	7340	0	DN 3	0	62120
53.0	9860	140	UP 0	1400	14660	120	UP 0	1200	7190	120	UP 0	1200	5340	140	UP 0	1400	7140	160	UP 0	1440	63400
54.0	9860	140	UP 0	1400	14860	120	UP 0	1200	7190	120	UP 0	1200	5540	0	DN 1	140	5680	160	UP 0	1600	65000
55.0	9860	140	UP 0	1400	16260	0	DN 1	120	6190	120	UP 0	1200	7740	0	DN 2	0	4090	160	UP 0	1600	66600
56.0	10000	0	DN 1	140	16260	120	UP 0	1080	6190	120	UP 0	1200	8490	0	DN 3	0	4080	0	DN 1	160	66920
57.0	9860	140	UP 0	1260	16260	120	UP 0	1200	6190	120	UP 0	1200	10190	0	DN 4	0	2410	160	UP 0	1440	68300
58.0	9860	140	UP 0	1400	16460	120	UP 0	1200	6190	120	UP 0	1200	11340	0	DN 5	0	890	160	UP 0	1600	69900
59.0	9860	140	UP 0	1400	16660	120	UP 0	1200	6190	120	UP 0	1200	11190	140	UP 0	1260	540	160	UP 0	1500	71400
60.0	9860	140	UP 0	1400	16860	120	UP 0	1200	5190	120	UP 0	1200	10790	140	UP 0	1400	340	160	UP 0	1500	73000
61.0	9860	140	UP 0	1400	17060	120	UP 0	1200	6190	120	UP 0	1200	10790	140	UP 0	1400	140	160	UP 0	1600	74600
62.0	9860	140	UP 0	1400	16260	120	UP 0	1200	6190	120	UP 0	1200	10590	140	UP 0	1400	140	140	UP 0	1420	76040
63.0	9860	140	UP 0	1400	16460	120	UP 0	1200	6190	120	UP 0	1200	10390	140	UP 0	1400	140	140	UP 0	1400	77440
64.0	9860	140	UP 0	1400	16660	120	UP 0	1200	6190	120	UP 0	1200	10190	140	UP 0	1400	140	140	UP 0	1400	78840
65.0	9860	140	UP 0	1400	16960	120	UP 0	1200	6190	120	UP 0	1200	9390	140	UP 0	1400	140	140	UP 0	1400	80240
66.0	9860	140	UP 0	1400	17260	120	UP 0	1200	6190	120	UP 0	1200	9780	140	UP 0	1400	140	140	UP 0	1400	81640
67.0	10000	0	DN 1	140	16660	120	UP 0	1200	6190	120	UP 0	1200	9590	140	UP 0	1400	140	140	UP 0	1400	83040
68.0	9860	140	UP 0	1260	16860	120	UP 0	1200	6190	120	UP 0	1200	9340	140	UP 0	1400	1540	0	DN 1	140	83320
69.0	9860	140	UP 0	1400	16260	120	UP 0	1200	6190	120	UP 0	1200	10590	0	DN 1	140	80	160	UP 0	1440	84500
70.0	9860	140	UP 0	1400	16460	120	UP 0	1200	6190	120	UP 0	1200	11790	0	DN 2	0	0	0	UP 0	240	85300
71.0	10000	0	DN 1	140	16660	0	DN 1	120	6120	0	DN 1	120	10500	140	UP 0	1260	140	140	UP 0	980	85940
72.0	9860	140	UP 0	1260	16660	120	UP 0	1080	6190	120	UP 0	1080	10190	140	UP 0	1400	140	140	UP 0	1400	87240
73.0	10000	0	DN 1	140	16860	0	DN 1	120	5190	120	UP 0	1200	11390	0	DN 1	140	0	0	UP 0	420	87800
74.0	9860	140	UP 0	1260	18060	0	DN 2	0	3190	120	UP 0	1200	12590	0	DN 2	0	0	0	UP 0	0	87800
75.0	10000	0	DN 1	140	18260	0	DN 3	0	2790	120	UP 0	1200	12350	140	UP 0	1260	140	140	UP 0	980	88640

TABLE 7.3.--Proof Model 3, Part I

TIME MIN	DEPALLETIZER C1	M1	D1		P1	FILLER C2	M2	D2		P2
76.0	9880	140	UP	0	1760	19460	0	DN	4	0
77.0	10000	140	UP	0	540	20000	0	DN	5	0
78.0	10000	140	UP	0	0	20000	0	DN	6	0
79.0	9880	140	UP	0	1200	20000	120	UP	0	1090
80.0	9880	140	UP	0	1200	20000	120	UP	0	1200
81.0	9990	140	UP	0	1200	20000	120	UP	0	1200
82.0	9880	140	UP	0	1200	20000	120	UP	0	1200
83.0	9880	140	UP	0	1200	20000	120	UP	0	1200
84.0	9880	140	UP	0	1200	20000	120	UP	0	1200
85.0	9890	140	UP	0	1200	20000	120	UP	0	1200
86.0	9880	140	UP	0	1200	20000	120	UP	0	1200
87.0	10000	140	UP	0	0	20000	0	DN	1	120
88.0	9880	140	UP	0	1200	20000	120	UP	0	1090
89.0	10000	0	DN	1	140	19940	120	UP	0	1200
90.0	9880	140	UP	0	1260	19600	120	UP	0	1200
91.0	10000	140	UP	0	1300	20000	0	DN	1	120
92.0	9880	140	UP	0	1200	20000	120	UP	0	1090
93.0	9880	140	UP	0	1200	20000	120	UP	0	1200
94.0	9980	140	UP	0	1200	20000	120	UP	0	1200
95.0	10000	140	UP	0	0	20000	0	DN	1	120
96.0	10000	140	UP	0	0	20000	0	DN	2	0
97.0	9880	140	UP	0	1200	20000	120	UP	0	1090
98.0	9880	140	UP	0	1200	20000	120	UP	0	1200
99.0	9880	140	UP	0	1200	20000	120	UP	0	1200
100.0	9890	140	UP	0	1200	20000	120	UP	0	1200
101.0	9980	140	UP	0	1200	20000	120	UP	0	1200
102.0	9880	140	UP	0	1200	20000	120	UP	0	1200
103.0	9880	140	UP	0	1200	20000	120	UP	0	1200
104.0	10000	0	DN	1	140	19940	120	UP	0	1200
105.0	10000	140	UP	0	1260	20000	0	DN	1	120
106.0	9880	140	UP	0	1200	20000	120	UP	0	1090
107.0	9880	140	UP	0	1200	20000	120	UP	0	1200
108.0	10000	0	DN	1	140	19940	120	UP	0	1200
109.0	10000	140	UP	0	1350	20000	0	DN	1	120
110.0	9880	140	UP	0	1200	20000	120	UP	0	1080
111.0	9880	140	UP	0	1200	20000	120	UP	0	1200
112.0	10000	0	DN	1	140	19940	120	UP	0	1200
113.0	10000	0	DN	2	0	17740	120	UP	0	1200
114.0	10000	0	DN	3	0	16540	120	UP	0	1200
115.0	9860	140	UP	0	1260	17400	0	DN	1	120
116.0	10000	0	DN	1	140	17940	0	DN	2	0
117.0	9860	140	UP	0	1350	19260	0	DN	3	0
118.0	10000	140	UP	0	800	20000	0	DN	4	0
119.0	10000	140	UP	0	0	20000	0	DN	5	0
120.0	10000	140	UP	0	0	20000	0	DN	6	0
121.0	10000	140	UP	0	0	20000	0	DN	7	0
122.0	9880	140	UP	0	1200	20000	120	UP	0	1090
123.0	10000	0	DN	1	140	19940	120	UP	0	1200
124.0	9880	140	UP	0	1260	19600	120	UP	0	1200
125.0	9880	140	UP	0	1400	19200	120	UP	0	1200
126.0	10000	0	DN	1	140	19140	120	UP	0	1200
127.0	9880	140	UP	0	1260	18200	120	UP	0	1200
128.0	10000	0	DN	1	140	17140	120	UP	0	1200
129.0	10000	0	DN	2	0	16040	120	UP	0	1200
130.0	10000	0	DN	3	0	15940	0	DN	1	120
131.0	10000	0	DN	4	0	14740	120	UP	0	1090
132.0	10000	0	DN	5	0	14740	0	DN	1	120
133.0	9860	140	UP	0	1260	14800	120	UP	0	1080
134.0	9900	140	UP	0	1400	15000	120	UP	0	1200
135.0	9880	140	UP	0	1400	15200	120	UP	0	1200
136.0	9860	140	UP	0	1400	15400	120	UP	0	1200
137.0	9860	140	UP	0	1400	16500	0	DN	1	120
138.0	9880	140	UP	0	1400	17200	120	UP	0	1340
139.0	9860	140	UP	0	1400	17200	120	UP	0	1200
140.0	9860	140	UP	0	1400	17400	120	UP	0	1200
141.0	9980	140	UP	0	1400	17600	120	UP	0	1200
142.0	9860	140	UP	0	1400	17800	120	UP	0	1200
143.0	9860	140	UP	0	1400	18000	120	UP	0	1200
144.0	9980	140	UP	0	1400	19460	0	DN	1	120
145.0	9860	140	UP	0	1400	19400	120	UP	0	1090
146.0	9860	140	UP	0	1400	19600	120	UP	0	1200
147.0	9860	140	UP	0	1400	19800	120	UP	0	1200
148.0	9880	140	UP	0	1280	20000	120	UP	0	1200
149.0	9880	140	UP	0	1200	20000	120	UP	0	1200
150.0	10000	140	UP	0	0	20000	0	DN	1	120

TIME MIN	SEAMER C3	M3	D3		P3	PACKER C4	M4	D4		P4	TRAYMAKER C5	M5	D5		P5	TOTAL
76.0	1530	120	UP	0	1200	12140	140	UP	0	1400	140	140	UP	0	1400	93040
77.0	130	120	UP	0	1200	13390	0	DN	1	140	0	0	UP	0	420	90500
78.0	0	0	UP	0	420	12600	140	UP	0	1260	140	140	UP	0	980	91440
79.0	120	120	UP	0	840	11940	140	UP	0	1400	140	140	UP	0	1400	92940
80.0	120	120	UP	0	1200	11540	140	UP	0	1400	140	140	UP	0	1400	94240
81.0	120	120	UP	0	1200	12940	0	DN	1	140	0	0	UP	0	420	94930
82.0	120	120	UP	0	1200	14340	0	DN	2	0	0	0	UP	0	0	94900
83.0	960	120	UP	0	960	15000	0	DN	3	0	0	0	UP	0	0	94900
84.0	1560	120	UP	0	0	15000	0	DN	4	0	0	0	UP	0	0	94900
85.0	2760	120	UP	0	0	15000	0	DN	5	0	0	0	UP	0	0	94900
86.0	3960	120	UP	0	0	15000	0	DN	6	0	0	0	UP	0	0	94900
87.0	4290	0	DN	1	120	13720	140	UP	0	1260	140	140	UP	0	980	95540
88.0	3960	120	UP	0	1080	13300	140	UP	0	1400	140	140	UP	0	1400	97300
89.0	3760	120	UP	0	1200	14600	0	DN	1	140	0	0	UP	0	420	97500
90.0	5160	0	DN	1	120	14720	0	DN	2	0	0	0	UP	0	0	97600
91.0	5290	0	DN	2	0	14720	0	DN	3	0	0	0	UP	0	0	97500
92.0	6160	0	DN	3	0	13320	140	UP	0	1260	140	140	UP	0	980	98440
93.0	6160	120	UP	0	1090	13300	140	UP	0	1400	140	140	UP	0	1400	99940
94.0	6160	120	UP	0	1200	12400	140	UP	0	1400	140	140	UP	0	1400	101240
95.0	5290	120	UP	0	1200	12500	140	UP	0	1400	140	140	UP	0	1400	102540
96.0	5190	0	DN	1	120	11120	140	UP	0	1400	1540	0	DN	1	140	103120
97.0	6160	0	DN	2	0	10720	140	UP	0	1400	2940	0	DN	2	0	103120
98.0	6160	120	UP	0	1090	9600	140	UP	0	1400	4340	0	DN	3	0	102120
99.0	5160	120	UP	0	1200	9600	140	UP	0	1400	5740	0	DN	4	0	103320
100.0	6160	120	UP	0	1200	9200	140	UP	0	1400	5540	160	UP	0	1440	104200
101.0	6160	120	UP	0	1200	9000	140	UP	0	1400	5340	160	UP	0	1500	105900
102.0	6360	120	UP	0	1200	10200	0	DN	1	140	3980	160	UP	0	1500	107400
103.0	7560	0	DN	1	120	9120	140	UP	0	1260	3540	160	UP	0	1600	109000
104.0	7560	120	UP	0	1080	8510	140	UP	0	1400	3340	160	UP	0	1600	110300
105.0	6490	120	UP	0	1200	9520	140	UP	0	1400	3140	160	UP	0	1600	112200
106.0	6160	120	UP	0	1200	8200	140	UP	0	1400	2940	160	UP	0	1600	113900
107.0	6160	120	UP	0	1200	9300	140	UP	0	1400	4340	0	DN	1	160	114120
108.0	6360	120	UP	0	1200	9200	0	DN	1	140	4430	0	DN	2	0	114120
109.0	6490	0	DN	1	120	7920	140	UP	0	1260	5740	0	DN	3	0	114120
110.0	6160	120	UP	0	1090	7600	140	UP	0	1400	5540	160	UP	0	1440	115400
111.0	6160	120	UP	0	1200	7400	140	UP	0	1400	5340	160	UP	0	1500	117000
112.0	6160	120	UP	0	1200	7200	140	UP	0	1400	5140	160	UP	0	1500	118600
113.0	6360	120	UP	0	1200	7000	140	UP	0	1400	4940	160	UP	0	1600	120200
114.0	6160	120	UP	0	1200	6900	140	UP	0	1400	4740	160	UP	0	1600	121800
115.0	5760	120	UP	0	1200	6500	140	UP	0	1400	6140	0	DN	1	160	122120
116.0	4640	120	UP	0	1200	6400	140	UP	0	1400	5940	160	UP	0	1440	123400
117.0	2990	120	UP	0	1200	6200	140	UP	0	1400	5740	160	UP	0	1500	125000
118.0	1640	120	UP	0	1200	7600	0	DN	1	140	4290	160	UP	0	1500	126500
119.0	1640	0	DN	1	120	6120	140	UP	0	1260	3340	160	UP	0	1600	128200
120.0	1640	0	DN	2	0	4720	140	UP	0	1400	3740	160	UP	0	1500	129300
121.0	1690	0	DN	3	0	3320	140	UP	0	1400	3540	160	UP	0	1500	131400
122.0	2760	0	DN	4	0	1720	140	UP	0	1400	3340	160	UP	0	1600	133000
123.0	3960	0	DN	5	0	520	140	UP	0	1400	3140	160	UP	0	1500	134500
124.0	3160	120	UP	0	1090	200	140	UP	0	1400	2940	160	UP	0	1600	136200
125.0	5160	0	DN	1	120	0	0	UP	0	460	1830	160	UP	0	1600	137900
126.0	5160	120	UP	0	1090	120	120	UP	0	840	2640	0	DN	1	160	139120
127.0	5160	120	UP	0	1200	120	120	UP	0	1200	3940	0	DN	2	0	139120
128.0	5150	120	UP	0	1200	120	120	UP	0	1200	5040	0	DN	3	0	139120
129.0	5160	120	UP	0	1200	120	120	UP	0	1200	6240	0	DN	4	0	139120
130.0	4140	120	UP	0	1200	120	120	UP	0	1200	7440	0	DN	5	0	139120
131.0	3760	120	UP	0	1200	1320	0	DN	1	120	7560	0	DN	6	0	139120
132.0	4090	0	DN	1	120	1440	0	DN	2	0	7560	0	DN	7	0	139120
133.0	3160	120	UP	0	1090	2520	0	DN	3	0	5960	160	UP	0	1440	140600
134.0	3460	120	UP	0	1200	3720	0	DN	4	0	6360	160	UP	0	1500	141000
135.0	3760	120	UP	0	1200	3520	140	UP	0	1260	4020	160	UP	0	1600	142600
136.0	3160	120	UP	0	1200	3320	140	UP	0	1400	3820	160	UP	0	1600	144200
137.0	3990	120	UP	0	1200	3120	140	UP	0	1400	3620	160	UP	0	1600	145900
138.0	2760	120	UP	0	1200	2720	140	UP	0	1400	5020	0	DN	1	160	146120
139.0	2760	120	UP	0	1200	2720	140	UP	0	1400	6420	0	DN	2	0	146120
140.0	2760	120	UP	0	1200	2520	140	UP	0	1400	7820	0	DN	3	0	146120
141.0	2760	120	UP	0	1200	2320	140	UP	0	1400	9220	0	DN	4	0	146120
142.0	2760	120	UP	0	1200	2120	140	UP	0	1400	9020	160	UP	0	1440	147600
143.0	2760	120	UP	0	1200	1920	140	UP	0	1400	8820	160	UP	0	1600	149000
144.0	1690	120	UP	0	1200	1720	140	UP	0	1400	8620	160	UP	0	1600	150500
145.0	1560	120	UP	0	1200	1520	140	UP	0	1400	8420	160	UP	0	1500	152200
146.0	1560	120	UP	0	1200	1370	140	UP	0	1400	8220	160	UP	0	1600	153900
147.0	1560	120	UP	0	1200	1120	140	UP	0	1400	8020	160	UP	0	1600	155400
148.0	1560	120	UP	0	1200	920	140	UP	0	1400	7820	160	UP	0	1600	157000
149.0	1560	120	UP	0	1200	720	140	UP	0	1400	7620	160	UP	0	1500	159500
150.0	1440	0	DN	1	120	0	0	UP	0	980	7830	160	UP	0	1600	160200

TABLE 7.3.--Proof Model 3, Part II

1. The efficiency of each machine, excluding idling time is the same as that discussed in comment (2) of Proof Model 1. The line efficiency based on the filler is

Total Production:	160,200 cans
Length of Run:	150 minutes
Slowest Machine:	$M_{(2)}$-Filler 1200 cpm

$$\frac{160{,}200 \text{ cans}}{150 \text{ min} \times 1200 \text{ cpm}} \times 100\% = 89\%$$

2. Filler idling time is as small as possible. Idle time as a percent of total running time is:

$$\frac{19 \text{ min}}{150 \text{ min}} \times 100\% = 12.7\%$$

This idle time is due to the 6 second start-up time step of the filler while it is being loaded with cans.

3. In analyzing the operation of this model it is found that the 20,000 can capacity of the conveyor entering the filler never falls below 5,000 cans. This section of conveyor forms a 'permanent' storage area for cans. If the size of this conveyor is reduced by $\leq$ 5,000 cans it is logical to expect no loss in efficiency from this machine. It was noted previously that the filler is the heart of the high speed beverage line. It is of paramount importance to keep this machine at optimum efficiency.

The conveyor entering the seamer can handle 15,000 units per minute. The seamer itself produces 1200 cpm. The only time its conveyor runs below this 1200 can machine capacity is the 77.0 to 83.0 minute range. This is due to a six minute downtime in the filler. The conveyor never accumulates more than 11,000 cans at any time in the run, therefore a decrease in capacity to $\leq$ 11,000 cans is warranted.

The packer can handle 1400 cpm. Its conveyor in this particular model can accommodate 15,000. Only in the 83.0 to 86.0 minute time frame does it fill up. This is due to a six minute jam in the packer. In the 123.0 to 130.0 minute range the machine shows idle capacity due to lack of cans. A larger conveyor seems warranted in this case.

The traymaker is the fastest machine on the line, handling 1600 cpm. Its feeding conveyor was set at a 30,000 unit capacity. The most cans it accumulates (except at the startup) is 9,220 in the 141.0 minute of operation. Although it has idle capacity for a total of 43 minutes because of no cans, little can be done other than to increase the size of conveyor C4 entering the packer.

4. Conveyor Cost and production figures:

Total Conveyor Capacity:	90,000 cans
Each Unit:	2.5 inches
Cost of Conveyor:	$100.00 per running foot

Capital Cost:

$$90{,}000 \text{ cans} \times \frac{2.5 \text{ in}}{\text{can}} \times \frac{1 \text{ ft}}{12 \text{ in}} \times \frac{\$100.00}{\text{ft}} = \$1{,}875{,}000$$

Total Output:	160,200 cans
Incremental Revenue per Unit of Output:	$0.03
Length of Run:	150 minutes

Incremental Revenue:

$$160{,}200 \text{ cans} \times \frac{480 \text{ min}}{150 \text{ min}} \times \frac{\$0.03}{\text{can}} = \$15{,}379.20/\text{eight hour shift}$$

Necessary time to return investment working 3, eight hour shifts per day, 5 days a week:

$$\frac{\$1{,}875{,}000}{\$15{,}379.20} \times \frac{1 \text{ shift}}{3 \text{ shifts/day}} = 40.7 \sim 41 \text{ days}$$

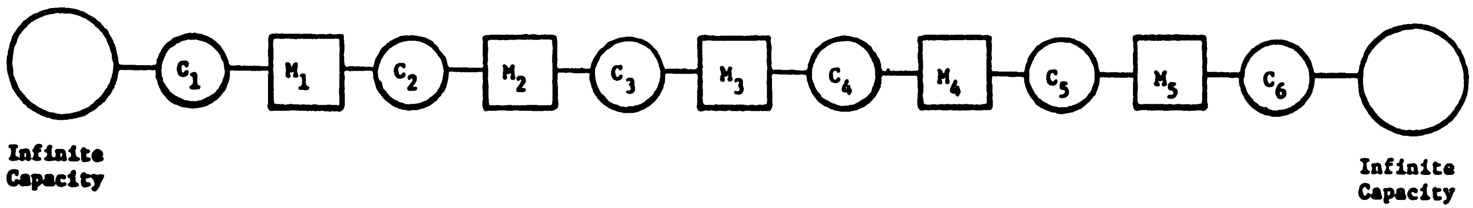
6.4 Proof Model 4

Proof Model 4 utilizes conveyor lengths of 10,000, 17,000, 11,000, 17,000 and 15,000 units (Figure 6.4).

An analysis of Table 6.4 follows:

1. The efficiency of each machine according to accumulated downtime over an eight hour simulation run is again the same as comment (2) of Proof Model 1. The line efficiency based on the filler is:

Total Production:	152,700 cans
Length of Run:	150 minutes
Slowest Machine:	1200 cpm



M : Machine

C : Conveyor

C_1	10,000 Unit Capacity
C_2	17,000 Unit Capacity
C_3	11,000 Unit Capacity
C_4	17,000 Unit Capacity
C_5	15,000 Unit Capacity

Figure 7.4.--Proof Model 4.

TIME MIN	DEPALLETIZER C1	M1	D1	P1	FILLER C2	M2	D2	P2
1.0	10000	0	DN 1	0	8500	0	DN 1	0
2.0	9860	140	UP 0	1260	8560	120	UP 0	1090
3.0	10000	0	DN 1	140	7500	120	UP 0	1200
4.0	9860	140	UP 0	1260	7500	120	UP 0	1200
5.0	10000	0	DN 1	140	6500	120	UP 0	1200
6.0	10000	0	DN 2	0	5300	120	UP 0	1200
7.0	10000	0	DN 3	0	4100	120	UP 0	1200
8.0	9960	140	UP 0	1260	4100	120	UP 0	1200
9.0	9860	140	UP 0	1400	4100	120	UP 0	1200
10.0	9960	140	UP 0	1400	4500	120	UP 0	1200
11.0	9860	140	UP 0	1400	4700	120	UP 0	1200
12.0	9960	140	UP 0	1400	4900	120	UP 0	1200
13.0	9860	140	UP 0	1400	6100	0	DN 1	120
14.0	9860	140	UP 0	1400	6500	120	UP 0	1090
15.0	9960	140	UP 0	1400	6700	120	UP 0	1200
16.0	9860	140	UP 0	1400	6500	120	UP 0	1200
17.0	10000	0	DN 1	140	5900	120	UP 0	1200
18.0	10000	0	DN 2	0	4700	120	UP 0	1200
19.0	10000	0	DN 3	0	3500	120	UP 0	1200
20.0	9960	140	UP 0	1260	4700	0	DN 1	120
21.0	9860	140	UP 0	1400	4460	120	UP 0	1090
22.0	9960	140	UP 0	1400	5100	120	UP 0	1200
23.0	10000	0	DN 1	140	4100	120	UP 0	1200
24.0	9860	140	UP 0	1260	5300	0	DN 1	120
25.0	9460	140	UP 0	1400	5500	120	UP 0	1090
26.0	9860	140	UP 0	1400	5700	120	UP 0	1200
27.0	9860	140	UP 0	1400	5900	120	UP 0	1200
28.0	9960	140	UP 0	1400	6100	120	UP 0	1200
29.0	9960	140	UP 0	1400	6300	120	UP 0	1200
30.0	9960	140	UP 0	1400	6500	120	UP 0	1200
31.0	9960	140	UP 0	1400	5700	120	UP 0	1200
32.0	10000	0	DN 1	140	5700	120	UP 0	1200
33.0	9860	140	UP 0	1260	5740	120	UP 0	1200
34.0	9960	140	UP 0	1400	5400	120	UP 0	1200
35.0	9860	140	UP 0	1400	6100	120	UP 0	1200
36.0	9860	140	UP 0	1400	6300	120	UP 0	1200
37.0	10000	0	DN 1	140	5300	120	UP 0	1200
38.0	9860	140	UP 0	1260	5300	120	UP 0	1200
39.0	9960	140	UP 0	1400	5500	120	UP 0	1200
40.0	9960	140	UP 0	1400	5700	120	UP 0	1200
41.0	9960	140	UP 0	1400	5900	120	UP 0	1200
42.0	9860	140	UP 0	1400	6100	120	UP 0	1200
43.0	9960	140	UP 0	1400	6300	120	UP 0	1200
44.0	9860	140	UP 0	1400	6500	120	UP 0	1200
45.0	9960	140	UP 0	1400	7400	0	DN 1	120
46.0	9960	140	UP 0	1400	8100	120	UP 0	1090
47.0	9960	140	UP 0	1400	9300	120	UP 0	1200
48.0	9960	140	UP 0	1400	9700	0	DN 1	120
49.0	9960	140	UP 0	1400	11100	0	DN 2	0
50.0	9860	140	UP 0	1400	12500	0	DN 3	0
51.0	9860	140	UP 0	1400	12700	120	UP 0	1090
52.0	9860	140	UP 0	1400	12900	120	UP 0	1200
53.0	9860	140	UP 0	1400	13100	120	UP 0	1200
54.0	9860	140	UP 0	1400	13300	120	UP 0	1200
55.0	9860	140	UP 0	1400	14700	0	DN 1	120
56.0	10000	0	DN 1	140	13700	120	UP 0	1090
57.0	9860	140	UP 0	1260	13700	120	UP 0	1200
58.0	9860	140	UP 0	1400	13900	120	UP 0	1200
59.0	9860	140	UP 0	1400	14100	120	UP 0	1200
60.0	9960	140	UP 0	1400	14300	120	UP 0	1200
61.0	9960	140	UP 0	1400	14500	120	UP 0	1200
62.0	9860	140	UP 0	1400	14700	120	UP 0	1200
63.0	9860	140	UP 0	1400	14900	120	UP 0	1200
64.0	9960	140	UP 0	1400	15100	120	UP 0	1200
65.0	9860	140	UP 0	1400	15300	120	UP 0	1200
66.0	9860	140	UP 0	1400	15500	120	UP 0	1200
67.0	10000	0	DN 1	140	14500	120	UP 0	1200
68.0	9860	140	UP 0	1260	14560	120	UP 0	1200
69.0	9860	140	UP 0	1400	14760	120	UP 0	1200
70.0	9860	140	UP 0	1400	14900	120	UP 0	1200
71.0	10000	0	DN 1	140	15100	0	DN 1	120
72.0	9860	140	UP 0	1260	15160	120	UP 0	1090
73.0	10000	0	DN 1	140	15300	0	DN 1	120
74.0	9860	140	UP 0	1260	16500	0	DN 2	0
75.0	10000	0	DN 1	140	16700	0	DN 3	0

TIME MIN	SEAMER C3	M3	D3	P3	PACKER C4	M4	D4	P4	TRAYMAKER C5	M5	D5	P5	TOTAL
1.0	6300	120	UP 0	1090	9590	0	DN 1	0	5900	160	UP 0	1440	1280
2.0	6190	120	UP 0	1200	10790	0	DN 2	0	4300	160	UP 0	1600	2880
3.0	6190	120	UP 0	1200	11990	0	DN 3	0	2700	160	UP 0	1600	4480
4.0	6190	120	UP 0	1200	13190	0	DN 4	0	1100	160	UP 0	1600	6080
5.0	5190	0	DN 1	120	13190	0	DN 5	0	0	0	UP 0	1260	7500
6.0	5190	120	UP 0	1090	14390	0	DN 6	0	0	0	UP 0	0	7500
7.0	5190	120	UP 0	1200	14190	140	UP 0	1260	140	140	UP 0	980	9340
8.0	6590	0	DN 1	120	12700	140	UP 0	1400	140	140	UP 0	1400	9740
9.0	6590	120	UP 0	1090	12590	140	UP 0	1400	140	140	UP 0	1400	11140
10.0	6590	120	UP 0	1200	12190	140	UP 0	1400	140	140	UP 0	1400	12540
11.0	6590	120	UP 0	1200	12190	140	UP 0	1400	140	140	UP 0	1400	13940
12.0	6590	120	UP 0	1200	11190	140	UP 0	1400	140	140	UP 0	1400	15340
13.0	5590	120	UP 0	1200	12140	0	DN 1	140	0	0	UP 0	420	15100
14.0	6590	0	DN 1	120	13300	0	DN 2	0	0	0	UP 0	0	15300
15.0	6590	120	UP 0	1090	12730	140	UP 0	1260	140	140	UP 0	980	16740
16.0	6590	120	UP 0	1200	12790	140	UP 0	1400	140	140	UP 0	1400	19140
17.0	7790	0	DN 1	120	11500	140	UP 0	1400	140	140	UP 0	1400	19540
18.0	7790	120	UP 0	1080	11190	140	UP 0	1400	140	140	UP 0	1400	20140
19.0	7790	120	UP 0	1200	10990	140	UP 0	1400	140	140	UP 0	1400	22340
20.0	6700	120	UP 0	1200	10790	140	UP 0	1400	1540	0	DN 1	140	22620
21.0	6590	120	UP 0	1200	10590	140	UP 0	1400	2940	0	DN 2	0	22520
22.0	6590	120	UP 0	1200	10390	140	UP 0	1400	4340	0	DN 3	0	22520
23.0	6590	120	UP 0	1200	10190	140	UP 0	1400	5740	0	DN 4	0	22520
24.0	6700	0	DN 1	120	9900	140	UP 0	1400	5540	160	UP 0	1440	23300
25.0	6590	120	UP 0	1090	9590	140	UP 0	1400	5340	160	UP 0	1500	25500
26.0	6590	120	UP 0	1200	9190	140	UP 0	1400	5140	160	UP 0	1500	27100
27.0	6590	120	UP 0	1200	8190	140	UP 0	1400	4940	160	UP 0	1600	28700
28.0	6590	120	UP 0	1200	7190	140	UP 0	1400	4740	160	UP 0	1500	30300
29.0	6590	120	UP 0	1200	7790	140	UP 0	1400	4540	160	UP 0	1500	31900
30.0	6590	120	UP 0	1200	9390	0	DN 1	140	3380	160	UP 0	1600	33500
31.0	6590	120	UP 0	1200	9780	140	UP 0	1260	2740	160	UP 0	1500	35100
32.0	6590	120	UP 0	1200	8590	140	UP 0	1400	2540	160	UP 0	1600	36700
33.0	6590	120	UP 0	1200	9390	140	UP 0	1400	3940	0	DN 1	150	37020
34.0	6590	120	UP 0	1200	8190	140	UP 0	1400	3740	160	UP 0	1440	39300
35.0	6590	120	UP 0	1200	7390	140	UP 0	1400	3540	160	UP 0	1600	39300
36.0	6590	120	UP 0	1200	9190	0	DN 1	140	2040	160	UP 0	1600	41500
37.0	7790	0	DN 1	120	7300	140	UP 0	1260	1740	160	UP 0	1600	43100
38.0	7790	120	UP 0	1090	7590	140	UP 0	1400	1540	160	UP 0	1500	44700
39.0	7790	120	UP 0	1200	7390	140	UP 0	1400	2940	0	DN 1	160	45020
40.0	7790	120	UP 0	1200	7190	140	UP 0	1400	4340	0	DN 2	0	45020
41.0	9190	0	DN 1	120	5190	140	UP 0	1400	5740	0	DN 3	0	45020
42.0	9190	120	UP 0	1090	6990	0	DN 1	140	4290	160	UP 0	1440	46300
43.0	9190	120	UP 0	1200	6790	140	UP 0	1260	3340	160	UP 0	1600	47900
44.0	9190	120	UP 0	1200	6590	140	UP 0	1400	3740	160	UP 0	1600	49500
45.0	7190	120	UP 0	1200	6380	140	UP 0	1400	3540	160	UP 0	1500	51100
46.0	7790	120	UP 0	1200	5190	140	UP 0	1400	3340	160	UP 0	1500	52700
47.0	9190	0	DN 1	120	4990	140	UP 0	1400	4740	0	DN 1	160	53020
48.0	7190	120	UP 0	1090	4590	140	UP 0	1400	6140	0	DN 2	0	53020
49.0	6790	120	UP 0	1200	4190	140	UP 0	1400	5940	160	UP 0	1440	54300
50.0	5590	120	UP 0	1200	5590	0	DN 1	140	6340	0	DN 1	160	54520
51.0	5190	120	UP 0	1200	6790	0	DN 2	0	6090	0	DN 2	0	54520
52.0	5190	120	UP 0	1200	6590	140	UP 0	1260	7340	0	DN 3	0	54620
53.0	5190	120	UP 0	1200	6390	140	UP 0	1400	7140	160	UP 0	1440	55100
54.0	5190	120	UP 0	1200	7590	0	DN 1	140	5690	160	UP 0	1600	57500
55.0	4190	120	UP 0	1200	8780	0	DN 2	0	4080	160	UP 0	1600	59100
56.0	4190	120	UP 0	1200	9990	0	DN 3	0	4080	0	DN 1	160	59420
57.0	4190	120	UP 0	1200	11190	0	DN 4	0	2440	160	UP 0	1440	60700
58.0	4190	120	UP 0	1200	12390	0	DN 5	0	840	160	UP 0	1500	62300
59.0	4190	120	UP 0	1200	12190	140	UP 0	1260	540	160	UP 0	1500	63300
60.0	4190	120	UP 0	1200	11990	140	UP 0	1400	340	160	UP 0	1600	65500
61.0	4190	120	UP 0	1200	11790	140	UP 0	1400	140	160	UP 0	1600	67100
62.0	4190	120	UP 0	1200	11590	140	UP 0	1400	140	140	UP 0	1420	69540
63.0	4190	120	UP 0	1200	11390	140	UP 0	1400	140	140	UP 0	1400	69940
64.0	4190	120	UP 0	1200	11190	140	UP 0	1400	140	140	UP 0	1400	71340
65.0	4190	120	UP 0	1200	10990	140	UP 0	1400	140	140	UP 0	1400	72740
66.0	4190	120	UP 0	1200	10790	140	UP 0	1400	140	140	UP 0	1400	74140
67.0	4190	120	UP 0	1200	10590	140	UP 0	1400	140	140	UP 0	1400	75540
68.0	4190	120	UP 0	1200	10390	140	UP 0	1400	1540	0	DN 1	140	75920
69.0	4190	120	UP 0	1200	11590	0	DN 1	140	80	160	UP 0	1440	77100
70.0	4190	120	UP 0	1200	12790	0	DN 2	0	0	0	UP 0	240	77500
71.0	4300	0	DN 1	120	11500	140	UP 0	1260	140	140	UP 0	980	79340
72.0	4190	120	UP 0	1090	11190	140	UP 0	1400	140	140	UP 0	1400	79740
73.0	3190	120	UP 0	1200	12390	0	DN 1	140	0	0	UP 0	420	80300
74.0	1990	120	UP 0	1200	11590	0	DN 2	0	0	0	UP 0	0	80300
75.0	760	120	UP 0	1200	13350	140	UP 0	1260	140	140	UP 0	980	81140

TABLE 7.4.--Proof Model 4, Part I

TIME	DEPALLETIZER					FILLER					SEAMER					PACKER					TRAYMAKER					
MIN	C1	M1	D1		P1	C2	M2	D2		P2	C3	M3	D3		P3	C4	M4	D4		P4	C5	M5	D5		P5	TOTAL
76.0	10000	140	UP	0	300	17000	0	DN	4	0	0	0	UP	0	820	12900	140	UP	0	1400	140	140	UP	0	1600	82540
77.0	10000	140	UP	0	0	17000	0	DN	5	0	0	0	UP	0	0	12900	0	DN	1	140	0	0	UP	0	620	83100
78.0	10000	140	UP	0	0	17000	0	DN	6	0	0	0	UP	0	0	11400	140	UP	0	1260	140	140	UP	0	980	83140
79.0	9880	140	UP	0	1200	17000	120	UP	0	1080	120	120	UP	0	840	10940	140	UP	0	1400	140	140	UP	0	1400	85140
80.0	9880	140	UP	0	1200	17000	120	UP	0	1200	120	120	UP	0	1200	10940	140	UP	0	1400	140	140	UP	0	1400	86740
81.0	9980	140	UP	0	1200	17000	120	UP	0	1200	120	120	UP	0	1200	11940	0	DN	1	140	0	0	UP	0	620	87100
82.0	9880	140	UP	0	1200	17000	120	UP	0	1200	120	120	UP	0	1200	13040	0	DN	2	0	0	0	UP	0	0	87300
83.0	9980	140	UP	0	1200	17000	120	UP	0	1200	120	120	UP	0	1200	14240	0	DN	3	0	0	0	UP	0	0	87300
84.0	9880	140	UP	0	1200	17000	120	UP	0	1200	120	120	UP	0	1200	15440	0	DN	4	0	0	0	UP	0	0	87300
85.0	9880	140	UP	0	1200	17000	120	UP	0	1200	120	120	UP	0	1200	16440	0	DN	5	0	0	0	UP	0	0	87300
86.0	9980	140	UP	0	1200	17000	120	UP	0	1200	960	120	UP	0	360	17000	0	DN	6	0	0	0	UP	0	0	87300
87.0	10000	140	UP	0	0	17000	0	DN	1	120	1080	0	DN	1	120	15720	140	UP	0	1260	140	140	UP	0	980	88140
88.0	9880	140	UP	0	1200	17000	120	UP	0	1080	360	120	UP	0	1080	15530	140	UP	0	1400	140	140	UP	0	1400	89540
89.0	10000	0	DN	1	140	16960	120	UP	0	1200	480	120	UP	0	1200	15630	0	DN	1	140	0	0	UP	0	620	90100
90.0	9880	140	UP	0	1200	16800	120	UP	0	1200	2160	0	DN	1	120	15720	0	DN	2	0	0	0	UP	0	0	90100
91.0	10000	140	UP	0	1200	17000	0	DN	1	120	2280	0	DN	2	0	15720	0	DN	3	0	0	0	UP	0	0	90130
92.0	9980	140	UP	0	1200	17000	120	UP	0	1080	3160	0	DN	3	0	15920	140	UP	0	1260	140	140	UP	0	980	91140
93.0	9880	140	UP	0	1200	17000	120	UP	0	1200	3160	120	UP	0	1080	15030	140	UP	0	1400	140	140	UP	0	1400	92140
94.0	9880	140	UP	0	1200	17000	120	UP	0	1200	3160	120	UP	0	1200	14930	140	UP	0	1400	140	140	UP	0	1400	93740
95.0	10000	140	UP	0	0	17000	0	DN	1	120	2290	120	UP	0	1200	14500	140	UP	0	1400	140	140	UP	0	1400	95140
96.0	10000	140	UP	0	0	17000	0	DN	2	0	2290	0	DN	1	120	13320	140	UP	0	1400	1540	0	DN	1	140	95420
97.0	9980	140	UP	0	1200	17000	120	UP	0	1080	1160	0	DN	2	0	11970	140	UP	0	1400	2940	0	DN	2	0	95420
98.0	9880	140	UP	0	1200	17000	120	UP	0	1200	3160	120	UP	0	1040	11500	140	UP	0	1400	4340	0	DN	3	0	95420
99.0	9880	140	UP	0	1200	17000	120	UP	0	1200	3160	120	UP	0	1200	11400	140	UP	0	1400	5740	0	DN	4	0	95420
100.0	9880	140	UP	0	1200	17000	120	UP	0	1200	3160	120	UP	0	1200	11230	140	UP	0	1400	5540	160	UP	0	1440	96700
101.0	9880	140	UP	0	1200	17000	120	UP	0	1200	3300	120	UP	0	1200	11030	140	UP	0	1400	5340	160	UP	0	1600	98300
102.0	9980	140	UP	0	1200	17000	120	UP	0	1200	3160	120	UP	0	1200	12700	0	DN	1	140	3880	160	UP	0	1600	99700
103.0	9880	140	UP	0	1200	17000	120	UP	0	1200	4460	0	DN	1	120	10170	140	UP	0	1260	3540	160	UP	0	1600	101530
104.0	10000	0	DN	1	140	16940	120	UP	0	1200	4390	120	UP	0	1080	10500	140	UP	0	1400	3340	160	UP	0	1600	103100
105.0	10000	140	UP	0	1160	17000	0	DN	1	120	3440	120	UP	0	1200	10430	140	UP	0	1400	3140	160	UP	0	1600	104700
106.0	9980	140	UP	0	1200	17000	120	UP	0	1080	3160	120	UP	0	1200	10730	140	UP	0	1400	2940	160	UP	0	1600	106300
107.0	9880	140	UP	0	1200	17000	120	UP	0	1200	3160	120	UP	0	1200	10000	140	UP	0	1400	6340	0	DN	1	160	106520
108.0	10000	0	DN	1	140	16940	120	UP	0	1200	3160	120	UP	0	1200	11200	0	DN	1	140	6490	0	DN	2	0	106520
109.0	10000	140	UP	0	1260	17000	0	DN	1	120	1490	0	DN	1	120	9720	140	UP	0	1260	5740	0	DN	3	0	106520
110.0	9890	140	UP	0	1200	17000	120	UP	0	1080	3160	120	UP	0	1080	9530	140	UP	0	1400	5540	160	UP	0	1440	107900
111.0	9880	140	UP	0	1200	17000	120	UP	0	1200	3160	120	UP	0	1200	9530	140	UP	0	1400	5340	160	UP	0	1600	109500
112.0	10000	0	DN	1	140	16960	120	UP	0	1200	3160	120	UP	0	1200	9200	140	UP	0	1400	5140	160	UP	0	1500	111100
113.0	10000	0	DN	2	0	14740	120	UP	0	1200	3160	120	UP	0	1200	9600	140	UP	0	1400	4940	160	UP	0	1500	112700
114.0	10000	0	DN	3	0	13540	120	UP	0	1200	3160	120	UP	0	1200	8930	140	UP	0	1400	4740	160	UP	0	1600	114300
115.0	9880	140	UP	0	1260	14800	0	DN	1	120	2240	120	UP	0	1200	8500	140	UP	0	1400	6140	0	DN	1	160	114520
116.0	10000	0	DN	1	140	16440	0	DN	2	0	1190	120	UP	0	1220	9630	140	UP	0	1400	5940	160	UP	0	1440	115100
117.0	9880	140	UP	0	1260	16200	0	DN	3	0	0	0	UP	0	1230	9230	140	UP	0	1400	5740	160	UP	0	1600	117500
118.0	10000	140	UP	0	930	17000	0	DN	4	0	0	0	UP	0	0	8230	0	DN	1	140	6290	160	UP	0	1500	119100
119.0	10000	140	UP	0	0	17000	0	DN	5	0	0	0	DN	1	0	6930	140	UP	0	1260	3940	160	UP	0	1600	120700
120.0	10000	140	UP	0	0	17000	0	DN	6	0	0	0	DN	2	0	5630	140	UP	0	1400	3740	160	UP	0	1600	122300
121.0	10000	140	UP	0	0	17000	0	DN	7	0	0	0	DN	3	0	4030	140	UP	0	1400	3540	160	UP	0	1500	123300
122.0	9880	140	UP	0	1200	17000	120	UP	0	1080	1640	0	DN	4	0	2530	140	UP	0	1400	3340	160	UP	0	1500	125500
123.0	10000	0	DN	1	140	16960	120	UP	0	1200	2290	0	DN	5	0	1200	140	UP	0	1400	3140	160	UP	0	1500	127100
124.0	9880	140	UP	0	1260	16900	120	UP	0	1200	2290	120	UP	0	1090	880	140	UP	0	1400	2940	160	UP	0	1500	128700
125.0	9860	140	UP	0	1400	16900	120	UP	0	1200	3490	0	DN	1	120	0	0	UP	0	1140	2490	160	UP	0	1600	130300
126.0	10000	0	DN	1	140	17140	120	UP	0	1200	3490	120	UP	0	1090	120	120	UP	0	840	3320	0	DN	1	160	130520
127.0	9860	140	UP	0	1200	17240	120	UP	0	1200	3490	120	UP	0	1200	120	120	UP	0	1200	4520	0	DN	2	0	130520
128.0	10000	0	DN	1	140	17140	120	UP	0	1200	3490	120	UP	0	1200	120	120	UP	0	1200	5720	0	DN	3	0	130620
129.0	10000	0	DN	2	0	17440	120	UP	0	1200	3490	120	UP	0	1200	120	120	UP	0	1200	6920	0	DN	4	0	130520
130.0	10000	0	DN	3	0	12740	0	DN	1	120	2640	120	UP	0	1200	120	120	UP	0	1200	8120	0	DN	5	0	130520
131.0	10000	0	DN	4	0	11740	120	UP	0	1040	2240	120	UP	0	1200	1320	0	DN	1	120	8240	0	DN	6	0	130520
132.0	10000	0	DN	5	0	11740	0	DN	1	120	2400	0	DN	1	120	1540	0	DN	2	0	9240	0	DN	7	0	130620
133.0	9880	140	UP	0	1260	11960	120	UP	0	1040	2290	120	UP	0	1040	2520	0	DN	3	0	6640	160	UP	0	1440	131100
134.0	9880	140	UP	0	1400	12000	120	UP	0	1200	2240	120	UP	0	1200	3720	0	DN	4	0	5640	160	UP	0	1600	133500
135.0	9880	140	UP	0	1400	12200	120	UP	0	1200	2290	120	UP	0	1250	3520	140	UP	0	1260	4730	160	UP	0	1600	135100
136.0	9880	140	UP	0	1400	12400	120	UP	0	1200	2290	120	UP	0	1220	3320	140	UP	0	1400	4530	160	UP	0	1600	136700
137.0	9880	140	UP	0	1400	11990	0	DN	1	120	1660	120	UP	0	1200	3120	140	UP	0	1400	4330	160	UP	0	1600	138300
138.0	9960	140	UP	0	1430	14000	120	UP	0	1090	1640	120	UP	0	1220	2920	140	UP	0	1400	5730	0	DN	1	160	138520
139.0	9560	140	UP	0	1400	14200	120	UP	0	1200	1640	120	UP	0	1210	2720	140	UP	0	1400	7100	0	DN	2	0	139620
140.0	9860	140	UP	0	1400	14400	120	UP	0	1200	1690	120	UP	0	1200	2520	140	UP	0	1400	8500	0	DN	3	0	139620
141.0	9980	140	UP	0	1400	14600	120	UP	0	1200	1690	120	UP	0	1200	2320	140	UP	0	1400	9900	0	DN	4	0	139520
142.0	9860	140	UP	0	1400	14800	120	UP	0	1200	1690	120	UP	0	1200	2120	140	UP	0	1400	9700	160	UP	0	1440	139300
143.0	9860	140	UP	0	1400	15000	120	UP	0	1200	1690	120	UP	0	1220	1920	140	UP	0	1400	9560	160	UP	0	1600	141500
144.0	9860	140	UP	0	1400	16400	0	DN	1	120	[illegible]	120	UP	0	1230	1720	140	UP	0	1400	9330	160	UP	0	1500	143100
145.0	9980	140	UP	0	1400	16600	120	UP	0	1040	120	120	UP	0	960	1240	140	UP	0	1400	9110	160	UP	0	1600	144700
146.0	9960	140	UP	0	1400	16960	120	UP	0	1200	120	120	UP	0	1230	1390	140	UP	0	1400	8900	160	UP	0	1600	146300
147.0	9860	140	UP	0	1400	17000	120	UP	0	1200	120	120	UP	0	1220	890	140	UP	0	1400	8700	160	UP	0	1600	147900
148.0	9880	140	UP	0	1400	17000	120	UP	0	1200	120	120	UP	0	1200	690	140	UP	0	1400	8500	160	UP	0	1600	149500
149.0	9880	140	UP	0	1200	17000	120	UP	0	1200	120	120	UP	0	1230	640	140	UP	0	1400	8300	160	UP	0	1500	151100
150.0	10000	140	UP	0	0	17000	0	DN	1	120	240	0	DN	1	120	0	0	UP	0	740	7440	160	UP	0	1600	152700

TABLE 7.4.--Proof Model 4, Part II

$$\frac{152,700 \text{ cans}}{150 \text{ min} \times 1200 \text{ cpm}} \times 100\% = 84.8 \sim 85\%$$

2. Filler idling time is the same as in Proof Model 3.

3. The conveyor C_2, entering the filler has been reduced to a 17,000 can capacity. The filler still produces at its peak output but the cost of its conveyor has been reduced by $62,500.

Conveyor C_3, entering the seamer has been lowered to 11,000 cans as recommended in Model 3. The six minute idletime in Model 3 has increased to 20 minutes because the simulation run started with only 4500 cans versus 7500 in Model 3. However, the most units C_3 ever accumulates is 8,980. A judgment is needed by management at this point concerning conveyor investment as opposed to machine idle time.

The packer has an entering conveyor capacity of 17,000 as compared to 15,000 in the last model. Only in the 86.0 minute does it completely fill up. It shows idle capacity in the 123.0 to 131.0 and 145.0 to 150.0 time frames. A small increase in this conveyor based on changes in conveyor C_3 should be experimented with.

Conveyor C_5 accumulates 53 minutes of idle time as opposed to 43 in the previous model but its length has been cut by one half.

4. Conveyor cost and production figures:

Total Conveyor Capacity:	70,000 cans
Each Unit:	2.5 inches
Cost of Conveyor:	\$100.00 per running foot

Capital Cost:

$$70{,}000 \text{ cans} \times \frac{2.5 \text{ in}}{\text{can}} \times \frac{1 \text{ ft}}{12 \text{ in}} \times \frac{\$100.00}{\text{ft}} = \$1{,}458{,}333$$

This is a savings of \$416,667 over Model 3.

Total Output:	152,700 cans
Incremental Revenue per Unit of Output:	\$0.03
Length of Run:	150 minutes

Incremental Revenue:

$$152{,}700 \text{ cans} \times \frac{480 \text{ min}}{150 \text{ min}} \times \frac{\$0.03}{\text{can}} = \$14{,}659.20\text{/eight hour shift}$$

Necessary time to return investment working 3, eight hour shifts per day, 5 days a week:

$$\frac{\$1{,}458{,}333.00}{\$14{,}659.20} \times \frac{1 \text{ shift}}{3 \text{ shifts/day}} = 33.2 \sim 33 \text{ days}$$

5. Table 6.5 shows the simulation program with the addition of the subroutine PLINE. The regular program calculates the position of the assembly line each six seconds or ten times each minute and prints a numeric summary of the status of the line at the end of each minute of operation. With the addition of the subroutine PLINE the line status is not only calculated each six seconds but is also printed out in a unique visual 'picture', one line for each six seconds. Due to the space needed by this printout only six minutes can be shown per page. Two

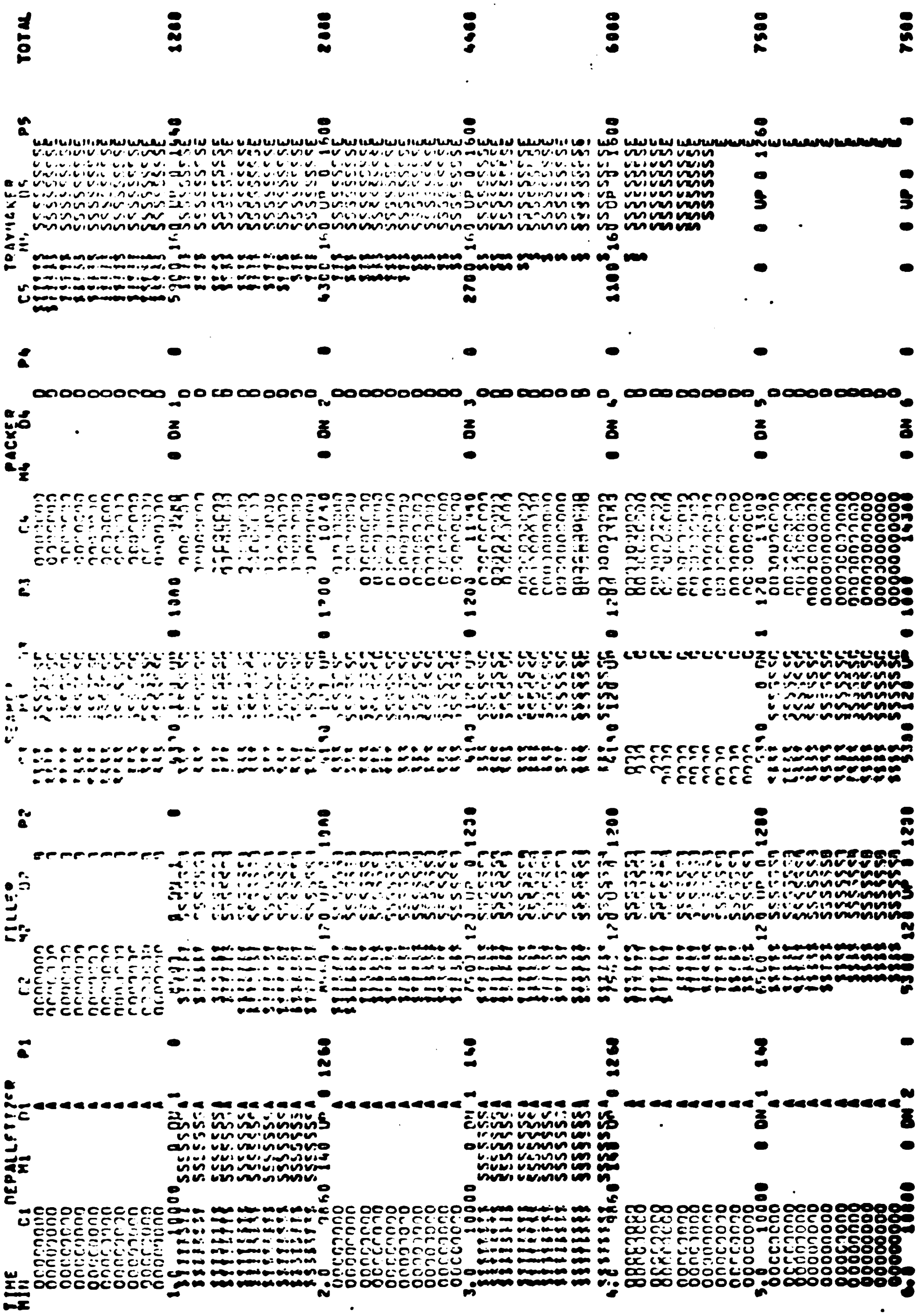


TABLE 7.5.--Visual to Proof Model 4, Part I

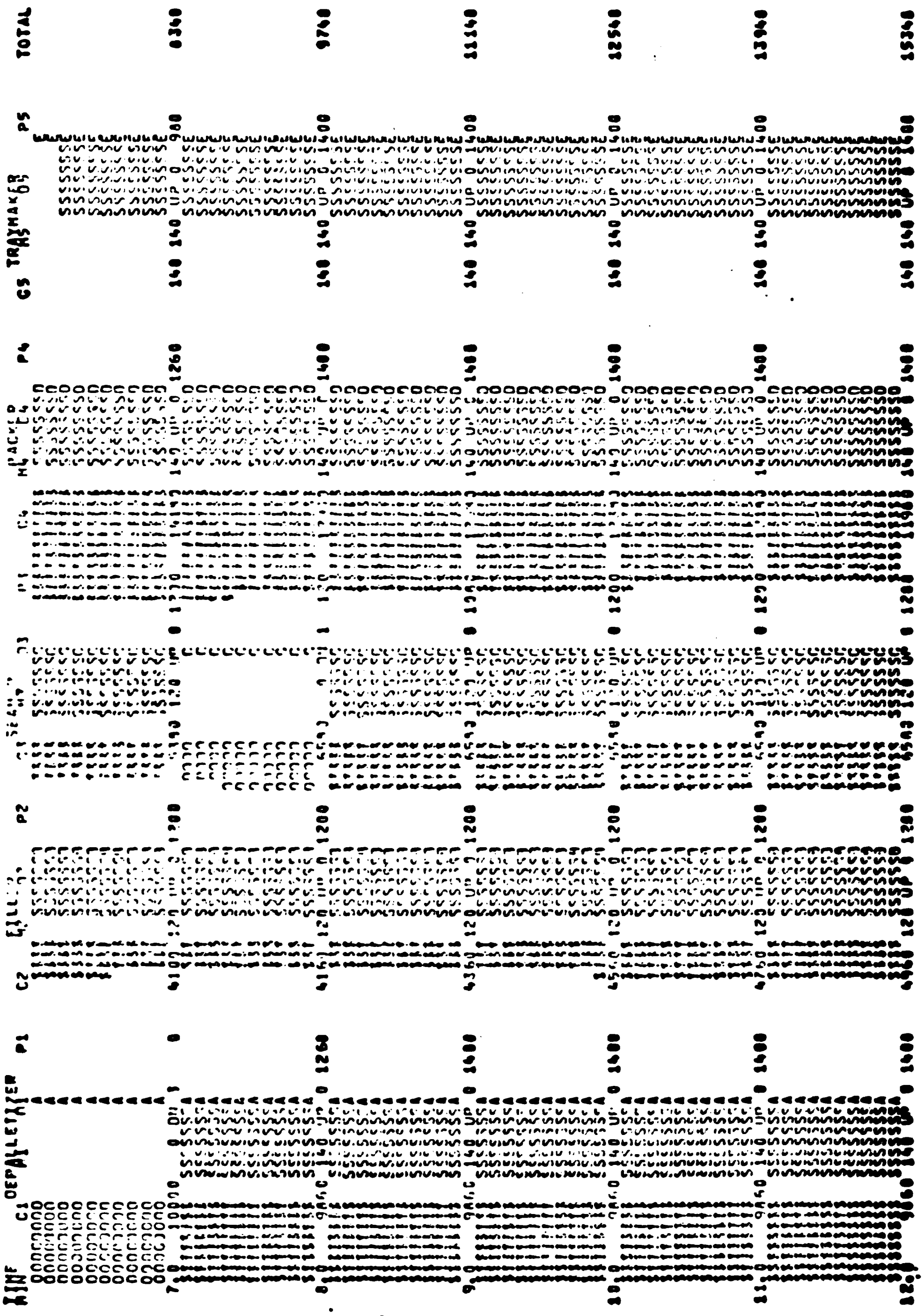


TABLE 7.5.--Visual to Proof Model 4, Part II

pages are included for a total of 12 minutes. The print-out for an eight hour shift would be lengthy but trends in the line can be spotted very easily by virtually anyone.

Four symbols are used in this picture:

1. $
2. O (alphabetic symbol)
3. S
4. 0 (numeric symbol)

1. Each $ represents 1300 units moving on a conveyor to a station.

2. Each O (alphabetic symbol) represents 1300 units on a conveyor that are stationary. This is due to a breakdown in one or more of the succeeding machines.

3. Each S represents 20 units (cans) that are moving through the machine.

4. Each 0 (numeric symbol) represents 20 units that are stationary in the machine. This machine is running but its exiting conveyor is full. The packages are not moving due to a breakdown in one or more of the succeeding machines. When a machine goes down all the units it contains are emptied into the exit conveyor if this conveyor has the space available to accept them.

In this model 1300 and 20 units are represented. It is very easy to change the amounts to suit the user.

Each machine is distinguishable because of the letter that follows its symbols:

A - depalletizer

B - filler

C - seamer

D - packer

E - traymaker

In analyzing the line during the first minute of operation machines M_1, M_2, and M_4 have gone down. Machine M_3 is producing cans that move to conveyor C_4 and machine M_5 produces units that are counted in the total line production. Looking over the entire 12 minutes conveyor C_2 entering the filler tends to decrease its can supply. Conveyor C_4 has become well stocked with cans due to the six minutes of downtime in the packer and the traymaker (M_5) soon exhausts its supply which never rises above 140 cans in the 12 minutes.

CHAPTER VII

SUMMARY

A high speed beverage line is a complex system with many interacting components. It involves a variety of expensive line machines and transfer equipment. Because of this complexity and the variable nature of the machines in terms of breakdowns and idle activity, analytic techniques are inadequate in selecting or designing the optimum assembly line. Simulation models then, are necessary in trying to predict the consequences of changes in conditions, or methods without having to spend the money or take the risk of actually making the change in real life. Models are not perfect, they cannot replace the real world, but they can reduce a complex system, in this case a high speed beverage line, to manageable proportions.

It can be seen from the Proof Models that there is a trade off between conveyor equipment investment and efficient line production. A larger capital investment, however, does not necessarily mean a more efficient line and vice versa. This balance is different for each company depending on the objectives and attitudes of its higher management.

It was found, while talking to managers of two different high speed brewing lines, that there is a ready market for as much product as can be produced. In this case then, the manufacturer would want to make as efficient use of his packaging line as possible, meaning increased conveyor investment. Without the use of a simulation program, such as this, a company could easily invest more money than is necessary for efficient production, thus tying up capital needlessly which could be used to purchase other assets that would better serve its goals in the competitive business arena. Working closely with higher management and running several test models similar to those shown in Proof Models 3 and 4, it is relatively easy to narrow down the ranges of optimum conveyor length to get the most for the capital invested.

A computer program for the simulation model has been developed and, given the assumptions in section six, has been proven to work successfully. If a high speed packaging line can be described by Figure 3.1 or any combined form of it, this simulation program will be found useful in designing a more cost efficient line.

APPENDIX

APPENDIX

Figures A1, A2 and A3 show the actual computer program. The main program, PKGLINE is a general representation of a packaging line. As mentioned previously the substitution of different numbers, sppeds, and capacities of the machines as well as the conveyors is relatively simple. The subroutine DOWN is more specific and is accurate only for a high speed beverage packaging line. The subroutine PLINE is a visual aid to understanding the workings of PKGLINE and DOWN,

```
      PROGRAM PKGLINE(INPUT,OUTPUT)
C
C   ICP=ACTUAL NUMBER ON CONVEYOR FROM PREVIOUS CYCLE.
C   ICM=HOLDUP=MAXIMUM NUMBER ON CONVEYOR
C   NMP=HOLDUP=NUMBER IN MACHINE FROM PREVIOUS CYCLE (THESE WILL EXIT ON THIS
C   CYCLE IF THE EXIT CONVEYOR C(I+1) IS OPEN)
C   NMM=MAXIMUM HOLDUP=MAXIMUM NUMBER IN THE MACHINE THIS IS Q(I)*(CHANGE IN T)
C   MD=MACHINE DOWN IF =1, RUNNING IF =0
C   KLP=PRODUCTION FOR EACH MACHINE
C   KPT=1..2..3..4.. IT DISTINGUISHES THE INDIVIDUAL MACHINES
C   NC=THE NUMBER OF PKG TO LEAVE MACHINE I TO ENTER CONVEYOR I+1.  IT IS THE
C   SMALLER OF THE CONVEYOR CAPACITY AND THE MACHINE CONTENT.
C   NH=THE NUMBER OF PKG TO LEAVE CONVEYOR I TO ENTER MACHINE I
C   IT GOES TO ZERO IF MD(I) IS *ON*.  IT IS THE SMALLER OF THE MACHINE
C   CAPACITY AND THE CONVEYOR CONTENT.
C   DELT=1.0 MINUTE INCREMENTS     T=TIME IN MINUTES
C   N=NUMBER OF MACHINES=5
C   LP=TOTAL LINE PRODUCTION
C
      DIMENSION ICP(11), ICM(11), NMP(10), NMM(10), MD(10), KLP(10)
      DIMENSION KPT(20), UPD(10),NHX(10)
      DATA NMP,ICP/10*0,5*250000,5*0/
      DATA ICM/11*500000/
      DATA NMM/140,120,120,140,160,5*0/
      DATA MD/10*0/
      DATA KPT/4*1,4*2,4*3,4*4,4*5/
      DATA UP,DN/2HUP,2HDN/
      CALL RANSET(5)
      DELT=1.0
      N=5
      LP=0
      NPAGE=75
      KPRINT=0
      T=0
      CALL PLINE(ICM,NMM,MD,N)
      DO 150 JTIME=1,150
      KPRINT=KPRINT+1
      IF(KPRINT.EQ.NPAGE) KPRINT=0
      IF(KPRINT.EQ.1) GO TO 220
      GO TO 240
 220  PRINT 200
 200  FORMAT(*1*,* TIME*,6X,*DEPALLETIZER*,13X,*FILLER*,13X,*SEAMER*,
     120X,*PACKER*,13X,*TRAYMAKER*)
      PRINT 210, KPT
 210  FORMAT(* 4,* MIN*,1X,5(4X,*C*,I1,3X,*M*,I1,3X,*D*,I1,4X,*P*,I1),
     1 5X,*TOTAL*)
 240  CALL DOWN (MD,T,N)
C
```

TABLE A1.--Main Program PKGLINE, Part I

```
C       CHECK IF  ICM(I+1)-ICP(I+1).GE.NMP(I)
C       IF YES,   ICP(I+1).EQ.ICP(I+1)+NMP(I), EMPTY MACHINE NMP(I).EQ.0
C       IF NO     NC.EQ.ICM(I+1)-ICP(I+1)
C                 ICP(I+1).EQ.ICP(I+1)+NC
C                 NMP(I).EQ.NMP(I)-NC
C
C       CHECK IF  MD(I).EQ.1    (MACHINE IS DOWN)
C       IF YES    NMP(I).EQ.NMP(I)
C       IF NO     NH.EQ.NMM(I)-NMP(I)    (NUMBER MACHINE COULD TAKE)
C       CHECK IF  ICP(I).GE.NH
C       IF YES    NMP(I).EQ.NMP(I)+NH
C                 ICP(I).EQ.ICP(I)-NH
C       IF NO     NMP(I).EQ.NMP(I)+ICP(I), EMPTY CONVEYOR ICP(I)=0
C
        DO 105 I=1,N
        KLP(I)=0
  105   CONTINUE
        T=T+DELT
        DO 160 KTIME=1,10
        LP=LP+ICP(N+1)
        ICP(N+1)=0
        ICP(1)=ICM(1)
        DO 170 I1=1,N
        I=N+1-I1
        NC=ICM(I+1)-ICP(I+1)
        IF (NC.GT.NMP(I))  NC=NMP(I)
        KLP(I)=KLP(I)+NC
        ICP(I+1)=ICP(I+1)+NC
        NMP(I)=NMP(I)-NC
C
        NH=NMM(I)-NMP(I)
        IF(MD(I).GE.1)   NH=0
        IF(ICP(I).LT.NH)   NH=ICP(I)
        NHX(I)=NH
        NMP(I)=NMP(I)  + NH
        ICP(I)=ICP(I)-NH
  170   CONTINUE
        CALL PLINE(ICP,NMP,NHX,N)
  160   CONTINUE
        DO 180 J=1,N
        UPD(J)=UP
        IF(MD(J).EQ.0)  GO TO 180
        UPD(J)=DN
  180   CONTINUE
        PRINT 250,    T,(ICP(I),NMP(I),UPD(I),MD(I),KLP(I),I=1,N),LP
  250   FORMAT(' ',F5.1,5(1X,I7,I4,1X,A2,I2,I5),I10)
  150   CONTINUE
        END
```

TABLE A2.--Main Program PKGLINE, Part II

```
      SUBROUTINE DOWN (MD,T,N)
C
C   PROBLEM OF SHUTDOWNS
C   ONE SHIFT=60*8=480MINUTES,   .80*480=404 MIN, AND 76 MIN DOWNTIME
C   MDOWN=COUNTS THE AMOUNT OF DOWNTIME BY MINUTES, 1,2,...7
C   NX=THE DOWNTIME DATA FOR EACH OF THE FIVE MACHINES
C   NTOT=THE TOTAL DOWNTIME TO INSURE 80 PERCENT MACHINE EFFICIENCY
C   RANF=THE RANDOM NUMBER SELECTOR SUBROUTINE IN THE COMPUTER
C
      DIMENSION MD(5),MDOWN(5)
      DIMENSION NTOT(5),NX(7,5)
      DATA (NX(1,K),K=1,5) /49,35,24,30,20/
      DATA (NX(2,K),K=1,5) /55,40,26,35,23/
      DATA (NX(3,K),K=1,5) /59,43,27,37,25/
      DATA (NX(4,K),K=1,5) /60,44,29,39,29/
      DATA (NY(5,K),K=1,5) /62,44,30,40,32/
      DATA (NX(6,K),K=1,5) /62,46,30,41,34/
      DATA (NX(7,K),K=1,5) /62,47,30,41,36/
      DATA NTOT /435,355,220,325,440/
C
      DO 300 K=1,N
      IF(MD(K).EQ.0)   GO TO 310
      IF(MDOWN(K).EQ.MD(K)) GO TO 340
      MD(K)=MD(K)+1
      GO TO 300
C   THE NUMBER OF MINUTES DOWN
 310  M=NTOT(K)*RANF(0.5)+1.0
      IF(M.GT.NX(7,K)) GO TO 300
C
      DO 320 I=1,7
      L=I
      IF(M.LE.NX(I,K)) GO TO 330
 320  CONTINUE
 330  MDOWN(K)=L
      MD(K)=1
      GO TO 300
 340  MD(K)=0
 300  CONTINUE
      RETURN
      END
```

TABLE A2.--Subroutine DOWN

```
      SUBROUTINE PLINE(IC,NM,MD,K)
C
C   K=THE NUMBER OF MACHINES
C   NPER=THE NUMBER PER SYMBOL FOR THE CONVEYORS
C   NMAS=THE NUMBER PER SYMBOL FOR THE MACHINES
C   L(I,J)=THE LOCATION OF THE ITH MACHINE OR CONVEYOR IN THE OUTPUT
C   VECTOR, SL
C   S(K)=THE SYMBOL VECTOR, SYMBOLS USED ARE $  O  S  0
C   S=UNITS MOVING ON THE CONVEYOPS
C   O (ALPHABETIC)=UNITS STATIONARY ON THE CONVEYORS
C   S=UNITS MOVING IN THE MACHINES
C   0 (NUMERIC)=UNITS STATIONARY IN THE MACHINES
C   A B C D E INDICATE MACHINES 1 2 3 4 5
C
      DIMENSION IC(10),NM(10),MD(10),S(15),SL(125),L(10,2)
      DATA LQQ,NPER,NMAS/0,1200,20/
      IF (LQQ.GT.0) GO TO 120
      NP2=NPER/2
      READ 200,S
      PRINT 210,S
 200  FORMAT (15A1)
C  INITIAL CALL FOR SET-UP
      M=0
      DO 100 I=1,K
      M=M+IC(I)/NPER+3
      L(I,1)=M
      M=M+NM(I)/NMAS+2
      L(I,2)=M
 100  CONTINUE
      IF(L(K,2).GT.125) PRINT 220,L(K,2)
      LQQ=5
C
 120  DO 130 I=1,125
      SL(I)=S(5)
 130  CONTINUE
C
      DO 160 I=1,K
      JM=(IC(I)+NP2)/NPER
      M=L(I,1)
      LET=1
      IF(MD(I).EQ.0) LET=2
      IF (JM.EQ.0) GO TO 145
      DO 140 J=1,JM
      M=M-1
      SL(M)=S(LET)
 140  CONTINUE
 145  LET=LET+2
      M=L(I,2)
```

TABLE A3.--Subroutine PLINE, Part I

```
      SL(M)=S(I+5)
      JM=NM(I)/NMAS
      IF(JM.EQ.0) GO TO 160
      DO 150 J=1,JM
      M=M-1
      SL(M)=S(LET)
  150 CONTINUE
  160 CONTINUE
C
      PRINT 210, SL
  210 FORMAT(3X,125A1)
  220 FORMAT(10X,*OVERRUN OF SL*,I5)
      RETURN
      END
```

TABLE A3.--Subroutine PLINE, Part II

BIBLIOGRAPHY

BIBLIOGRAPHY

American Can Co. The Canned Food Reference Manual. New York: Rogers-Kellogg-Stillson, Inc., 1947. Chapters 1, 2 and 6.

Arthur, William. "To Simulate or Not to Simulate: That is the Question." Educational Data Processing Newsletter, Vol. 2, No. 4 (1965), 9.

Belshaw, Fran. "Computers Keep Products Moving at General Mills." Canner/Packer (February, 1975), p. 52.

Bloedorn, William H. "New Series: Improving Conveyor Performance, Part I: Downtime--What Are the Major Causes." Beverage World (January, 1975), p. 54.

________. "Part II: Chain Wear Strip Compatibility." Beverage World (March, 1975), p. 48.

Chorafas, Dimitris N. Systems and Simulation. New York: Academic Press, 1965, Chapters 1, 2 and 3.

Church, Janis. Simulation as a Tool in Assembly Line Design. Dearborn, Mich.: Society of Manufacturing Engineers, 1971.

"Equipment for Speed and Accuracy." PIRA Packaging Abstracts, #3029, Vol. 31, No. 12 (December, 1974), p. 671.

"Filling Can Still Present Problems." PIRA Packaging Abstracts, #2646, Vol. 31, No. 11 (November, 1974), p. 591.

"Focus On: Filling and Crowning." PIRA Packaging Abstracts, #2374, Vol. 30, No. 9 (September, 1973), p. 480.

Francis, Richard L., and John A. White. Facility Layout and Location, an Analytical Approach. Englewood Cliffs, N.Y.: Prentice-Hall, Inc., 1972.

"Glass Bottling at New Speeds." PIRA Packaging Abstracts, #520, Vol. 31, No. 2 (February, 1974), p. III.

Hall, J. R., and R. L. Swaine. "Trends in the Carbonated Beverage Industry." PIRA Packaging Abstracts, #177, Vol. 30, No. 1 (January, 1973), p. 33.

Howard, A. J. Canning Technology. Washington, D.C.: Sherwood Press, Chapters 3, 8 and 9.

Jacobs, Morris B. Manufacture and Analysis of Carbonated Beverages. New York: Chemical Publishing Co., Inc., 1959, Chapter 2.

Jones, Gwendolyn. Packaging--A Guide to Information Sources. New York: Gale Research Co., 1967.

Judge, Edward E., and Son. The Directory of the Canning, Freezing, Preserving Industries. New York: Edward E. Judge Co., 1968.

Lamble, P. M. "High-Speed Filling of Carbonated Soft-Drinks." PIRA Packaging Abstracts, #522, Vol. 31, No. 2 (February, 1974), p. III

Manetsch, Thomas J., and Gerald L. Park. System Analysis and Simulation with Applications to Economic and Social Systems, Part II. East Lansing, Michigan: Department of Electrical Engineering and System Science, Michigan State University, 1974.

McMillan and Gonzalez. Systems Analysis--A Computer Approach to Decision Models. Homewood, Ill.: R. D. Irwin, 1968, Chapters 1 and 2.

Mullins, Paul E. "Two Packaging Breakthroughs from DuPont." Beverage World (February, 1975), pp. 38-44.

________. "Horizontal Arm Stores More Lids, Saves Time." Softdrinks (March, 1971), pp. 62-63.

________. "It Talks, It Trains, It Trouble Shoots." Softdrinks (May, 1971), pp. 28-29.

________. "Retractable Roller Conveyors Speed Trailer Loading, Simplify Unloading." Softdrinks (September, 1971), pp. 38-39.

National Canners Association. The Canning Industry. Washington, D.C.: Communications Services, 1971, pp. 21-29.

Page, B. V. "Assessing Liquid Filling Systems." PIRA Packaging Abstracts, #792, Vol. 31, No. 3 (March, 1974), p. 171.

Pyler, E. J. "Australia's Fastest Beer Packaging Line." Brewers Digest (June, 1975), pp. 30-34.

________. "Brewery Packaging Technology at M.S.U. in East Lansing." Brewers Digest (February, 1975), pp. 30-36.

________. "Continuous Motion Bottle Cleaner Operates at 1600 bpm." Brewers Digest (March, 1975), pp. 57-62.

________. Heineken's New Brewery." Brewers Digest (May, 1975), pp. 30-40.

________. "Preventing Materials Handling Bottlenecks." Brewers Digest (July, 1974), pp. 38-39.

"Shrinkwrap Line Tray-Packs 6000 Cans a Minute." PIRA Packaging Abstracts, #2370, Vol. 30, No. 9 (September, 1973), p. 479.

Smith, John. Computer Simulation Models and Techniques--Case Studies. London: Charles Griffin and Co., Ltd., 1968, Chapters 1 and 13.

Teichroeu, David, and John F. Lubin. "Computer Simulation: Discussion of the Technique and Comparison of Languages." Working Paper No. 20. Stanford, Calif.: Graduate School of Business, Stanford University, 1964, pp. 27-29.

"Two-Piece Can Filling Lines Will Run at 1,250 a Minute." PIRA Packaging Abstracts, #155, Vol. 32, No. 1 (January, 1975), p. 34.

Weeks, Morris, Jr. Beer and Brewing in America (New York: U.S. Brewers Foundation, 1949.

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