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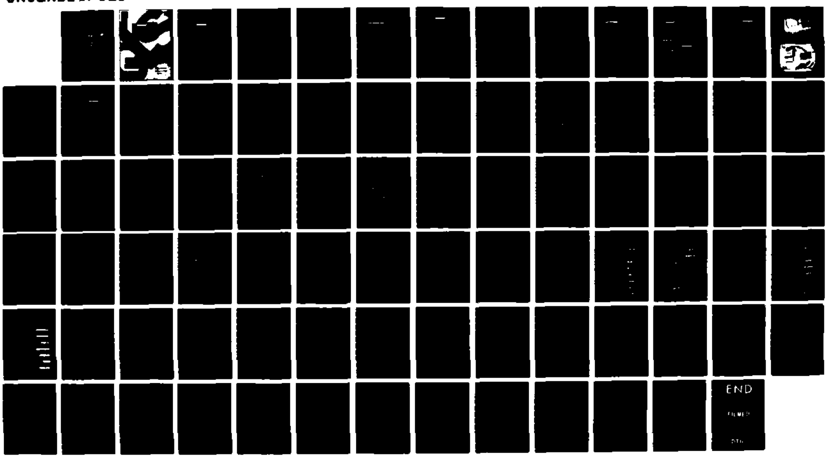

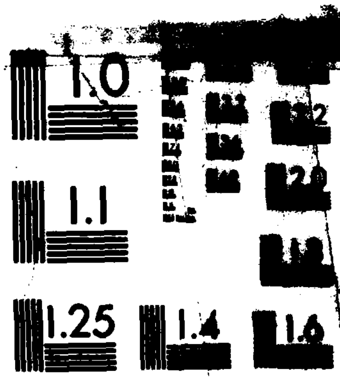

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[redacted] INSTRUMENTS

TRANSMITTER SIMULATION MODEL

PRADEEP BANSAL
DAVID NIELSEN
SUSAN SHERER

OR 800
MAY 1985

decision sciences
The Wharton School
University of Pennsylvania

[redacted] INSTRUMENTS

TRANSMITTER SIMULATION MODEL

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MAY 1985

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AFIT RESEARCH ASSESSMENT

The purpose of this questionnaire is to ascertain the value and/or contribution of research accomplished by students or faculty of the Air Force Institute of Technology (AU). It would be greatly appreciated if you would complete the following questionnaire and return it to:

AFIT/NR
Wright-Patterson AFB OH 45433

RESEARCH TITLE: Instruments Transmitter Simulation Model

AUTHOR: Pradeep Bansal, David Nielse, Susan Sherer

RESEARCH ASSESSMENT QUESTIONS:

1. Did this research contribute to a current Air Force project?

( ) a. YES ( ) b. NO

2. Do you believe this research topic is significant enough that it would have been researched (or contracted) by your organization or another agency if AFIT had not?

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3. The benefits of AFIT research can often be expressed by the equivalent value that your agency achieved/received by virtue of AFIT performing the research. Can you estimate what this research would have cost if it had been accomplished under contract or if it had been done in-house in terms of manpower and/or dollars?

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4. Often it is not possible to attach equivalent dollar values to research, although the results of the research may, in fact, be important. Whether or not you were able to establish an equivalent value for this research (3. above), what is your estimate of its significance?

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5. AFIT welcomes any further comments you may have on the above questions, or any additional details concerning the current application, future potential, or other value of this research. Please use the bottom part of this questionnaire for your statement(s).

NAME GRADE POSITION

ORGANIZATION LOCATION

STATEMENT(s):

C

1.0 EXECUTIVE SUMMARY (Abstract)

A simulation model of (a) ~~the~~ transmitter production line at [redacted]* was developed ~~in order~~ to ascertain how well the line could be expected to perform, where improvements could be made, and what the impact of specific management policies would be. The model validated some basic operating assumptions. It showed that maintenance of batch integrity during repair cycles is superior to splitting off repair work. Usage of critical ratio for establishing processing priority was validated. The single shift could accommodate most of the production requirements at a production input level of 87 units per week.

In terms of lead time improvement, it was determined that small increases in worker efficiency or increases in yield at specific locations did not have a significant impact on throughput. The largest reduction in throughput time was accomplished by the equalization of batch sizes, mostly at approximately 20-30 units each. Usage of very small (1-2 units) or very large (50 units) batch sizes was detrimental to throughput performance.

The current configuration was found to be inadequate when production input increases by 50% (to a level of 130 units input per week). Performance can be improved significantly by running the line on a two shift basis or through the acquisition of specific additional facilities.

* The company for which we completed the project requested their name not be released.

[redacted] INSTRUMENTS
TRANSMITTER SIMULATION MODEL

LIST OF FIGURES AND TABLES

FIGURES

TABLES

Note: Table Numbers correspond to sections of report where each is discussed.

APPENDICES

Appendix A : Case Results

Case	Table	Description
1	A4.1	Base Case Results
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3		b. Critical Ratio - 2 shifts on welder
4		c. FIFO - 2 shifts on welder
5	A4.3.1.2	Yield Improvement to 90% at Bench Test, Step 43
6	A4.3.1.3	Yield Improvement to 90% at NGT Computer, Steps 41 and 47
7	A4.3.2	100% Labor Efficiency
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9,10	A4.3.4	Base Case with 4 Bench Test Facilities
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Appendix B: Sample Data Forms and Input Files

Appendix C: Sample Output

Appendix D: Program Listing

Note: Table Numbers correspond to sections in report where each is discussed.

1.0 EXECUTIVE SUMMARY (Abstract)

A simulation model of the transmitter production line at [redacted] Company was developed in order to ascertain how well the line could be expected to perform, where improvements could be made, and what the impact of specific management policies would be. The model validated some basic operating assumptions. It showed that maintenance of batch integrity during repair cycles is superior to splitting off repair work. Usage of critical ratio for establishing processing priority was validated. The single shift could accommodate most of the production requirements at a production input level of 87 units per week.

In terms of lead time improvement, it was determined that small increases in worker efficiency or increases in yield at specific locations did not have a significant impact on throughput. The largest reduction in throughput time was accomplished by the equalization of batch sizes, mostly at approximately 20-30 units each. Usage of very small (1-2 units) or very large (50 units) batch sizes was detrimental to throughput performance.

The current configuration was found to be inadequate when production input increases by 50% (to a level of 130 units input per week). Performance can be improved significantly by running the line on a two shift basis or through the acquisition of specific additional facilities.

2.0 BACKGROUND

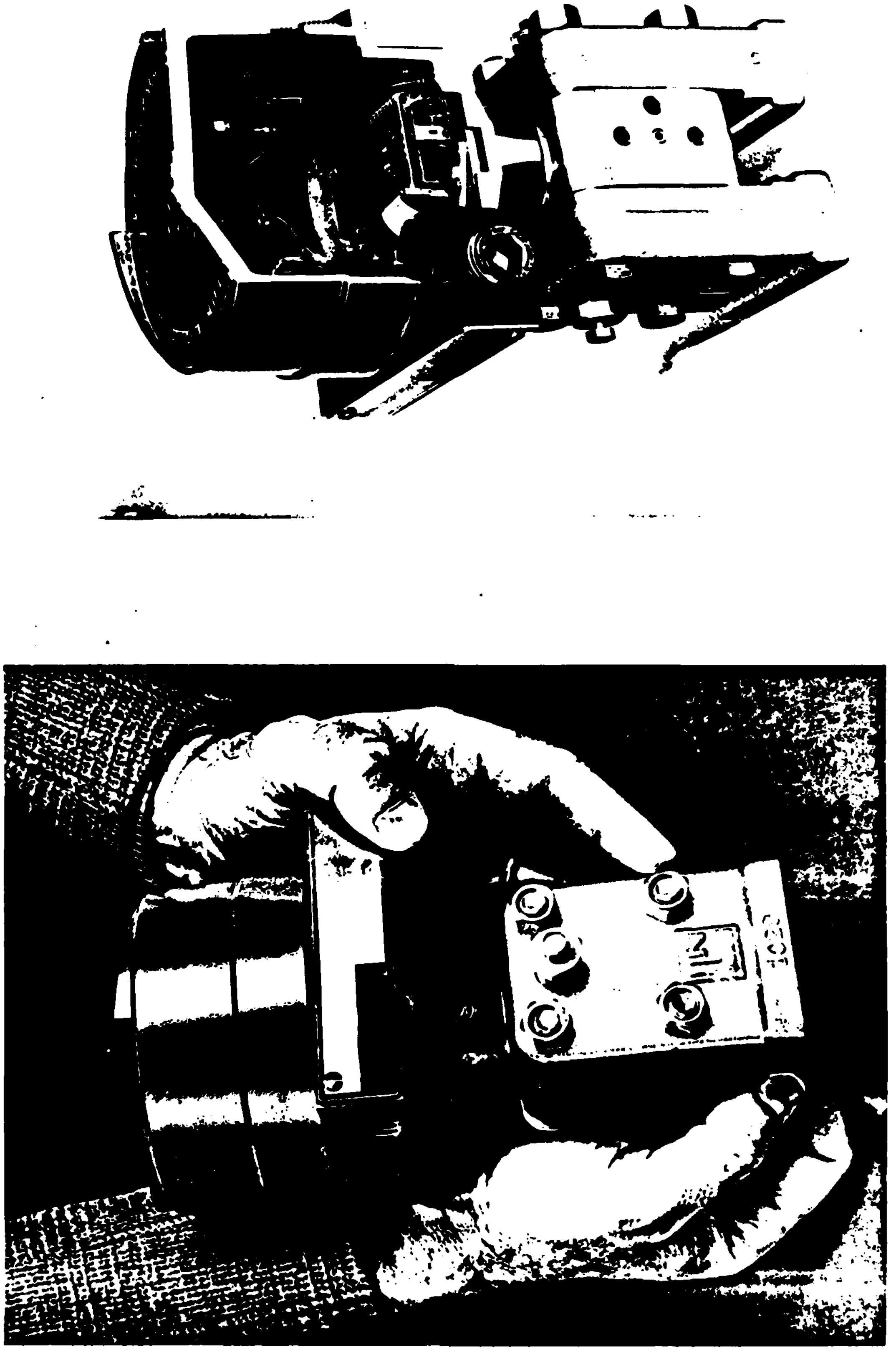
[redacted] Instruments is a producer of process control instruments, analog and digital process controllers, analytical instruments and environmental monitoring equipment, electronic recorders, laboratory type electrical monitoring instruments and graphic displays. Their product offerings measure and control temperature, flow, pressure, pH (acidity-alkalinity), conductivity, gas concentration, a-c current, a-c load, particle size, and environmental pollution. Their products are used in many markets including utilities, chemical, petroleum, cement, glass, plastics & rubber processors, metal refining and metalworking, machinery and transportation equipment manufacturers, water treatment and food and drug processing. The company's headquarters is at North Wales, Pa. They have additional manufacturing facilities in St. Petersburg, Florida and Dublin, Ireland. Since September 29, 1978, the company has been a subsidiary of [redacted], Stamford, Connecticut, a $1.7 billion company in instrumentation and control technology for industrial automation, conservation and management of electric energy, rail transportation, telecommunications and semiconductor processing.

On November 12, 1984, [redacted] released for sale an all new line of electronic transmitters. (See Fig. 2.1) These will be marketed for reliable, high-accuracy measurement of low range differential pressures and flows. In addition, [redacted] intends to add to its offering high range differential pressure transmitters by the end of this year. Transmitters can be considered the "eyes and ears" of a control system in that they sense the primary process variables and transmit them back to the control system for further data manipulation. The parameters are typically temperature, pressure, level, flow, pH and conductivity. The new transmitter line can measure differential pressures with ranges from 0 to 0.2 in of water column up to 0 to 10000 psi with an accuracy that they believe to be better than that of any other draft transmitter on the market. The new draft-range transmitters employ an [redacted] patented version of the proven differential-capacitance detection technique which provides high measuring reliability and performance under rigorous industrial environments. It is felt to be ideal for low-range measurements in a variety of industries such as furnaces in glass plants and steel mills, kilns in ceramic or cement plants, paper mills, and power plant boilers. Advanced solid-state technology employed in the transmitter's circuitry should maintain optimum signal quality and integrity in the face of adverse process and environmental conditions. Mean time between failures for this circuitry is 400,000 hours (over 45 years) at 70^{C}C.

In early November 1984, [redacted] Company began what they call preproduction of the manufacturing process to test the machinery and production flow. The company began production with a limited schedule/work force in early 1985 and are now producing a limited quantity.

The production process is highly complex with jobs cycling many times through common machines. Figure 2.2 is an overview of the flow. During this early production phase, [redacted] requested that we help them anticipate production problems and aid them in developing production strategies for this new line. They wanted to know where bottlenecks might occur as they began production. For material planning purposes, since each product type and batch quantity may vary in yield, they wanted to know how many material kits to enter to the process in order to obtain their required output. They also wanted to find out the average anticipated lead time under full production in order to determine their promised schedules to customers.

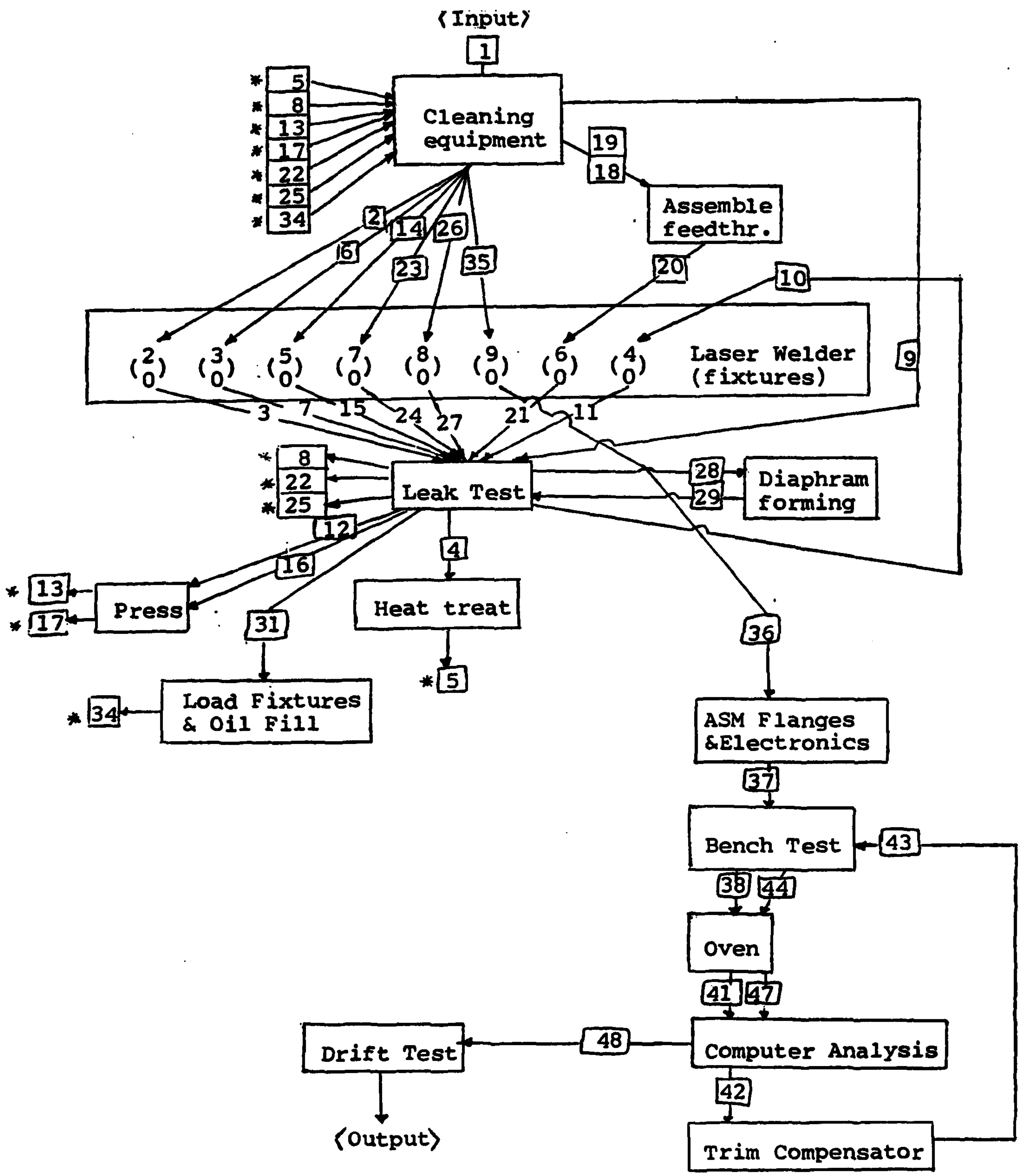
Figure 2.1



Transmitter Illustration

Figure 2.2

MANUFACTURING FLOW



3.0 PROCEDURE

Due to the complexity of the production process, we decided to simulate the problem in order to develop the type of information which [redacted] wanted. The simulation model was developed using SLAM (See Section 3.1). As the model was developed, data was collected concerning order quantities, processing sequence, resource requirements, service times, repair information and resource reliability (See Section 3.2). All of the data is kept in files so that the model is flexible and easily updated for changes. Various types of statistics concerning the operation of the system were collected by the model (Section 3.3). Once the data was collected and the model tested, we began to investigate different scenarios. (Section 3.4) The analysis is discussed in Section 4. Results are compared in Section 5. Section 6 lists conclusions and recommendations.

3.1 SIMULATION MODEL DESIGN

The simulation model was written in Fortran using SLAM, Simulation Language for Alternative Modeling. (A copy of the program is included in Appendix D). It is based upon a network structure with a node established for each processing location. Jobs, along with their identifying attributes, enter the system and are moved from one processing location to another where they are put in queue (filed at the specific node) until they can be processed. Jobs input, route structure, processing times, and location descriptions are input through data files to allow the greatest amount of flexibility in use.

Each job, as it moves throughout the system, has the following identifying attributes:

1. Current Time
2. Event Type
3. Identification Number
4. Job Type

Type	Part Number
1	0-4
2	5-9
3	10-14
4	15-20

5. Number of items in lot
6. Previous node
7. Current node
8. Original number of items in lot
9. Node where lot was created (if rework)
10. Previous step number
11. Current step number
12. Due date = Time job enters + Lead Time
13. Total number of repair lots created
14. Number of repair lots created at a given step
15. Loss at a given step
16. Critical Ratio

Each processing location is described by the number of servers available and the number of servers in use. A file is maintained at each location which includes all jobs at that location, either in queue or in service, along with the job's identifying attributes.

The program has several modules controlled by a central controller (Figure 3.1). The initialization module reads all the input data. Once the model is initialized, the central controller takes over. It reads entries in the calendar file to determine what event takes place next.

There are four types of events: Daily Arrivals, Arrivals, Service and End. The SLAM software maintains a calendar file which includes all events which are scheduled to take place along with the time and location of the event.

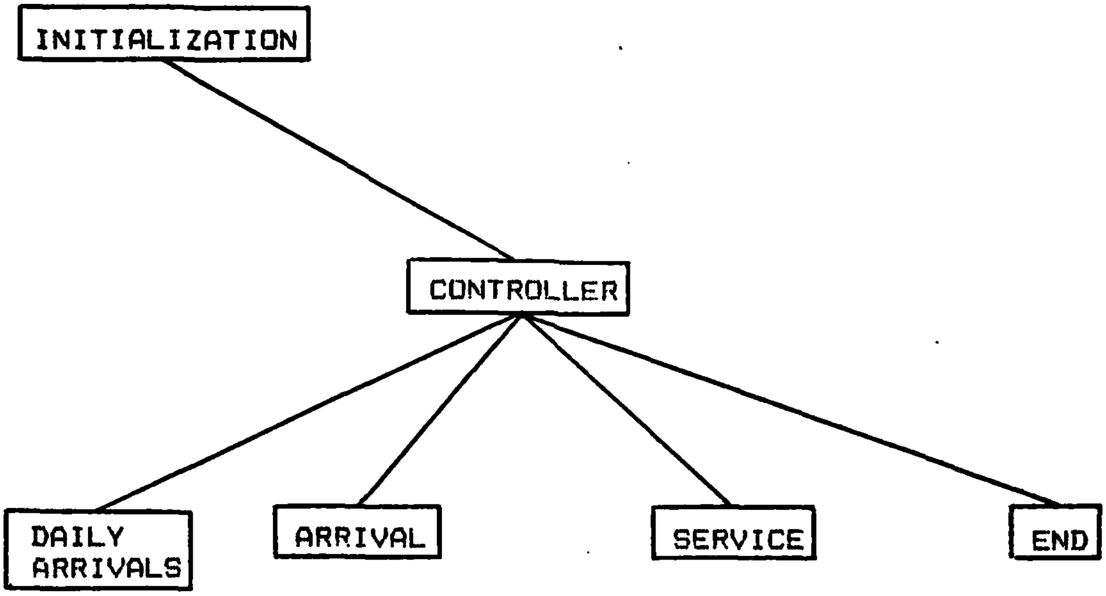
Daily Arrivals take place each morning of every weekday. The program checks to see if there are any new jobs to enter the system on that day. The user controls the number of jobs, the type of job and the quantity of items in each batch entering on a daily basis through the input data file. If new jobs arrive, this module schedules them to arrive at the first processing location at the scheduled time of that day.

The Arrival module puts a job in queue at the specific processing location. If a server is available, it will schedule a service at the current time. When batch integrity must be maintained, this module also performs the task of collecting common jobs before they are moved on to the next processing step.

The Service module chooses the next job in queue based upon the processing priority, FIFO or Highest Critical Ratio. Based upon the step of the current job, this module will then schedule the end of service based upon the data input and a random number generator. Using the random number generator and the data rules input, it will also determine the yield of the process.

The End module performs several functions. If there are items to be repaired, it creates a repair job and schedules it to arrive at the appropriate processing point. The percent repairable and repair location are all user inputs. The original job will then be scheduled to arrive at the next processing location. If batch integrity is to be maintained, the job will move to a collection node and wait there until the repair job catches up to it. Otherwise, the original lot moves on to the next processing location and completes the entire sequence without ever recombining with the repair lot. Finally, the module will schedule a service event at the processing location where the job has just completed service.

SIMULATION MODULES



Initialization - Reads data files

Daily Arrivals - Reads in new work on a daily basis

Arrival - Puts job in queue; Schedules service if server is available

Service - Picks job from queue; Schedules end of service; Determines loss

End - Updates yield; Determines if repairs are necessary and schedules repair work at appropriate processing point; Schedules arrival of completed work at next point; Schedules service at current location from existing queue

Fig. 3.1

3.2 DATA INPUT

There are five types of data input: Simulation Control, Daily Input, Routing, Node Description, and Step Description. Information Flow is shown in Figure 3.2. The information describing the process was supplied to us by L&N personnel who completed data sheets for each step of the operation. Examples of these data forms as well as the data input files are included in Appendix B.

Simulation Control

Priority Rules (FIFO, Critical Ratio)

Initialization Time - time at which statistics begin to be collected to allow reaching steady state conditions - Our studies initialized statistics after 12 weeks of operation for base case input level and after 24 weeks for base case input increased 50%.

Number of days to be simulated - We simulated either 24 or 36 weeks of operation depending upon the size of input lots and the time required to reach steady state

Movement time between nodes - time in addition to queue time for a lot to move between nodes. This was assumed to be zero except for the NGT computer where a three day move time was used. We felt that the queue times were sufficiently large so as to include move time considering the close proximity of the remaining operations.

Hourly Efficiencies at the nodes for each hour in a week - Total service time is calculated by stepwise integration of service time divided by the hourly efficiencies through time until normal service time for the lot is achieved

Lead Time - used to compute Critical Ratio for priority processing of jobs. This was set equal to 8 weeks.

Daily Input

Time of Arrival (Hours)
Job Type (1,2,3,4)
Job Identification Number
Number of items in batch

Routing Information

Node and Step Numbers in order of processing sequence

Rework Node and Step Numbers - node and step where rework will go when leaving the current node and step

Rework Fraction - percent repairable at current step

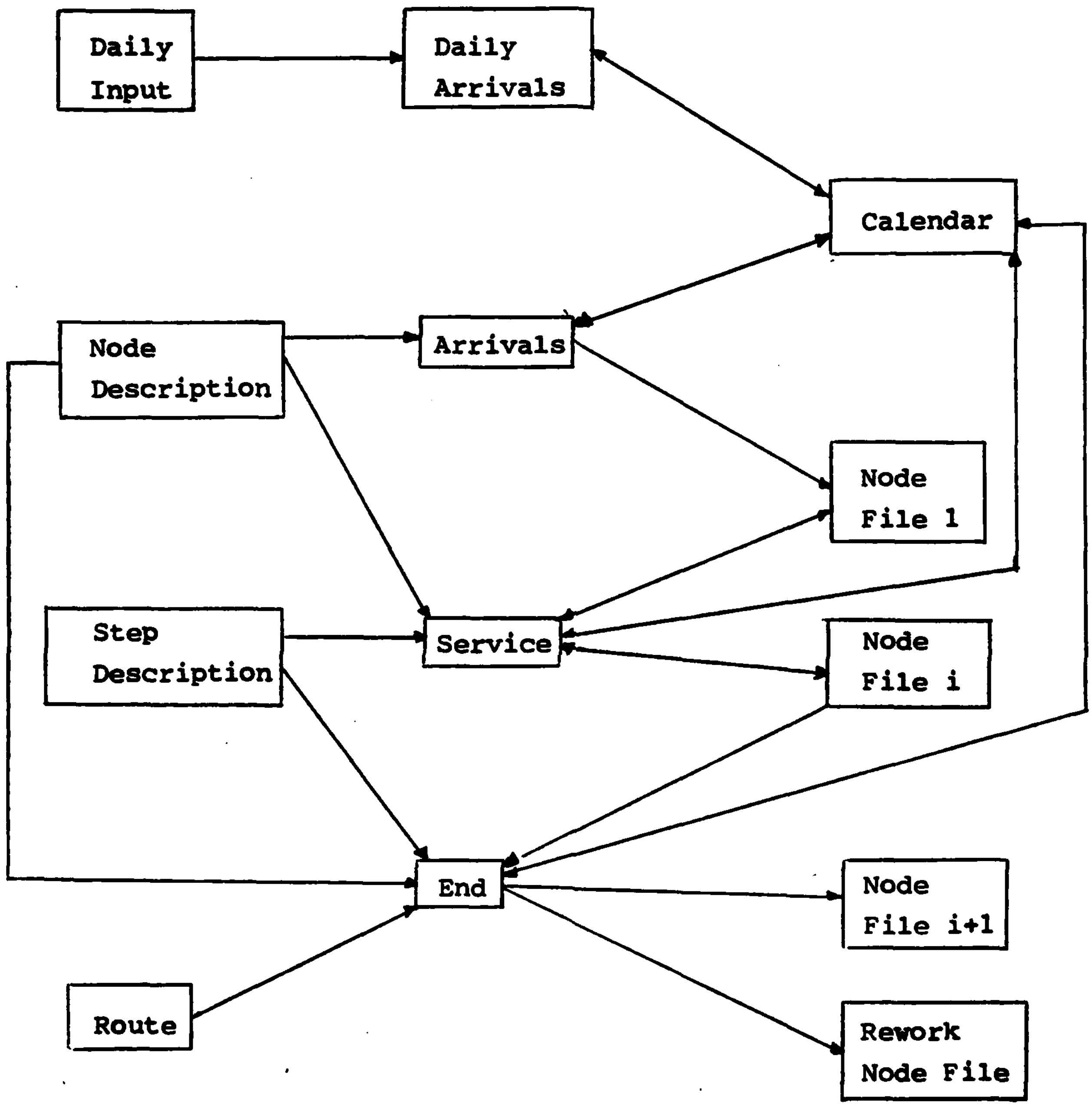
Node Description

Number of servers at the node
Maximum allowable queue size

Step Description - By job type (1,2,3,4)

For each step, two possibilities are considered: The job may or may not yield 100%. The user inputs the percent of jobs which will yield 100% at that step and the processing time (fixed and unit times) for these jobs. The user also inputs the processing time (fixed and unit) and yield for jobs which will not yield 100%. The program uses a random number generator at each step to determine the category that the specific job falls in. The fraction of the loss which is repairable is supplied with the Routing information.

Information Flow



3.3 OUTPUT

Several different types of output are produced and are shown in Appendix C. They are as follows:

Input Data Reflection - Lists all node and route data for verification

Lead Time - Total time in the system (Time between completion and start of a job) - Mean, minimum and maximum is computed for each job type

Yield - Number of units completed/Number of units started - Mean, minimum and maximum is computed for each job type

Waiting (Idle Time) - Time a job waits at each node = Time job enters service - Time job arrives at node This includes wait time between shifts. Mean, minimum and maximum is computed for each node. Note that this time represents the time a job waits each time it reaches this node. Thus, for certain nodes, jobs may return many times, in some cases as much as 8 times; thus, waiting this amount each time.

Queue Lengths - Average number and maximum in queue including number in service

Completed jobs - list of all jobs at time of completion - Includes quantity completed, job ID, total time in system and number of repair lots created during its time in the system

File Statistics - At the completion of the simulation, contents of all queues are listed for trace.

Event Tracing - This output was only produced for testing purposes. It tracked all events that took place.

3.4 SCENARIOS

Base Case

Our base case simulated the process which [redacted] management felt would most closely represent the manner in which their line would operate. Assumptions are as follows:

1. Priority based upon critical ratio
2. Maintain batch integrity
3. Personnel efficiencies of 80%.
4. Routing as shown in Table 3.3.1.
5. Yields as shown in Table 3.3.2.
6. Processing times as shown in Table 3.3.2.
7. Facilities as shown in Table 3.3.4.
8. Weekly input of one lot of each part type of the following quantities:

Part Type	Items per Lot
1	50
2	25
3	10
4	2
Total	87

Batch Integrity

Although [redacted] management originally said that they wished to maintain batch integrity throughout the process, further discussion with [redacted] personnel suggested that this policy might be difficult to institute. Thus we simulated both situations in order to compare throughput. In the base case, we maintained batch integrity. This means that all repair lots were collected. After every repair lot split off, the original job would wait until the repair lot caught up before completing processing. In the alternative situation, when a repair lot split off, the original lot was completed separately from the repair lot.

Processing Priority

[redacted] planned to implement a priority system which would pick from a queue a job with the highest critical ratio defined as

Critical Ratio = Remaining Process Time/(Due Time - Present time)

The model simulated this policy by establishing the critical ratio as

Critical Ratio = Remaining Steps/(Due Time - Present Time)

This policy was then compared with FIFO to insure that it would, in fact, provide better performance.

Resources

In order to identify potential resource deficiences, we simulated the process assuming 100% yield. This gave us the opportunity to identify if a resource would limit our throughput even if yields could be improved.

We identified the bottlenecks and then simulated the system with additional resources to improve throughput.

Yields

Since the current yields are so low, we considered the effect of improvements in certain yields. This would give [redacted] important information concerning where they ought to concentrate their efforts on yield improvement and what the impact of these improvements would be.

Batch Sizes

The impact of original batch size (maintaining the same weekly total input) on throughput rate was analyzed by varying sizes of input lots.

Weekly Input

The impact of increasing the total weekly input on the throughput rate and potential resource deficiences was analyzed by varying total weekly input.

Labor Efficiency Improvement

In order to see the effects of improved labor efficiency, we increased efficiences to 100%. This gave us some upper bounds on the impact of policies to improve efficiency.

Model Validation

The model was run with a single job and then with only a small number of jobs and compared against actual data input. This was done by complete tracking of every event that took place. Review with [redacted] personnel showed reasonable performance. Actual performance results were not available for comparison with model results due to very low current production at [redacted].

Table 3.3.1

PROCESS SEQUENCE

STEP NO	STEP DESCRIPTION	NODE NO	NODE DESCRIPTION	REWORK STEP
1	Clean Pump & Diaphragm	11	Cleaning Equipment	
2	Weld Pump & Diaphragm	12	Laser Welder	
3	Lead Check Pump & Diap	13	Leak Tester	2
4	Heat Treat Pump & Diap	14	Heat Treat Equip	
5	Clean Body, Diap, Plug, and Ring	11	Cleaning Equipment	
6	Weld Body and Ring	12	Laser Welder	7
7	Leak Test Body & Ring	13	Leak Tester	6
8	Clean & Ass Housing	11	Cleaning Equipment	
9	Leak Test & IR Test Sensors	13	Leak Tester	11
10	Weld Sensor Tip to Housing	12	Laser Welder	11
11	Leak Test	13	Leak Tester	9
12	Press Nameplate	15	Press	
13	Clean Spacers	11	Cleaning Equipment	
14	Weld Spacer and Housing	12	Laser Welder	15
15	Leak Test	13	Leak Tester	14
16	Press HP Plug	15	Press	
17	Clean & Prepare Feedthru	11	Cleaning Equipment	
18	Assemble Feedthrus	16	Assemble	
19	ASM in Weld Fixt & Test	17	Fixture	
20	Weld Feedthru	12	Laser Welder	21
21	Leak test	13	Leak Tester	20
22	Clean Parts	11	Cleaning Equipment	
23	Weld HP to HSG	12	Laser Welder	24
24	Leak Test	13	Leak Tester	23
25	Clean Parts	11	Cleaning Equipment	
26	Weld LP to Hsg	12	Laser Welder	27
27	Leak Check	13	Leak Tester	26
28	Diaphragm Forming	18	Forming Equipment	28
29	Leak Test	13	Leak Tester	26
30	Assemble	19	Assemble	
31	Oil Fill(Load,Fill,Test)	20	Oil Fill Equipment	30
34	Clean Parts	11	Cleaning Equipment	
35	Weld LP Cover	12	Laser Welder	34
36	ASM Flanges	21	Assemble	
37	Bench Test	22	Bench Test	37
38	Oven Cycle (Load, Temp Run, Unload)	23	Oven	
41	Computer Analysis	24	NGT Computer	37
42	Trim Compensator	25	Laser Trimmer	42
43	Bench Test Verification	22	Bench Test	37
44	Oven Cycle	23	Oven	
47	Computer Analysis	24	NGT Computer	37
48	Drift Test	26	Drift Rack	37

Table 3.3.2

SUMMARY OF PROCESSING TIMES
BASE CASE DATA

STEP NO	STEP DESCRIPTION	FIXED TIME HRS	UNIT TIME HRS	YIELD %	REPAIR WORK REPAIRABLE %	REPAIR WORK FIXED TIME HRS	REPAIR WORK UNIT TIME HRS
1	Clean Pump&Diap	.084	.017	100			
2	Weld Pump&Diap	.258	.034	99	50	.601	.034
3	Leak Check	.084	.033	98	50	.421	.033
4	Heat Treat	.167	.017	100			
5	Clean Body, Diap Plug & Ring	.084	.017	100			
6	Weld Body&Ring	.258	.034	99	50	.601	.034
7	Leak Test	.084	.033	98	50	.42	.033
8	Clean&Ass Hsg	.084	.033	100			
9	Leak Test & IR Test Sensors	.084	.033	98	50	.505	.033
10	Weld Sensor Tip	.258	.034	99	50	.601	.034
11	Leak Test	.084	.033	98	50	.421	.033
12	Press Nameplate	.083	.017	100			
13	Clean Spacers	.084	.017	100			
14	Weld Spacer&Hsg	.258	.034	99	50	.601	.034
15	Leak Test	.084	.033	98	50	.421	.033
16	Press HP Plug	.083	.017	100			
17	Clean & Prepare Feedthru	.084	.017	100			
18	Assemble Feedthr	.084	.033	100			
19	ASM in Weld Fix & Test	.084	.033	100			
20	Weld Feedthru	.258	.034	99	50	.601	.034
21	Leak Test	.084	.033	98	50	.421	.033
22	Clean Parts	.084	.017	100			
23	Weld HP to Hsg	.258	.034	99	50	.601	.034
24	Leak Test	.084	.033	98	50	.421	.033
25	Clean Parts	.084	.017	100			
26	Weld LP to Hsg	.258	.034	99	50	.601	.034
27	Leak Check	.084	.033	98	50	.421	.033
28	Diap Forming	.117	.017	100			
29	Leak Test	.084	.033	98	50	.421	.033
30	Assemble	.05	.05	100			
31	Oil Fill	.263	.192	98	50	.612	.192
34	Clean Parts	.084	.017	100			
35	Weld LP Cover	.343	.069	98	50	.607	.069
36	ASM Flanges	.3	.2	100			
37	Bench Test	.204	2.04	75	50	.204	2.04
38	Oven Cycle	8.16	0	100			
41	Computer Anal	.05	.05	70	100	.05	.05
42	Trim Compensator	.5	.05	99	100	1.0	.05
43	Bench Test Verif	.204	.255	50	95	.204	.255
44	Oven Cycle	8.16	0	100			
47	Computer Anal	.05	.05	70	100	.05	.05
48	Drift Test	40.8	0	99	100	40.8	0

SUMMARY OF PROCESSING TIMES

Notes:

All times estimates are based upon estimates from [redacted] personnel which were then increased by anticipated downtime probabilites.

The yield factors were modeled as follows:

Yield %	% of Time	% Yield	% of Time	% Yield
99	75	100	25	96
98	75	100	25	92
95	50	100	50	92
70	50	100	50	40
50	37.5	100	62.5	20

For example, a yield of 99% was modeled so that 75% of the time no loss was incurred; 25% of the time yield was 96%. This was felt to be most representative of the realistic situation.

Repairable % is the % of the loss which can be repaired. For example, at step 2, 1% is lost and 1/2 of this loss is repairable.

Time estimates for repairables are the total time at the particular node to process these items. Thus, this reflects extra time which an item would spend at a node for repairs. The routing of the repairable after this node is shown in the Process Sequence.

Times of the oven cycle and drift rack represent actual work time rather than elapsed time.

Table 3.3.4

FACILITIES

NODE DESCRIPTION	NODE NUMBER	QUANTITY
Cleaning Equipment	11	1
Laser Welder	12	1
Leak Tester	13	1
Heat Treat Equipment	14	1
Press	15	1
Assemble Node 1	16	1
Fixture	17	1
Forming Equipment	18	1
Assemble Node 2	19	1
Oil Fill	20	2
Assemble Node 3	21	2
Bench Test	22	8
Oven	23	6
NGT Computer	24	1
Laser Trimmer and Lead Bonder	25	1
Drift Rack	26	1

4.0 ANALYSIS

4.1 Base Case Analysis

The key results for the base case are summarized in Table 4.1.1. The results represent an average of several repetitions of this simulation case. Average lead time ranges from approximately 4 weeks for the batches of size 2 to over 8 weeks for the batches of size 50. The weighted average lead time is 7.16 weeks.

Average yields range from 73-80%; weighted average is 79%. Note that this is the final yield. Although yields are low at many of the processing steps, in most cases, the items are repairable. Thus, the low yields at these steps do not affect the overall process yield as much as they contribute to longer throughput times since repairable items have to return to previous steps for further processing. These yields indicate that in order to obtain the required production quantities, [redacted] must enter the following material to their process:

Type	Required Output	Required Input
1	50	63
2	25	31
3	10	14
4	2	3

Average waiting times at each processing location are not very great in most cases. The major bottleneck location is the laser welder, where each job waits an average of 12.38 hours each time it arrives at the welder with maximum wait time equal to 167.7 hours. Maximum number of jobs waiting for service at the welder is 8, average is approximately 2.

CASE 1:
BASE CASE RESULTS

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	50	8.39	1.07	7.44	11.43	13	8
2	25	6.01	0.57	5.43	6.74	12	0
3	10	4.44	0.40	3.75	5.31	13	0
4	2	4.35	0.75	3.29	5.44	12	0

WEIGHTED AVERAGE 7.16

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	50	79.80	6.66
2	25	80.30	4.69
3	10	73.10	16.53
4	2	75.00	26.11

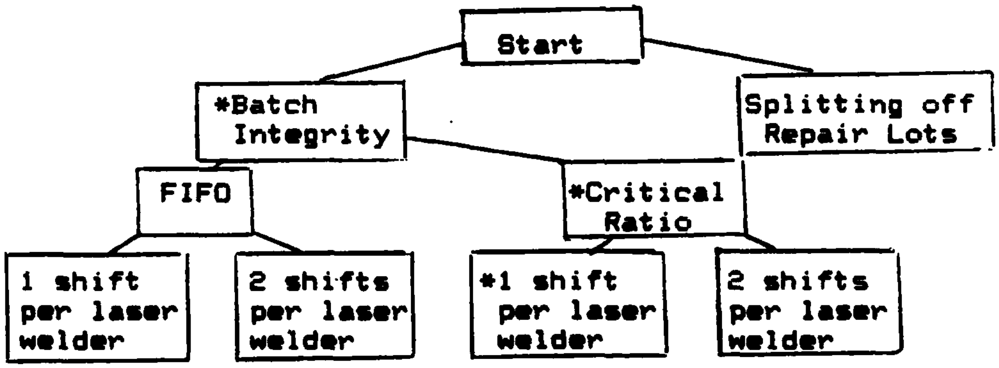
WEIGHTED AVERAGE 79.06

WAITING TIME

NODE NO	DESCRIPT	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	1	2.26	4.40	22.43	18.08
12	LASER WELDER	1	12.38	23.98	167.70	99.04
13	LEAK TESTER	1	3.45	9.01	66.51	31.05
14	HEAT TREAT EQUIP	1	0.17	0.33	1.33	0.17
15	PRESS	1	0.21	1.62	15.76	0.42
16	ASSEMBLE	1	0.04	0.14	0.76	0.04
17	FIXTURE	1	1.38	9.30	63.76	1.38
18	FORMING EQUIP	1	0.02	0.11	0.75	0.02
19	ASSEMBLE	1	1.26	8.78	63.35	1.26
20	OIL FILL	2	2.06	9.92	68.19	2.06
21	ASSEMBLE	2	1.45	9.65	65.44	1.45
22	BENCH TEST	8	1.15	5.34	49.98	2.30
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	0.26	1.72	17.54	0.52
25	LASER TRIMMER	1	1.65	9.17	64.18	1.65
26	DRIFT RACK	1	0.75	3.69	19.33	0.75
5	COLLECTION NODE	1	3.81	16.15	140.80	60.96
	TOTAL		32.30			221.15

4.2 Base Case Validation

Before proceeding to analyze different alternatives, we investigated the assumptions underlying the development of the base case by [redacted] management. We elected to hold the base case input constant at 87 units per week (Type 1 = 50, Type 2 = 25, Type 3 = 10, Type 4 = 2) and then evaluated alternative options. The following flow diagram depicts the options studied.



Note: The * indicates the recommended choice. The options selected: Maintaining batch integrity, Priority based upon critical ratio, and operating the production line as envisioned (no extra shifts), are consistent with and validate the use of the base case for further comparisons.

4.2.1 Batch Integrity

We initially hypothesized that maintenance of batch integrity might slow down the completion time of jobs because of the large number of times the items cycle back for repair. However, the results of our simulation without maintenance of batch integrity indicates the opposite effect. In fact, keeping batches together improves throughput. Table 4.2.1 compares the results of the base case with that obtained by relaxing the assumption that all lots will wait for repair items to catch up before continuing the process. The case where batch integrity is not maintained assumed that when units split off for repair, the main job would continue through the system without waiting for the repair units to catch up. What happens in this case is that many very small lots of size 1 and 2 are created, each of which incurs a set up time, thus creating very large queues. At the end of the simulation,

BATCH INTEGRITY COMPARISON

WAITING TIME

NODE		AVERAGE WAITING TIME HRS COLL. BATCH	SEP. REPAIR	INCR (DECR)	INCR TIMES # OF PASSES	MAXIMUM WAITING TIME HRS COLL. BATCH	SEP. REPAIR	INCR (DECR)
11	CLEANING	2.26	5.10	2.84	22.72	22.43	77.44	55.01
12	WELDER	12.38	55.45	43.07	344.56	167.70	2237.00	2069.30
13	LEAK TEST	3.45	5.31	1.86	16.74	66.51	90.97	24.46
14	HEAT TREAT	0.17	0.14	-0.03	-0.03	1.33	1.90	0.57
15	PRESS	0.21	0.62	0.41	0.82	15.76	63.61	47.85
16	ASSEMBLE	0.04	1.05	1.01	1.01	0.76	64.15	63.39
17	FIXTURE	1.38	1.08	-0.30	-0.30	63.76	64.45	0.69
18	FORMING	0.02	0.04	0.02	0.02	0.75	0.57	-0.18
19	ASSEMBLE	1.26	0.15	-1.11	-1.11	63.35	2.60	-60.75
20	OIL FILL	2.06	3.10	1.04	1.04	68.19	75.19	7.00
21	ASSEMBLE	1.45	0.44	-1.01	-1.01	65.44	5.87	-59.57
22	BENCH TEST	1.15	1.98	0.83	1.66	49.98	42.36	-7.62
23	OVEN	0.00	6.87	6.87	13.74	0.00	119.30	119.30
24	COMPUTER	0.26	0.38	0.12	0.24	17.54	17.05	-0.49
25	TRIMMER	1.65	0.18	-1.47	-1.47	64.18	2.65	-61.53
26	DRIFT RACK	0.75	0.00	-0.75	-0.75	19.33	0.00	-19.33
5	COLL. NODE	3.81	0.00	-3.81	-60.96			
	TOTAL				336.92			

4.2.1

after 24 weeks of operation, the queue at the laser welder was 133 batches, most containing very few items. Table 4.2.1. indicates a total increase in average waiting time for a single job throughout the process of 336.92 hours; the majority of the increase is at the laser welder, due to the increased number of setups.

In terms of completion of work, in the base case where batch integrity was maintained, 869 units were completed between weeks 12 and 24 as compared to only 644 units during the same period when batch integrity was not maintained.

A way to avoid the problem of the large number of setups might be to collect small batches and process these together. However, cost accounting for these small individual jobs would be extremely difficult and would probably not be worthwhile. After reviewing our results with [redacted] representatives, we decided not to investigate this area any further due to the accounting implications.

4.2.2 Processing Priority

The most widely used processing priority rule for scheduling jobs is the critical ratio. During the planning meetings held with [redacted], management felt that the manufacturing line would use this rule for scheduling. While we initially hypothesized that the critical ratio would yield better results than a simpler priority rule such as first-in-first-out (FIFO), we ran a number of validation runs (See Table 4.2.2). These alternative priority rules were run in conjunction with an attempt to smooth out the production process by running the laser welder for two shifts per day (See Section 4.2.3). The priority processing rule yielded better results both on a single and double shift for the laser welder. When the welder was run for two shifts, the FIFO rule resulted in larger maximum waiting time (8.6 hours vs. 6.4 hours) and a larger number of lots that were completed after scheduled delivery based upon an 8 week lead time. When the welder was run for a single shift, average waiting time for each return to the welder was 13.77 hours for FIFO vs. 12.78 hours for critical ratio priority processing and number of jobs completed after scheduled delivery was 11 with FIFO vs. 8 with priority processing. This confirms management's judgement. All future cases were then analyzed using priority scheduling based upon the critical ratio.

PROCESSING PRIORITY RULES
CRITICAL RATIO VS FIFO RULE
SINGLE SHIFT

WAITING TIME

NODE	AVERAGE WAITING TIME HRS BASE CASE	FIFO RULE	INCR (DECR)	INCR TIMES # OF PASSES	MAXIMUM WAITING TIME HRS BASE CASE	FIFO RULE	INCR (DECR)
11 CLEANING	2.26	5.09	2.83	22.64	22.43	66.47	44.[illegible]
12 WELDER	12.38	13.77	1.39	11.12	167.70	70.41	-97.29
13 LEAK TEST	3.45	5.34	1.89	17.01	66.51	68.15	[illegible]
14 HEAT TREAT	0.17	0.46	0.29	0.29	1.33	15.29	13.96
15 PRESS	0.21	0.76	0.55	1.10	15.76	63.77	45.[illegible]
16 ASSEMBLE	0.04	3.93	3.89	3.89	0.76	64.55	63.79
17 FIXTURE	1.38	0.71	-0.67	-0.67	63.76	15.36	-48.40
18 FORMING	0.02	0.01	-0.01	-0.01	0.75	0.27	[illegible]
19 ASSEMBLE	1.26	1.39	0.13	0.13	63.35	64.91	1.5[illegible]
20 OIL FILL	2.06	3.60	1.54	1.54	68.19	72.70	4.51
21 ASSEMBLE	1.45	0.00	-1.45	-1.45	65.44	0.00	[illegible]
22 BENCH TEST	1.15	0.37	-0.78	-1.56	49.98	19.32	-30.66
23 OVEN	0.00	0.00	0.00	0.00	0.00	0.00	[illegible]
24 COMPUTER	0.26	0.60	0.34	0.69	17.54	16.1[illegible]	[illegible]
25 TRIMMER	1.65	1.52	-0.13	-0.13	64.18	64.66	0.48
26 DRIFT RACK	0.75	0.07	-0.68	-0.68	19.33	2.86	[illegible]
5 COLL. NODE	3.81	4.93	1.12	17.92	140.90	138.70	-2.10
TOTAL				71.82			

4.2.3 Laser Welder Utilization

When reviewing the base case waiting times at each node, the most striking observation is that waiting time at the laser welder is so much larger than the waiting time at any of the other nodes. One way to try to remove this bottleneck is to increase resources. However, due to the prohibitive expense of obtaining another welder, an attempt was made to investigate running two shifts on the welder while maintaining the rest of the line on one shift. A series of runs were made with this scenario (with critical ratio and FIFO priorities) (See Table 4.2.3). The results were very interesting. Our intuition had been that the addition of the extra shift would help to eliminate the bottleneck at the laser welder, thereby smoothing product flow. We initially felt that this would shorten the total time in the system with the additional benefit of fewer late lots. The results did not support this hypothesis. When comparing the one shift case with the two shift case (based upon critical ratio scheduling), the mean number of lots that were late was the same (8 lots). The number of lots completed were almost identical (46.25 vs. 45.5) and the total time in the system for each case was very similar. Total waiting time at all nodes was reduced somewhat in the two shift case but waiting time increased at the leak tester and the oil fill equipment. Thus, while the second shift reduces the bottleneck at the laser welder, work moves on and can not be handled by the other equipment. Unless additional equipment can be made available at other locations or second shifts can then be run on other equipment, there is no real advantage to be gained by the additional expense of running the welder for two shifts.

4.3 Base Case Sensitivity

After validating the base case, it was clear that, given the current level of input, the manufacturing process was viable. However, improvement was needed considering that 8 out of 13 completed lots of part type 1 were completed late (Average time of 8.39 weeks compared to the given lead time of 8 weeks). Since we had already tried the addition of servers at the nodes with high relative waiting time (or the addition of an extra shift at one node with the remaining process unchanged) with little success, the next step was to investigate the effect of changes in yields at selected nodes, increasing the efficiency of the

LASER WELDER UTILIZATION
1 SHIFT VS 2 SHIFTS

WAITING TIME

NODE	AVERAGE WAITING TIME HRS BASE CASE	2 SHIFT CASE	INCR (DECR)	INCR TIMES # OF PASSES	MAXIMUM WAITING TIME HRS BASE CASE	2 SHIFT CASE	INCR (DECR)
11 CLEANING	2.26	2.80	0.54	4.32	22.43	22.30	-0.13
12 WELDER	12.38	1.66	-10.72	-85.76	167.70	11.28	-156.42
13 LEAK TEST	3.45	6.47	3.02	27.18	66.51	64.22	-2.29
14 HEAT TREAT	0.17	1.19	1.02	1.02	1.33	15.79	14.46
15 PRESS	0.21	0.08	-0.13	-0.26	15.76	0.67	-15.09
16 ASSEMBLE	0.04	0.17	0.13	0.13	0.76	2.19	1.43
17 FIXTURE	1.38	0.85	-0.53	-0.53	63.76	15.76	-48.00
18 FORMING	0.02	0.01	-0.01	-0.01	0.75	0.31	-0.44
19 ASSEMBLE	1.26	0.39	-0.87	-0.87	63.35	16.57	-46.78
20 OIL FILL	2.06	7.89	5.83	5.83	68.19	100.30	32.11
21 ASSEMBLE	1.45	0.61	-0.84	-0.84	65.44	10.72	-54.72
22 BENCH TEST	1.15	0.88	-0.27	-0.54	49.98	47.30	-2.68
23 OVEN	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24 COMPUTER	0.26	0.50	0.24	0.48	17.54	20.26	2.72
25 TRIMMER	1.65	0.45	-1.20	-1.20	64.18	15.21	-48.97
26 DRIFT RACK	0.75	0.00	-0.75	-0.75	19.33	0.00	-19.33
5 COLL. NODE	3.81	3.31	-0.50	-8.00	140.80	139.80	-1.00
TOTAL				-59.80			

4.2.3

work force, or varying batch size. Our intention was to identify which improvements would yield the greatest benefits in the event that management had additional but limited funds to allocate for manufacturing improvements.

4.3.1 Yields

We first ran a test case with 100% yield at all work stations. This 100% yield case, combined with the base case, gave us an upper bound on the pctential improvement. Then we analyzed the effect of increasing yields at specific processing locations and steps.

The original definition of "yield" at a specific step was the percent of product that passed through that step on the first try. The same step also had a percent repairable figure, which referred to the percent of the items that were not passed on to the next step that could be repaired. For example, if step 43 had a yield of 50% and a repairable figure of 95%, then after the end of repairs a total of 97.5% of the units would have reached the next step (50% + (.95)50% = 97.5%). Due to this breakdown of total yield into "yield" and repairable, any increase in the yield factor will not only increase final overall yield but would also decrease the total time in the system (i.e., the lead time) since less time would be required on repairs for each lot. Please note that the yield reported in the attached tables and in the computer output is the final overall yield (i.e., 97.5% in the above case).

Since changes in yield change lead time as well as output, to compare the results, time in system per unit was computed and used as a comparison figure (Average Lead Time/((yield)(# units input))). Similarly, in order to compare results, average waiting time per average output was computed for each node.

4.3.1.1 100% Yield at Every Node

As expected, the 100% yield case showed a drastic decrease in the ratio of time in system per unit in addition to the increase in yield. However, while it is evident that an improvement can be made in this area, it is equally apparent that other avenues of change need to be investigated. Once again the average lead time for Type 1 items was greater than the given lead time (8.18 weeks vs. 8 weeks) with the resultant nine late lots. Since it is not reasonable to expect the entire line to operate at a

100% yield level (both due to Engineering problems and the expense involved) we selected the three steps with the lowest yields for further study.

4.3.1.2 Yield Increase at Bench Test (Step 43)

Of all the given yields, the yield at the Bench test was the lowest at 50%. At the same time the fraction repairable is high, 95%. We simulated the effect of an increase to 90% yield. Recognizing that this increases final yield from 97.5% to 99.5% at this step, we did not expect a significant increase in final output but had hoped to see a decrease in total time in the system due to the reduction in required repairs. The resultant decrease in overall time, however, was minimal (See Table A4.3.1.2).

4.3.1.3 Yield Increase at NGT Computer (Steps 41 and 47)

The steps with the next lowest yields were Steps 41 and 47, both of which occur on the NGT computer. The yield factor is 70% while the fraction repairable is 100%. In this case the final yield factor should be unchanged from the base case since no items are lost at these steps, they simply require more time for repairs. Once again, the results indicated very small change in overall time in the system (See Table A4.3.1.3) when increasing yield to 90%.

In summary, while it is possible to achieve a significant reduction in lead time if this line could run at 100% yield for all processing steps, the results of changes at one or two steps are not significant. Since it is unreasonable to expect the entire line to run with 100% yield, we can not suggest expending large amounts of funds to improve yields at any particular step.

4.3.2 Labor Efficiency

The base case assumes a 40 hour work week with worker efficiencies of 80%. This allows for sick days, coffee breaks, worker fatigue and other factors which would prevent shop personnel from being 100% efficient. The figure of 80% is commonly used in production lines of this type and was considered reasonable by [redacted] representatives. To determine the potential effect of policies to increase efficiency we ran a test case with 100% efficiency (See Table A4.3.2). The results were not conclusive; maximum time in the system for Part Types 2 and 3 was longer than in the base case whereas it was reduced for Part Types 1 and 4. In other words, increased efficiencies had the greatest effect on the very large and very small lot sizes. While improving lead time on the big jobs, the medium batch size jobs ended up waiting longer for these jobs to complete. This indicated that batch size might have an effect on throughput.

4.3.3 Equalization of Batch Sizes

The base case assumed maintenance of batch integrity and therefore did not allow a batch to leave a process node until the entire batch was finished. For example, if a batch of size 50 was being processed at the laser welder, even if the queue at the next step, the leak tester, was empty, the batch would not pass any units from the welder to the leak test equipment until the entire batch was welded. This policy is preferred from a materials control standpoint because of the difficulty in tracking split lots. However, from a manufacturing standpoint, the leak lest equipment could be better utilized. In some production lines, this trade-off is accommodated by the creation of "processing batches", subsets of the original batch. For example, if the original batch size was 50 and the processing batch size was ten, then each time ten units finished at the welder, they would move on to the leak test equipment. At the succeeding node, the processing batches are recombined into the original batch to save on set up time.

Although the simulation did not have the capability to create processing lots and recombine, we attempted to equalize batch sizes in order to investigate the potential improvements due to this type of policy. In the base case scenarios, every Monday morning at 8:00 A.M., four orders were input to the system as follows:

Base Case Input

Part Type	Batch Size
1	50
2	25
3	10
4	2

In an attempt to equalize batch size, the following order sequence was repeated every 2 weeks:

Part Type	Equalization of Input Week 1 Batch Size	 Week 2 Batch Size
1	20	30
1	20	30
2	25	25
3	20	0
4	0	4

This new sequence keeps the number of units entering the system at approximately 87 per week (85 and 89) but allows for several advantages. The first is that the largest batch size of 50 is reduced to 2 batches of either size 20 or 30. This simulates the effect of having an "original" batch of 50 (or 60) and a "processing" batch size of 20 (or 30), except for the recombination of lots during the process. The added cost in this simulation is the additional set up, but it allows for the succeeding steps to receive the smaller batches at an earlier time, thereby smoothing out the queue sizes and waiting times. The second advantage is that it should allow for a more even distribution of lead times among the different types of parts. In the base case, Part Type 1 had a lead time of 8.39 weeks (greater than the required 8 week lead time) while the other 3 types had lead times of 6 weeks, 4.43 weeks, and 4.34 weeks respectively (all less than 8 weeks). We hoped that this new batch size would allow the Type 1 lead time to decrease below 8 weeks and that the increase in Types 3 & 4 lead times would still leave them below 8 weeks. The results were excellent (See Table 4.3.3). To summarize, the distribution of lead times between types was much more even, with the largest average lead time now less than 6 weeks (5.98). In fact, the largest lead time of any batch is now 7.71 weeks so that no batches are now late.

We had hoped that equalization of batch sizes would also produce a more even output rate, a desirable feature according to [redacted] management. In the base case, there was a large amount of variance betwen weekly outputs depending upon when the lots that started at size 50 would finish. In some weeks, three large batches would complete while in other weeks no large jobs completed. We had hoped that this problem would be improved by the fact that the batches were now more similar in size. The results are presented in Figure 4.3.3. Unfortunately, the fact that the input batches are more equal in size doe not seem to have helped even out the output. The maximum and minimum values of number of units completed per week are slightly improved (139 vs. 145 and 17 vs. 0) but there is still a large degree of variability.

BASE CASE VS. EQUALIZATION OF BATCH SIZES

WAITING TIME

NODE	AVERAGE WAITING TIME HRS BASE CASE	EVEN LOT	INCR (DECR)	INCR TIMES # OF PASES	MAXIMUM WAITING TIME HRS BASE CASE	EVEN LOT	INCR (DECR)
11 CLEANING	2.26	1.45	-0.81	-6.48	22.43	64.70	42.27
12 WELDER	12.38	6.02	-6.36	-50.88	167.70	115.30	-52.40
13 LEAK TEST	3.45	2.72	-0.73	-6.57	66.51	67.74	1.23
14 HEAT TREAT	0.17	0.71	0.54	0.54	1.33	15.48	14.15
15 PRESS	0.21	0.03	-0.18	-0.36	15.76	1.36	-14.40
16 ASSEMBLE	0.04	0.05	0.01	0.01	0.76	1.26	0.50
17 FIXTURE	1.38	0.05	-1.33	-1.33	63.76	1.26	-62.50
18 FORMING	0.02	1.10	1.08	1.08	0.75	63.27	62.52
19 ASSEMBLE	1.26	0.17	-1.09	-1.09	63.35	2.75	-60.60
20 OIL FILL	2.06	5.72	3.66	3.66	68.19	88.52	20.33
21 ASSEMBLE	1.45	0.00	-1.45	-1.45	65.44	0.00	-65.44
22 BENCH TEST	1.15	8.67	7.52	15.04	49.98	145.30	95.32
23 OVEN	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24 COMPUTER	0.26	0.45	0.19	0.38	17.54	15.60	-1.94
25 TRIMMER	1.65	1.84	0.19	0.19	64.18	66.28	2.10
26 DRIFT RACK	0.75	3.11	2.36	2.36	19.33	89.46	70.13
5 COLL. NODE	3.81	4.72	0.91	14.56	140.80	120.00	-20.80
TOTAL				-30.34			

4.3.3

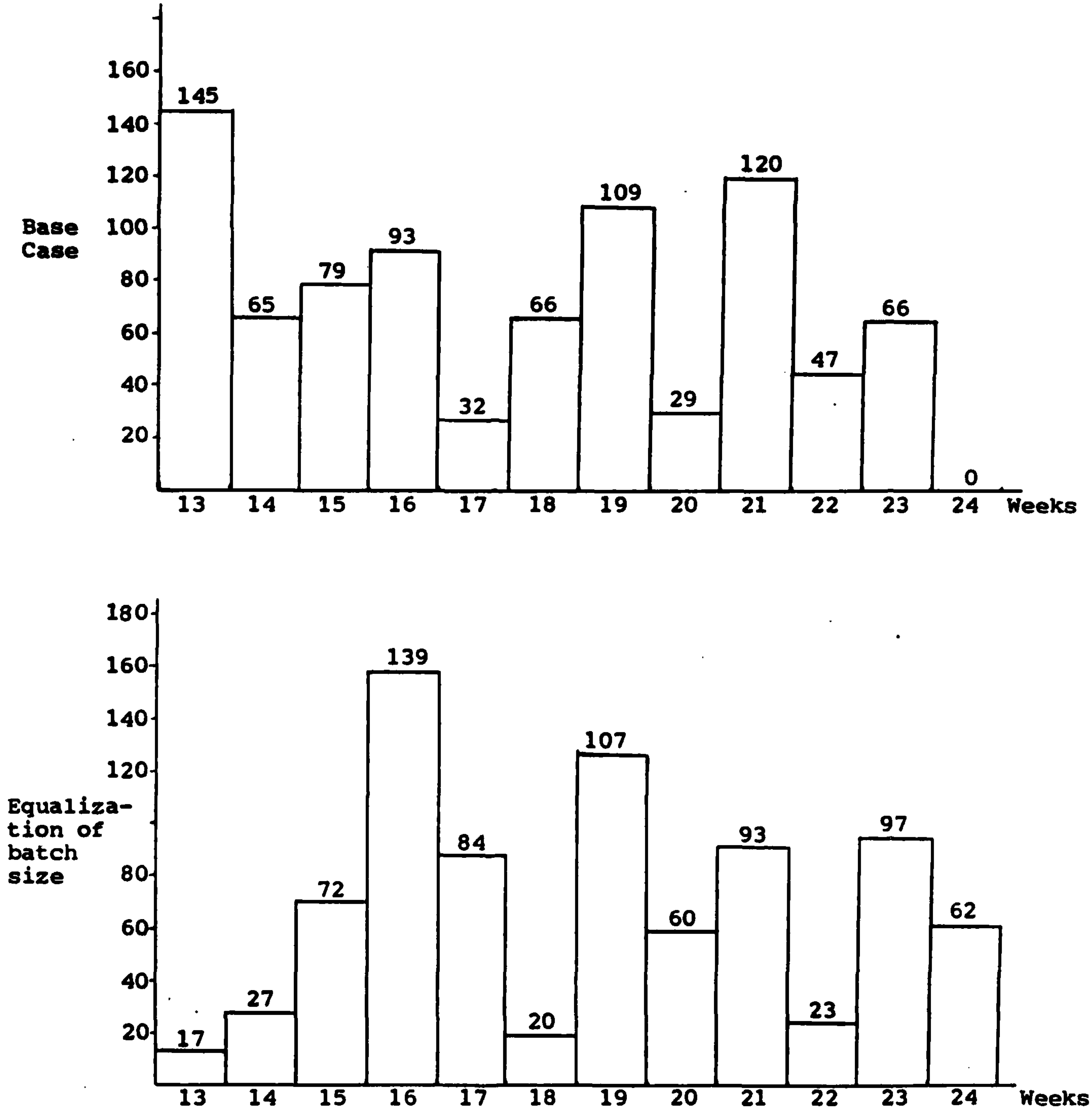


Figure 4.3.3

-Distribution of Weekly Completions-

4.3.4 Acquisition of Bench Test Resources

Our original input was that 8 bench test facilities would be available for the assumed level of production. Subsequent to our first series of analyses, we learned that there were currently only 2 bench test stations available, as the line is not yet up to the capacity which we are simulating. We analyzed the effect of having only 4 bench test stations in the event that [redacted] elected not to make the additional capital investment in these facilities. The simulation of the base case with only 4 bench test facilities showed dramatic results. Over the 12 week period from weeks 13 to 24, only 10 batches were able to finish as compared to 50 batches in the base case. During week 24 to 36, 14 batches completed and there was a queue of size 96 and an average waiting time of 166 hours at each arival to the bench test (See Table A4.3.4). This demonstrates the importance of acquiring all 8 bench test units for this level of production.

4.4 Input Variation

Per request of [redacted] management, we considered the requirements to obtain output of 100 units per week. To achieve this output rate, at the current yields, it was necessary to increase the base case input of 87 per week to a level of 130 units per week, an increase of 50%. For these cases, we input the following quantities of each part type per week:

Type	Quantity
1	75
2	37
3	15
4	3

Due to the larger volume in the system, in order to insure that the process had reached steady state prior to the collection of statistics, we ran the simulation for 36 weeks with new batches entering every week and with statistics collected from weeks 24 to 36.

4.4.1 Base Case Input Increased 50% (No other Changes)

The effects of the increased input highlights how sensitive the process is to the volume of product (See Table A4.4.1). The numbers of lots completed decreased from approximately 50 lots to 38 lots during a 12 week period. In addition, all output was late. The minimum lead time for each part type was 12.76 weeks, 10.46 weeks, 9.43 weeks, and 9.29 weeks, respectively. The problem is clearly one of a bottleneck at the cleaning equipment. (Note: Average waiting time of 128 hours per cleaning operation and a maximum queue length of 74 batches at the cleaning equipment). Since 9 out of the 16 work stations have average waiting times of less than an hour, we decided that one course of action would be to add an extra server (i.e., wash rack) at the cleaning equipment node rather than running two shifts. Since we did not have any cost figures at our disposal to compare the capital cost of obtaining additional equipment vs running additional shifts, we analyzed the effects of different policies so as to give [redacted] an indication of the results. It is expected that [redacted] would use these results in conjunction with their cost data to determine the optimal course of action.

4.4.2 Base Case Increased 50% with 2 Server Facilities at Cleaning Equipment

An additional machine at the cleaning equipment node was successful in reducing both the wait time (3.5 hours) and maximum queue lenth for that node, but the overall problem was not solved (See Table A4.4.2). The net result was that a portion of the backlog of batches that had previously been held up at the cleaning station was now waiting in the queues at the laser welder (Average waiting time 45 hours), the oil fill station (Wait time 85 hours) and the bench test (Wait time 65 hours). There were still no units being completed within the standard lead time of 8 weeks (the shortest lead time of any part type is 9.3 weeks). Since we were faced with a situation where half of the work stations still had average waiting time of less than one hour, we decided to investigate the effects of extra facilities at the oil fill and bench test stations as well as running two shifts on the laser welder.

4.4.3 Base Case Increased 50% with Two Shifts on Laser Welder, 2 Server Facilities at the Cleaning Equipment, 3 Server Facilties at the Oil Fill Station and 12 Servers at the Bench Test

The addition of the extra servers as well as the second shift for the laser welder had positive results (See Table A4.4.3). The average lead time for Part Types 3 and 4 were reduced below 8 weeks (7.58 and 6.29) but the average lead time for Part Types 1 and 2 were still unacceptable at 13.06 and 9.56 weeks, respectively. After reviewing the waiting time and maximum queue lenth statistics, it appeared that the process had one remaining bottleneck at the leak test equipment. The rest of the work stations appeared to have reasonable queue lengths and waiting times. To overcome this bottleneck, we investigated the usage of an additional machine.

4.4.4 Base Case Increased 50% with 2 Shifts on the Laser Welder, 2 Server Facilities at the Cleaning Equipment and Leak Test Stations, 3 Server Facilities at the Oil Fill Station, and 12 servers at the Bench Test

Even with the additional server at the leak test station, the results were not as good as we had hoped (See Table A4.4.4). The results are very similar to the Base Case. The average lead times for part types 2,3,and 4 were now below 8 weeks (6.98, 4.58, 3.97) while the average lead time for type 1 (11.87) was in excess of the goal. There were 12 lots, all Type 1, that finished late (after 8 weeks). On a positive note, the production line was now more balanced, in that the largest maximum waiting time at any node was 8.3 hours and there did not seem to be any excess queues. Much like the base case, this suggested that the problem may not be with the makeup of the line but rather the sizes of the batches. Therefore, we decided to even out the batch sizes, much as we did previously with the smaller input case.

4.4.5 Base Case Increased 50% with Even Batch Sizes

In the previous scenarios with production increased 50% over the base case, the following number of units were input every Monday morning at 8:00 A.M:

Type	Batch Size
1	75
2	37
3	15
4	3

For the even batch size scenarios, the input was changed to repeat the following inputs every two weeks:

Part Type	Week 1 Batch Size	Week 2 Batch Size
1	30	45
1	30	45
2	37	37
3	30	0
4	0	6

4.4.5.1 Base Case Increased 50% with Even Batch Sizes and No Additional Servers

We ran this scenario to compare the even batch case with the original increased input simulation (See Section 4.4.1). We did not expect the unaltered line to be able to handle the increase in input and we were correct (See Table A4.4.5.1). None of the average lead times were less than the required 8 weeks; in fact the smallest average was for Part Type 3 at 10.37 weeks. However, the product flow through the process was improved with smaller bottlenecks at the laser welder (average waiting time of 47.5 hours and maximum queue of 54) and the bench test (waiting time of 36.3 hours and maximum queue of 16). Since the bottlenecks developed at similar locations, we decided to combine the even batch size input with the best case combination of servers discovered under increased input (base case increased 50%) (See Section 4.4.4).

4.4.5.2 Base Case Increased 50% with Even Batch Sizes, 2 Shifts at the Laser Welder, 2 Server Facilities on the Cleaning and Leak Test Stations, 3 Server Facilities for Oil Fill and 12 servers for the Bench Test

The combination of even input batches and additional servers/shifts produced the best results to date (See Table A4.4.5.2). While all four part types now had average lead times below 8 weeks, there were still 8 lots that were late completions. However, these lots were not excessively late (i.e., of the 8 lots that were late, only one was more than .44 weeks overdue). At the same time, there were no bottlenecks in the process. The maximum waiting time was 5.98 hours at the drift rack and the maximum queue length of 14 lots occured at the bench test where the average waiting time was .12 hours. Once again, the even batch sizes improved the process by shortening the lead times.

4.4.5.3 Base Case Increased 50%, Even Batch Sizes, 2 Shifts for the Entire Line

Since cost information for the additional equipment was unavailable, we decided to consider two shift operation for the entire line to compare performance. In the absence of cost information, we will be unable to recommend a specific course of action. Rather, our analysis is designed to provide comparisons between the option of two shifts and the best case scenario provided by 1 shift operation with additional servers added.

The two shift results were excellent (See Table A4.4.5.3). For all part types, average lead times were less than the standard of 8 weeks. In fact, no units were late, the maximum lot time completion was only 5.6 weeks. These numbers were anticipated since we doubled the number of worker hours per week and only increased the input by 50% (Note that for even batch sizes with base case input levels, there were no late lots and the largest average lead time was 5.98 weeks). For the given level of input, it would be reasonable to lower the lead times given to customers if there was a competitive advantage in doing so. [redacted] management must consider the advantages of offering earlier deliveries (with a potential savings on inventory costs) vs operating on a two shift basis. Comparison of results is shown in Table 4.4.5.3.

BASE CASE INPUT INCREASED BY 50%
WITH EQUALIZATION OF BATCH SIZES
2 SHIFTS VS INCREASED FACILITIES

WAITING TIME

NODE	AVERAGE WAITING TIME HRS				MAXIMUM WAITING TIME HRS		
	2 SHIFT CASE	INCR FACIL	INCR (DECR)	INCR TIMES # OF PASSES	2 SHIFT CASE	INCR FACIL	INC[illegible] DEC[illegible]
11 CLEANING	1.63	0.74	-0.89	-7.12	26.00	16.56	-9.44
12 WELDER	1.63	2.69	1.06	8.48	22.11	34.13	12.02
13 LEAK TEST	0.54	3.87	3.33	29.97	11.04	62.83	51.79
14 HEAT TREAT	0.18	0.33	0.15	0.15	1.21	3.63	2.42
15 PRESS	0.25	0.04	-0.21	-0.42	7.46	0.74	-6.72
16 ASSEMBLE	0.05	1.49	1.44	1.44	1.22	64.14	62.92
17 FIXTURE	0.05	0.03	-0.02	-0.02	1.22	0.33	-0.89
18 FORMING	0.04	0.04	0.00	0.00	0.75	0.71	-0.04
19 ASSEMBLE	0.26	1.22	0.96	0.96	8.40	16.49	8.09
20 OIL FILL	11.83	0.38	-11.45	-11.45	80.32	18.99	-61.33
21 ASSEMBLE	0.06	3.06	3.00	3.00	2.11	63.89	61.78
22 BENCH TEST	.00	0.12	0.12	0.24	0.52	16.26	15.74
23 OVEN	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24 COMPUTER	0.09	0.62	0.53	1.06	2.76	16.73	13.97
25 TRIMMER	0.42	0.74	0.32	0.32	8.37	15.74	7.37
26 DRIFT RACK	13.65	5.98	-7.67	-7.67	143.90	93.43	-50.47
5 COLL. NODE	5.91	11.60	5.70	91.12	87.68	141.10	53.42
TOTAL				110.06			

[illegible].4.5.[illegible]

5.0 RESULTS

When we were developing a summary of results we were faced with a trade off. The most accurate comparison between cases would have to include an accounting for the different number of units completing between cases. We considered such aggregate ratios as "average lead time per average number of units completed" and "average waiting time per average number of units completed". While the ratios offer better comparisons, the numbers are not of much use to management. An average lead time per unit of 35.8 versus 50.7 is nice, but what does it mean? For this reason we decided to summarize the following measurements: comparison of lead times (See Fig. 5.2), comparison of total waiting time (See Fig. 5.3.), comparison of number of batch completions (See Fig. 5.4), and comparison of percent of batches late (See Fig. 5.5). By separating the cases into two groups, 87 versus 130 units input per week, we have been able to overcome most of the variance in number of units completing, thereby allowing for direct comparisons of lead time, waiting time, etc. Since the yields/percent repairable are held constant across cases, these four categories supply management with the most relevant data (more detailed comparisons are included in Section 4). For an index to case numbers, refer to Section 5.1.

5.1 Index To Case Numbers

Case 1: Base Case
Case 2: FIFO Case
Case 3: Critical ratio with 2 shifts on the laser welder
Case 4: FIFO with 2 shifts on laser welder
Case 5: Yield improvement to 90% at bench test step 43
Case 6: Yield improvement to 90% at NGT computer steps 41 and 47
Case 7: 100% labor efficiency case
Case 8: Equalization of batch sizes
Case 9: Base case with 4 bench test facilities (24 weeks)
Case 10: Base case with 4 bench test facilities (36 weeks)
Case 11: Base case input increased by 50%, 1 shift for entire line
Case 12: Base case input increased by 50%, extra server facility at cleaning equipment
Case 13: Base case input increased by 50%, 2 shifts on laser welder and extra facilities at cleaning equipment, oil fill, and bench test
Case 14: Base case input increased by 50%, 2 shifts on laser welder, and extra facilities at cleaning equipment, leak test, oil fill, and bench test
Case 15: Base case input increased by 50% with equalization of batch size (no additional servers)
Case 16: Base case input increased by 50%, with equalization of batch size and 2 shifts at the laser welder, and extra facilities at the cleaning equipment, leak test, oil fill, and bench test
Case 17: Base case input increased by 50%, with equalization of batch size and 2 shifts for the entire line

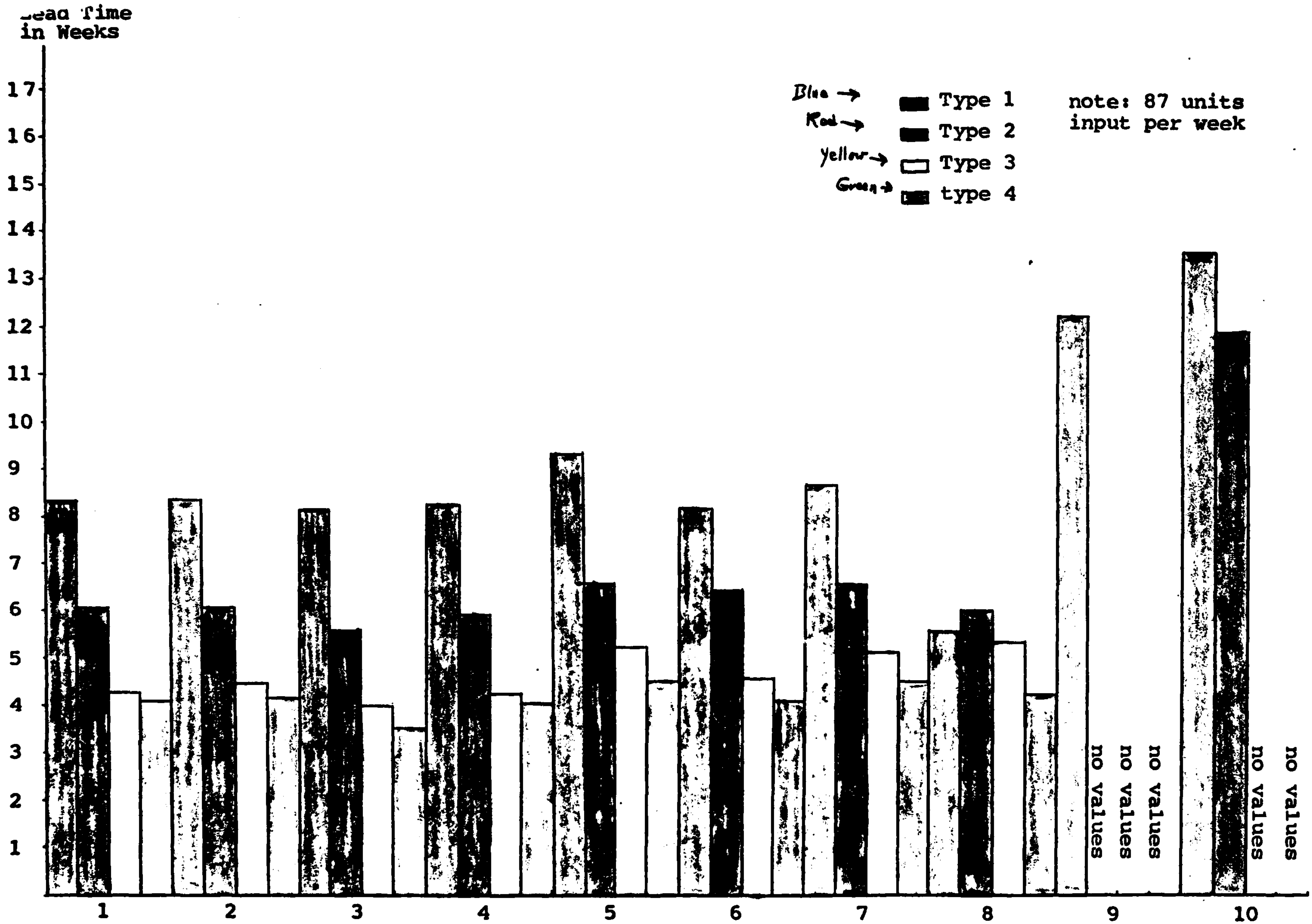


Fig. 5.2(a)

-Comparison of Lead Times-

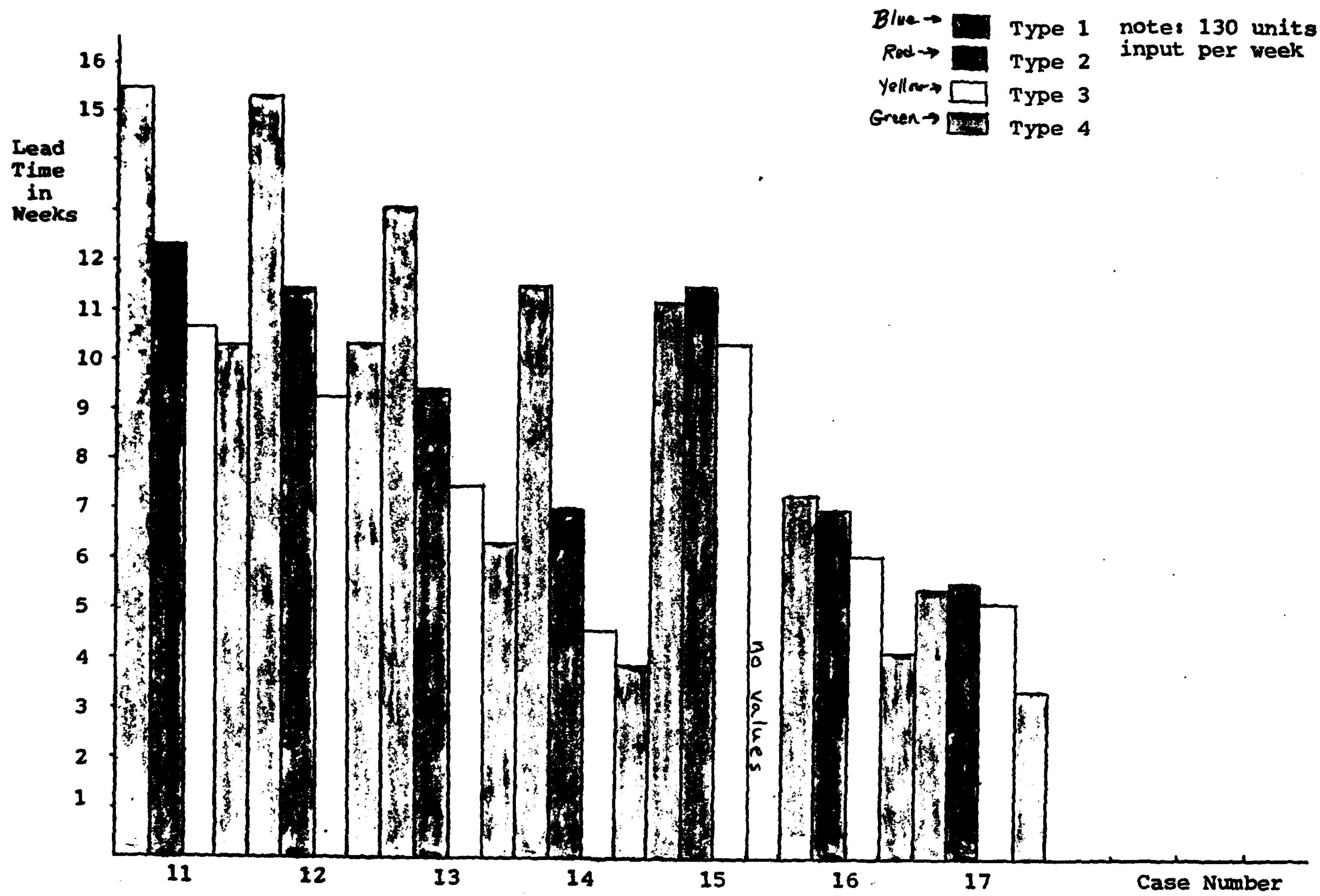


Fig. 5.2(b)

-Comparison of Lead Times-

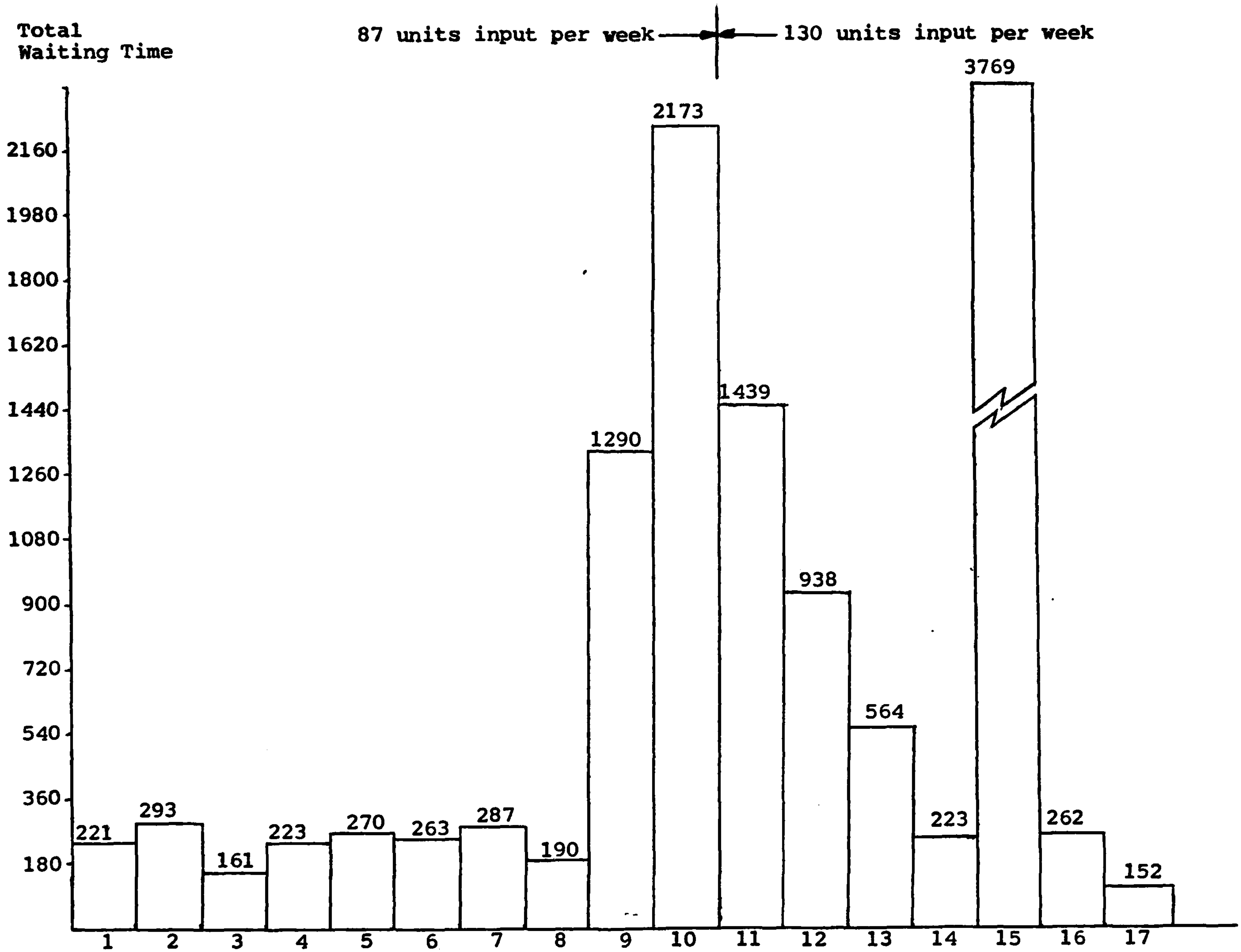


Fig. 5.3

-Comparison of Total Waiting Time-

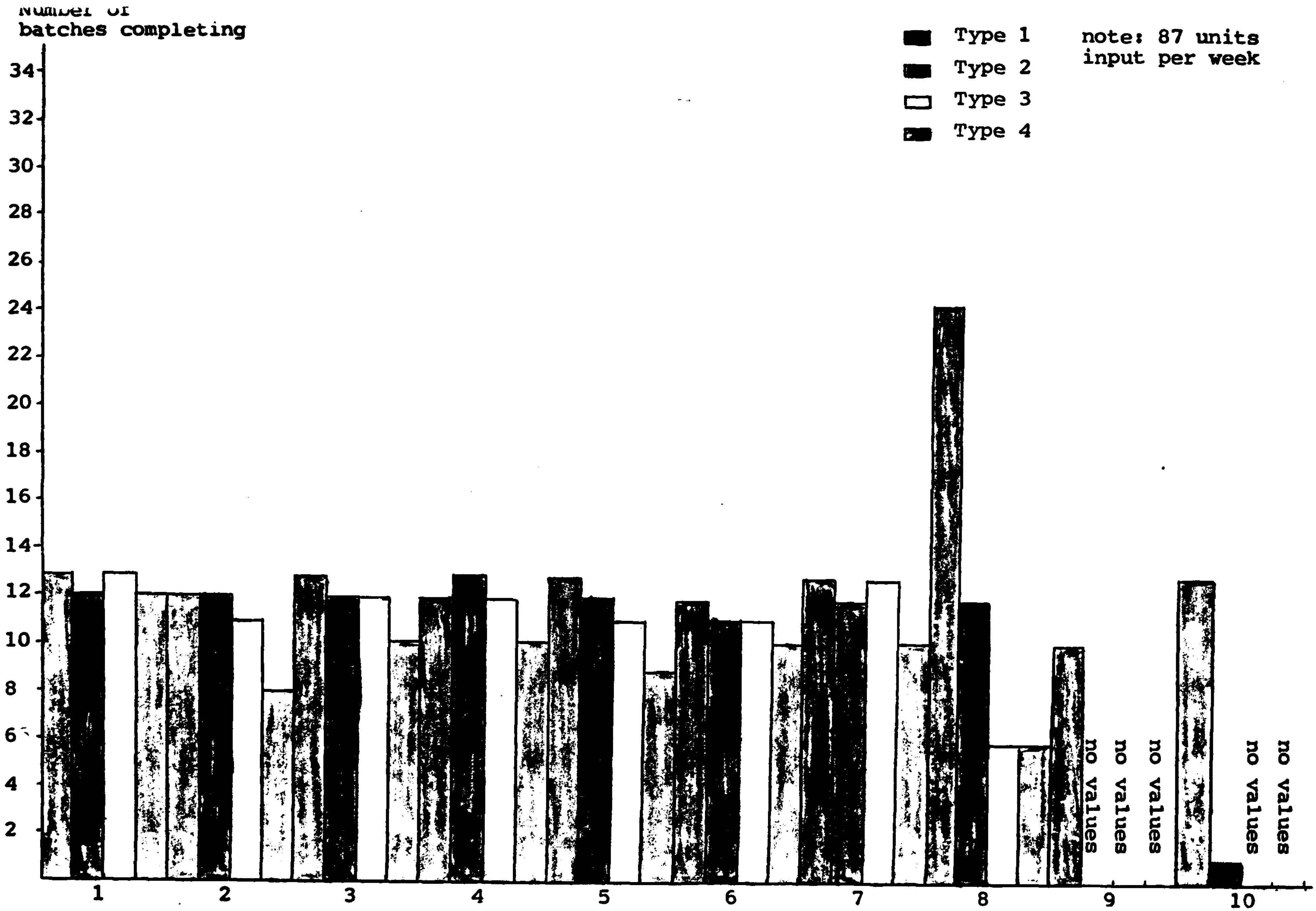


Fig. 5.4(a)

-Comparison of Number of Batches Completing-

5.6

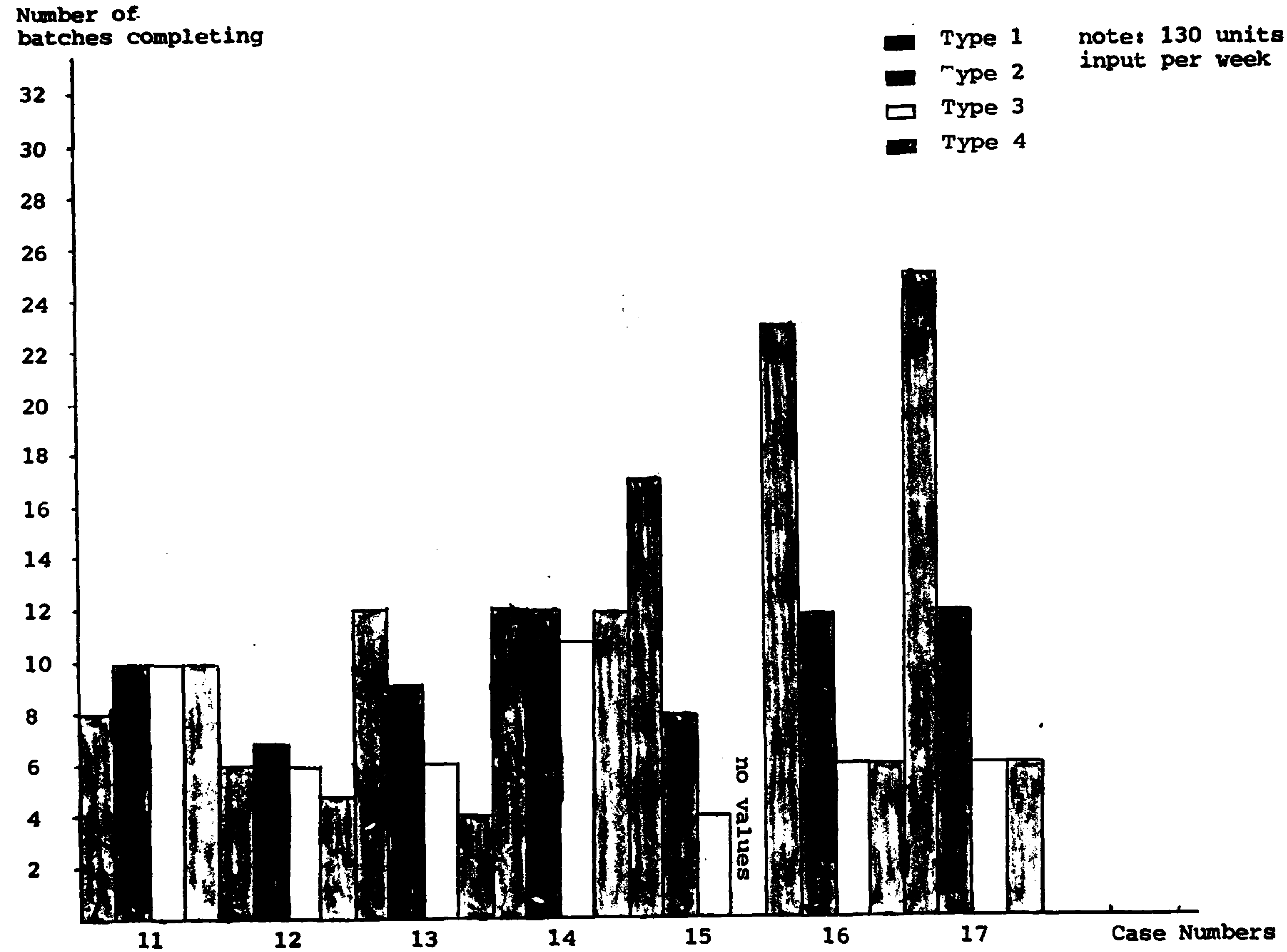


Fig. 5.4(b)
-Comparison of Number of Batches Completing-

5.7

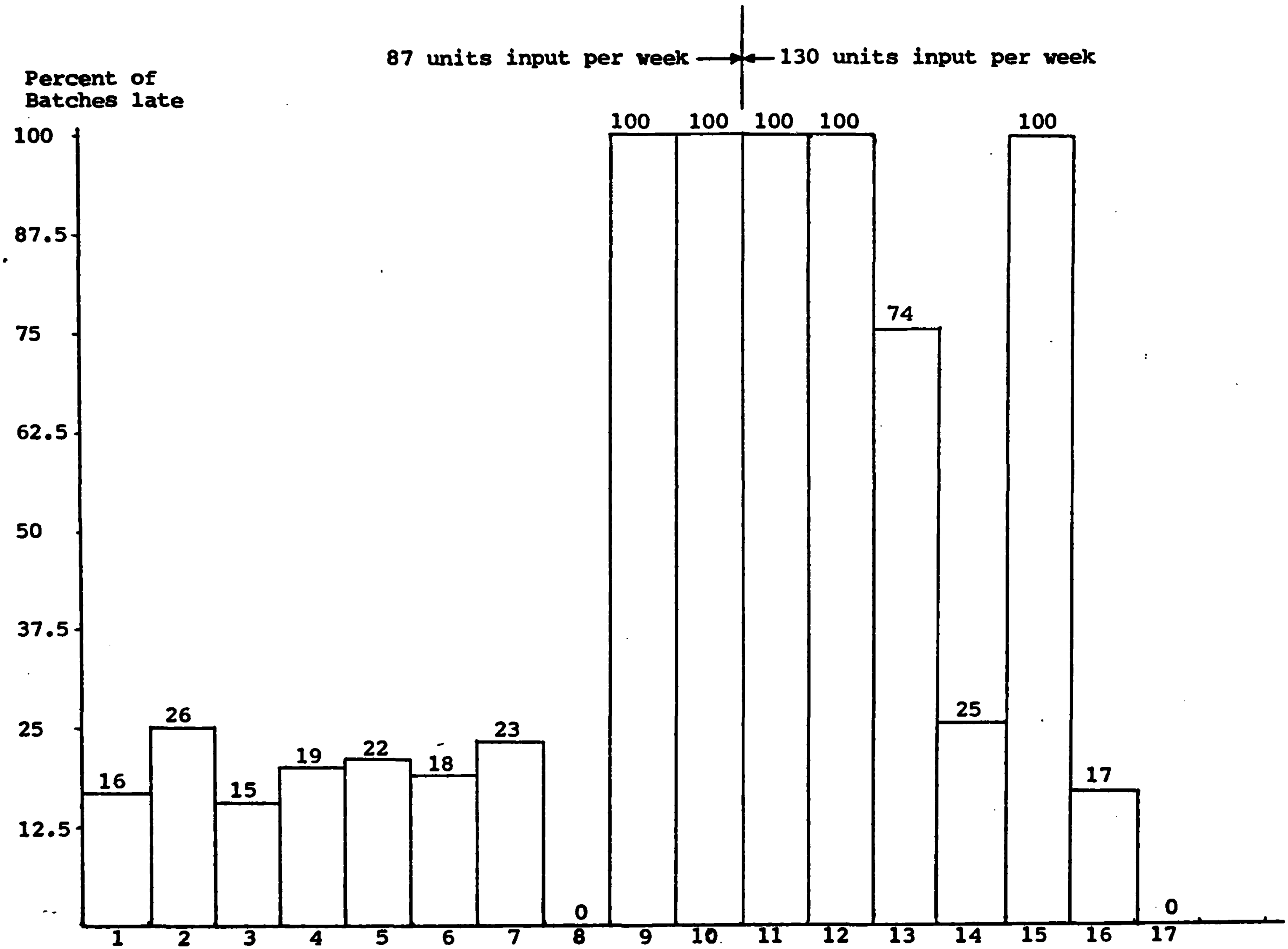


Fig. 5.5

-Comparison of Percent of Batches Late-

6.0 CONCLUSIONS AND RECOMMENDATIONS

At the onset of this project we were very concerned about the ability of the production process to produce at a high enough yield to be economically feasible. It was very disconcerting to have production steps with yields of 50%, 70%, and 75%. Even the welder, with a yield of 99%, seemed to be a problem since it was required 8 times in the process for a net yield of 92%. In fact we were very surprised when we ran the base case and discovered the overall process yield to be so high. The explanation for this was discussed in Section 4.3.1 and concerns the definition of the term yield as we report it and the conbination of yield and % repairable as initially developed with [redacted] for completing data input forms.

While the yields were higher than expected, the lead times were disappointing. Even with a 100% yield at each step of the process, a large percentage of Part Type 1 lots were finishing late. Likewise, when worker efficiency was raised to 100% the lead times still remained too high. A method of reducing lead times was found through the equalization of batch sizes. The concept of "processing batches" or the equalization of batch size input offer alternative methods of reducing lead time through reduction of batch sizes at individual queues (See Section 4.3.3 for further discussion). These methods prevent the large lot sizes from causing a bottleneck at one location while the subsequent location may be idle.

6.1 CONCLUSIONS/RECOMMENDATIONS when the line is operating with an input rate of approximately 85 units per week

1. Maintain batch integrity for repairables, i.e., Hold all lots until repair work catches up.

2. Use the critical ratio priority for selecting the next lot to be serviced from the queue

3. If [redacted] adopts its original policy and assumptions as detailed in Section 3.2, the following is anticipated:

Average Lead Time

Part Type	Batch Quantity	Lead Time Weeks
1	50	8.39
2	25	6.01
3	10	4.44
4	2	4.35

Overall average process yield is 79.06%.

3. If [redacted] hopes to produce 87 units per week according to the breakdown supplied, they will need to supply the following material to the system:

Material Requirements

Part Type	Output	Input
1	50	63
2	25	31
3	10	14
4	2	3

3. Batch Size:

Improved performance can be obtained through equalization of batch sizes. Depending upon the requirements for materials control, consideration should be given to the implementation of a processing batch system or a system which evens out the input batch size by combining small lots (run every other week) and splitting larger lots up into smaller jobs

4. Attempts to increase worker efficiency yields/% repairables at specific locations will not greatly improve throughput

6.2 CONCLUSIONS/RECOMMENDATIONS when the line is operating with an input rate of approximately 130 units per week

1. Maintain batch integrity for repairables

2. Use the critical ratio priority for selecting the next lot to be serviced

3. Batch Size: Depending upon the requirements for materials control, consider the implementation of a processing batch system or even out the input batch sizes

4. Attempts to increase worker efficiency or individual yields/% repairables will not greatly improve throughput

5. Using the results of our simulation scenarios combined with the costs of adding additional servers or running additional shifts, the following alternatives need to be examined:

a. Two shifts vs. additional facilities (Cleaning, Leak Test, Oil Fill, Bench Test) along with 2 shifts on the laser welder (See Section 4.4.4 and 4.4.5.2)

b. Decrease in the quoted lead time to six weeks

APPENDIX A

CASE RESULTS

APPENDIX A

Index To Case Numbers

Case 1: Base Case
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Case 17: Base case input increased by 50%, with equalization of batch size and 2 shifts for the entire line

PROCESSING PRIORITY RULES
(a) CASE 2: FIFO CASE

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	50	8.62	0.55	7.57	9.58	12	11
2	25	6.07	0.50	5.42	6.71	12	0
3	10	4.60	0.42	4.14	5.32	11	0
4	2	4.34	0.46	3.58	5.16	8	0

WEIGHTED AVERAGE 7.32

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	50	83.50	6.61
2	25	80.00	7.03
3	10	81.82	13.28
4	2	75.00	26.73

WEIGHTED AVERAGE 82.11

WAITING TIME

NODE NO	DESCRIPTION	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	1	5.09	8.59	66.47	40.72
12	LASER WELDER	1	13.77	16.01	70.41	110.16
13	LEAK TESTER	1	5.34	13.64	68.15	48.06
14	HEAT TREAT EQUIP	1	0.46	2.20	15.29	0.46
15	PRESS	1	0.76	6.61	63.77	1.52
16	ASSEMBLE	1	3.93	10.66	64.55	3.93
17	FIXTURE	1	0.71	2.27	15.36	0.71
18	FORMING EQUIP	1	0.01	0.05	0.27	0.01
19	ASSEMBLE	1	1.39	9.17	64.91	1.39
20	OIL FILL	2	3.60	14.61	72.70	3.60
21	ASSEMBLE	2	0.00	0.00	0.00	0.00
22	BENCH TEST	8	0.37	2.51	19.32	0.74
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	0.60	2.84	16.10	1.20
25	LASER TRIMMER	1	1.52	9.63	64.66	1.52
26	DRIFT RACK	1	0.07	0.44	2.86	0.07
5	COLLECTION NODE	1	4.93	17.22	138.70	78.88
	TOTAL					292.97

PROCESSING PRIORITY RULES
(b) CASE 3: CR WITH 2 SHIFTS ON LASER WELDER

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	50	8.13	0.65	7.47	9.46	13	7
2	25	5.67	0.71	4.57	6.61	12	0
3	10	4.07	0.44	3.33	4.75	12	0
4	2	3.75	0.48	3.28	4.33	10	0

WEIGHTED AVERAGE 6.85

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	50	82.31	5.94
2	25	81.33	3.94
3	10	77.50	14.22
4	2	65.00	24.15

WEIGHTED AVERAGE 81.08

WAITING TIME

NODE NO	DESCRIPT	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	1	2.80	5.12	22.30	22.40
12	LASER WELDER	1	1.66	1.96	11.28	13.28
13	LEAK TESTER	1	6.47	12.02	64.22	58.23
14	HEAT TREAT EQUIP	1	1.19	3.79	15.79	1.19
15	PRESS	1	0.08	0.17	0.67	0.16
16	ASSEMBLE	1	0.17	0.40	2.19	0.17
17	FIXTURE	1	0.85	3.19	15.76	0.85
18	FORMING EQUIP	1	0.01	0.04	0.31	0.01
19	ASSEMBLE	1	0.39	2.24	16.57	0.39
20	OIL FILL	2	7.89	22.66	100.30	7.89
21	ASSEMBLE	2	0.61	2.42	10.72	0.61
22	BENCH TEST	8	0.88	5.33	47.30	1.76
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	0.50	2.62	20.26	1.00
25	LASER TRIMMER	1	0.45	2.17	15.21	0.45
26	DRIFT RACK	1	0.00	0.00	0.00	0.00
5	COLLECTION NODE	1	3.31	14.14	139.80	52.96
	TOTAL					161.35

PROCESSING PRIORITY RULES
(c) CASE 4: FIFO CASE WITH 2 SHIFTS ON WELDER

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	50	8.61	1.04	7.44	11.33	12	9
2	25	5.92	0.57	4.71	6.48	13	0
3	10	4.27	0.55	3.43	5.17	12	0
4	2	4.12	0.41	3.29	4.43	10	0

WEIGHTED AVERAGE 7.23

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	50	85.50	7.04
2	25	80.00	8.33
3	10	73.33	11.55
4	2	80.00	25.82

WEIGHTED AVERAGE 82.39

WAITING TIME

NODE NO	DESCRIPTION	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	1	3.21	8.38	65.70	25.68
12	LASER WELDER	1	2.19	2.12	10.87	17.52
13	LEAK TESTER	1	8.64	12.43	64.58	77.76
14	HEAT TREAT EQUIP	1	0.43	2.20	15.29	0.43
15	PRESS	1	0.02	0.05	0.21	0.04
16	ASSEMBLE	1	5.53	17.86	64.58	5.53
17	FIXTURE	1	4.90	15.86	64.55	4.90
18	FORMING EQUIP	1	0.08	0.29	1.57	0.08
19	ASSEMBLE	1	0.74	3.26	17.47	0.74
20	OIL FILL	2	6.68	19.80	89.99	6.68
21	ASSEMBLE	2	0.53	2.16	10.54	0.53
22	BENCH TEST	8	2.28	8.61	67.60	4.56
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	0.51	2.46	17.24	1.02
25	LASER TRIMMER	1	0.12	5.17	3.35	0.12
26	DRIFT RACK	1	2.53	12.29	80.19	2.53
5	COLLECTION NODE	1	4.67	19.25	143.30	74.72
	TOTAL					222.84

CASE 5: YIELD IMPROVEMENT
TO 90% AT STEP 43 (BENCH TEST)

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF COMPLETE	LOTS LATE
1	50	9.30	1.24	7.61	11.30	13	10
2	25	6.67	0.59	5.60	7.74	12	0
3	10	5.22	0.75	4.31	6.43	11	0
4	2	4.75	0.56	4.15	5.59	9	0

WEIGHTED AVERAGE 7.97

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	50	85.23	6.19
2	25	82.33	7.71
3	10	73.64	11.20
4	2	61.11	22.05

WEIGHTED AVERAGE 82.51

WAITING TIME

NODE NO	DESCRIPT	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	1	5.78	14.29	71.51	46.24
12	LASER WELDER	1	10.34	18.82	159.90	82.72
13	LEAK TESTER	1	4.36	11.70	89.44	39.24
14	HEAT TREAT EQUIP	1	0.47	2.20	15.17	0.47
15	PRESS	1	0.24	1.69	16.27	0.48
16	ASSEMBLE	1	1.77	9.70	65.03	1.77
17	FIXTURE	1	0.08	0.23	1.24	0.08
18	FORMING EQUIP	1	0.33	2.13	15.36	0.33
19	ASSEMBLE	1	0.09	0.26	1.02	0.09
20	OIL FILL	2	0.34	12.18	71.85	0.34
21	ASSEMBLE	2	1.02	3.83	18.61	1.02
22	BENCH TEST	8	12.28	32.92	282.50	24.56
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	1.39	7.09	64.02	2.78
25	LASER TRIMMER	1	0.17	0.37	1.44	0.17
26	DRIFT RACK	1	10.28	25.53	118.50	10.28
5	COLLECTION NODE	1	3.76	15.73	140.80	60.16
	TOTAL					270.73

CASE 6: YIELD IMPROVEMENT TO 90%
AT NGT COMPUTER (STEPS 41 & 47)

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	50	8.28	0.52	7.59	9.14	12	8
2	25	6.16	0.50	5.45	7.19	11	0
3	10	4.86	0.65	3.76	5.61	11	0
4	2	4.27	0.56	3.31	5.16	10	0

WEIGHTED AVERAGE 7.19

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	50	83.17	6.12
2	25	83.27	7.12
3	10	67.27	19.54
4	2	75.00	26.35

WEIGHTED AVERAGE 81.18

WAITING TIME

NODE NO	DESCRIPT	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	1	3.81	9.70	90.35	30.48
12	LASER WELDER	1	17.74	36.08	340.80	141.92
13	LEAK TESTER	1	4.30	11.77	89.04	38.70
14	HEAT TREAT EQUIP	1	0.13	0.27	0.90	0.13
15	PRESS	1	0.07	0.18	1.04	0.14
16	ASSEMBLE	1	0.38	2.24	15.66	0.38
17	FIXTURE	1	0.06	0.17	0.79	0.06
18	FORMING EQUIP	1	0.02	0.08	0.52	0.02
19	ASSEMBLE	1	0.30	0.64	2.38	0.30
20	OIL FILL	2	0.70	20.07	94.17	0.70
21	ASSEMBLE	2	0.12	0.51	2.82	0.12
22	BENCH TEST	8	0.94	6.36	65.31	1.88
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	0.29	1.76	17.16	0.58
25	LASER TRIMMER	1	0.51	2.45	27.15	0.51
26	DRIFT RACK	1	0.00	0.00	0.00	0.00
5	COLLECTION NODE	1	2.98	11.11	95.63	47.68
	TOTAL					263.60

CASE 7: 100% LABOR EFFICIENCY CASE

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	50	8.57	0.94	6.44	10.29	13	11
2	25	6.47	0.85	4.44	7.60	12	0
3	10	5.07	0.76	4.30	6.61	13	0
4	2	4.60	0.71	3.58	5.44	10	0

WEIGHTED AVERAGE 7.47

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	50	82.77	4.87
2	25	81.67	5.24
3	10	73.85	20.63
4	2	75.00	26.35

WEIGHTED AVERAGE 81.25

WAITING TIME

NODE NO	DESCRIPT	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	1	2.91	7.51	70.73	23.28
12	LASER WELDER	1	12.03	25.68	261.00	96.24
13	LEAK TESTER	1	3.91	9.31	70.63	35.19
14	HEAT TREAT EQUIP	1	0.12	0.26	1.32	0.12
15	PRESS	1	0.52	2.74	15.80	1.04
16	ASSEMBLE	1	0.06	0.19	1.01	0.06
17	FIXTURE	1	0.08	0.34	2.21	0.08
18	FORMING EQUIP	1	0.04	0.16	0.83	0.04
19	ASSEMBLE	1	0.17	0.54	3.28	0.17
20	OIL FILL	2	6.99	19.48	88.07	6.99
21	ASSEMBLE	2	1.86	9.90	66.88	1.86
22	BENCH TEST	8	4.70	16.85	101.60	9.40
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	0.50	2.27	15.90	1.00
25	LASER TRIMMER	1	0.06	0.26	1.30	0.06
26	DRIFT RACK	1	3.30	17.01	113.00	3.30
5	COLLECTION NODE	1	6.81	20.97	163.20	108.96
	TOTAL					287.79

CASE 8: EQUALIZATION OF BATCH SIZES

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	25	5.63	0.99	4.43	7.71	24	0
2	25	5.98	0.83	4.57	7.46	12	0
3	20	5.28	0.78	4.43	6.46	6	0
4	4	4.27	0.76	3.29	5.17	6	0

WEIGHTED AVERAGE 5.58

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	25	80.00	10.86
2	25	79.67	6.26
3	20	71.67	14.02
4	4	54.17	24.58

WEIGHTED AVERAGE 76.24

WAITING TIME

NODE NO	DESCRIPT	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	1	1.45	6.88	64.70	11.60
12	LASER WELDER	1	6.02	12.51	115.30	48.16
13	LEAK TESTER	1	2.72	9.25	67.74	24.48
14	HEAT TREAT EQUIP	1	0.71	3.11	15.48	0.71
15	PRESS	1	0.03	0.15	1.36	0.06
16	ASSEMBLE	1	0.05	0.19	1.26	0.05
17	FIXTURE	1	0.05	0.19	1.26	0.05
18	FORMING EQUIP	1	1.10	8.24	63.27	1.10
19	ASSEMBLE	1	0.17	0.45	2.75	0.17
20	OIL FILL	2	5.72	15.87	88.52	5.72
21	ASSEMBLE	2	0.00	0.00	0.00	0.00
22	BENCH TEST	8	8.67	25.79	145.30	17.34
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	0.45	2.16	15.60	0.90
25	LASER TRIMMER	1	1.84	9.52	66.28	1.84
26	DRIFT RACK	1	3.11	13.51	89.46	3.11
5	COLLECTION NODE	1	4.72	15.13	120.00	75.52
	TOTAL					190.81

CASE 9: BASE CASE WITH
4 BENCH TEST FACILITIES (24 WEEKS)

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	50	12.08	1.55	9.32	13.72	10	10
2	25	-	-	-	-	0	
3	10	-	-	-	-	0	
4	2	-	-	-	-	0	

WEIGHTED AVERAGE 6.94

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	50	83.40	11.08
2	25	-	-
3	10	-	-
4	2	-	-

WEIGHTED AVERAGE 47.93

WAITING TIME

NODE NO	DESCRIPT	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	1	3.68	8.55	0.00	71.32
12	LASER WELDER	1	9.66	16.71	0.00	96.10
13	LEAK TESTER	1	2.73	6.83	0.00	68.10
14	HEAT TREAT EQUIP	1	0.77	3.14	0.00	15.79
15	PRESS	1	0.21	1.57	0.00	15.34
16	ASSEMBLE	1	1.42	9.31	0.00	63.86
17	FIXTURE	1	0.08	0.24	0.00	1.23
18	FORMING EQUIP	1	0.01	0.05	0.00	0.32
19	ASSEMBLE	1	0.04	0.31	0.00	2.15
20	OIL FILL	2	4.19	16.19	0.00	69.45
21	ASSEMBLE	2	0.02	0.18	0.00	1.22
22	BENCH TEST	4	115.40	120.50	0.00	503.30
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	0.04	0.17	0.00	0.83
25	LASER TRIMMER	1	0.04	0.13	0.00	0.45
26	DRIFT RACK	1	2.16	6.83	0.00	21.61
5	COLLECTION NODE	1	6.03	11.08	0.00	359.10
	TOTAL					1290.17

CASE 10: BASE CASE WITH
4 BENCH TEST FACILITIES (36 WEEKS)

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	50	13.80	2.56	9.72	17.60	13	13
2	25	11.76	0.00	11.76	11.76	1	1
3	10	-	-	-	-	0	
4	2	-	-	-	-	0	

WEIGHTED AVERAGE 11.31

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	50	80.92	11.82
2	25	80.00	0.00
3	10	-	-
4	2	-	-

WEIGHTED AVERAGE 69.49

WAITING TIME

NODE NO	DESCRIPT	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	1	4.72	11.86	0.00	71.89
12	LASER WELDER	1	12.04	22.89	0.00	161.90
13	LEAK TESTER	1	4.31	10.08	0.00	66.57
14	HEAT TREAT EQUIP	1	0.46	2.28	0.00	15.80
15	PRESS	1	0.19	1.62	0.00	15.78
16	ASSEMBLE	1	0.05	0.17	0.00	0.92
17	FIXTURE	1	0.08	0.36	0.00	2.14
18	FORMING EQUIP	1	0.03	0.11	0.00	0.72
19	ASSEMBLE	1	0.28	0.78	0.00	4.12
20	OIL FILL	2	15.34	30.24	0.00	114.90
21	ASSEMBLE	2	3.26	14.14	0.00	70.24
22	BENCH TEST	4	166.80	229.40	0.00	1055.00
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	0.87	3.80	0.00	17.45
25	LASER TRIMMER	1	0.07	0.23	0.00	0.81
26	DRIFT RACK	1	14.06	44.47	0.00	140.60
5	COLLECTION NODE	1	6.03	28.57	0.00	434.30
	TOTAL					2173.14

CASE 11: BASE CASE INPUT INCREASED BY 50%
1 SHIFTS FOR THE ENTIRE LINE

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	75	15.50	1.58	12.76	17.33	8	8
2	37	12.23	1.50	10.46	15.14	10	10
3	15	10.61	0.94	9.43	11.75	10	10
4	3	10.23	0.65	9.29	11.32	10	10

WEIGHTED AVERAGE 13.88

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	75	81.00	6.44
2	37	78.92	13.35
3	15	80.00	19.37
4	3	60.00	26.29

WEIGHTED AVERAGE 79.81

WAITING TIME

NODE NO	DESCRIPT	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	1	128.00	292.20	1275.00	1024.00
12	LASER WELDER	1	14.70	26.15	149.10	117.60
13	LEAK TESTER	1	8.29	18.21	118.80	74.61
14	HEAT TREAT EQUIP	1	0.50	2.69	15.24	0.50
15	PRESS	1	0.03	0.12	0.69	0.06
16	ASSEMBLE	1	0.24	0.60	3.02	0.24
17	FIXTURE	1	0.74	2.68	16.02	0.74
18	FORMING EQUIP	1	0.03	0.12	0.71	0.03
19	ASSEMBLE	1	0.85	2.80	16.62	0.85
20	OIL FILL	2	39.57	61.54	238.50	39.57
21	ASSEMBLE	2	1.42	5.07	22.83	1.42
22	BENCH TEST	8	7.04	16.89	94.72	14.08
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	0.66	2.34	17.26	1.32
25	LASER TRIMMER	1	0.18	0.78	4.04	0.18
26	DRIFT RACK	1	19.23	38.62	139.20	19.23
5	COLLECTION NODE	1	9.09	29.63	191.80	145.36
	TOTAL					1439.79

CASE 12: INPUT INCREASED BY 50%,
EXTRA FACILITY AT CLEANING EQUIP.

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	75	15.42	2.00	12.46	18.46	6	6
2	37	11.48	1.01	9.71	12.58	7	7
3	15	9.30	0.35	8.62	9.58	6	6
4	3	10.52	0.95	9.44	6.36	5	5

WEIGHTED AVERAGE 13.48

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	75	84.44	5.82
2	37	88.03	8.67
3	15	75.56	10.89
4	3	53.33	29.81

WEIGHTED AVERAGE 83.72

WAITING TIME

NODE NO	DESCRIPT	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	2	3.49	9.21	64.28	27.92
12	LASER WELDER	1	45.60	99.89	916.60	364.80
13	LEAK TESTER	1	14.02	28.99	215.10	126.18
14	HEAT TREAT EQUIP	1	0.05	0.16	0.83	0.05
15	PRESS	1	1.15	7.69	64.00	2.30
16	ASSEMBLE	1	1.83	10.67	64.06	1.83
17	FIXTURE	1	0.11	0.38	2.01	0.11
18	FORMING EQUIP	1	0.05	0.22	1.26	0.05
19	ASSEMBLE	1	0.15	0.46	2.20	0.15
20	OIL FILL	2	84.57	128.60	599.40	84.57
21	ASSEMBLE	2	0.82	3.50	19.88	0.82
22	BENCH TEST	8	64.57	115.20	692.40	129.14
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	0.87	3.16	17.39	1.74
25	LASER TRIMMER	1	2.79	11.99	65.80	2.79
26	DRIFT RACK	1	4.44	13.75	52.28	4.44
5	COLLECTION NODE	1	11.95	43.20	337.00	191.20
	TOTAL					938.09

CASE 13: INPUT INCREASED BY 50%,2 SHIFTS
ON LASER WELDER AND EXTRA FACILITIES
AT CLEANING EQUIP., OIL FILL AND BENCH TEST

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	75	13.06	0.90	11.71	14.19	12	12
2	37	9.56	1.06	8.18	11.18	9	9
3	15	7.58	1.15	6.33	9.46	6	2
4	3	6.29	0.68	5.31	6.76	4	0

WEIGHTED AVERAGE 11.28

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	75	81.33	6.85
2	37	78.38	8.55
3	15	91.11	5.44
4	3	66.67	38.49

WEIGHTED AVERAGE 81.28

WAITING TIME

NODE NO	DESCRIPT	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	2	5.60	14.88	97.97	44.80
12	LASER WELDER	1	4.26	8.59	80.90	34.08
13	LEAK TESTER	1	39.37	101.60	1250.00	354.33
14	HEAT TREAT EQUIP	1	0.40	2.35	16.27	0.40
15	PRESS	1	0.09	0.36	2.19	0.18
16	ASSEMBLE	1	0.83	3.33	16.02	0.83
17	FIXTURE	1	1.10	3.59	17.04	1.10
18	FORMING EQUIP	1	0.00	0.00	0.00	0.00
19	ASSEMBLE	1	0.18	0.73	4.25	0.18
20	OIL FILL	3	0.47	2.82	17.64	0.47
21	ASSEMBLE	2	0.81	3.74	20.92	0.81
22	BENCH TEST	12	0.00	0.00	0.00	0.00
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	1.17	7.72	64.93	2.34
25	LASER TRIMMER	1	1.82	10.74	65.36	1.82
26	DRIFT RACK	1	9.29	22.55	77.64	9.29
5	COLLECTION NODE	1	7.14	26.50	185.00	114.24
	TOTAL					564.87

CASE 14: INPUT INCREASED BY 50%,2 SHIFTS ON LASER WELDER AND EXTRA FACILITIES AT CLEANING EQUIP., LEAK TESTER, OIL FILL AND BENCH TEST

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	75	11.87	0.91	10.61	13.18	12	12
2	37	6.98	0.38	6.33	7.47	12	0
3	15	4.58	0.33	4.16	5.18	11	0
4	3	3.97	0.47	3.29	4.73	12	0

WEIGHTED AVERAGE 9.45

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	75	82.89	6.68
2	37	79.73	4.96
3	15	76.97	10.90
4	3	75.00	25.13

WEIGHTED AVERAGE 81.13

WAITING TIME

NODE NO	DESCRIPT	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	2	3.67	7.75	64.57	29.36
12	LASER WELDER	1	4.59	8.70	66.98	36.72
13	LEAK TESTER	2	4.46	10.83	62.99	40.14
14	HEAT TREAT EQUIP	1	0.22	0.63	3.09	0.22
15	PRESS	1	0.10	0.31	2.24	0.20
16	ASSEMBLE	1	0.12	0.36	1.71	0.12
17	FIXTURE	1	1.07	3.52	17.41	1.07
18	FORMING EQUIP	1	0.07	0.24	1.26	0.07
19	ASSEMBLE	1	0.82	3.40	18.25	0.82
20	OIL FILL	3	4.74	16.52	90.95	4.74
21	ASSEMBLE	2	0.59	1.54	12.48	0.59
22	BENCH TEST	12	0.26	2.45	25.21	0.52
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	1.62	7.62	66.13	3.24
25	LASER TRIMMER	1	3.20	13.00	66.75	3.20
26	DRIFT RACK	1	8.39	27.75	141.20	8.39
5	COLLECTION NODE	1	5.88	23.27	184.80	94.05
	TOTAL					223.45

CASE 15: BASE CASE INPUT INCREASED BY 50%
EQUALIZATION OF BATCH SIZES,1 SHIFT FOR THE ENTIRE LINE
NO EXTRA SERVERS

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	75	11.14	1.30	8.75	13.57	17	17
2	37	11.57	1.08	9.75	12.57	8	8
3	15	10.37	0.07	10.30	10.43	4	4
4	3	-	-	-	-	0	-

WEIGHTED AVERAGE 10.91

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	75	76.99	15.67
2	37	78.38	14.01
3	15	81.67	3.33
4	3	-	-

WEIGHTED AVERAGE 76.15

WAITING TIME

NODE NO	DESCRIPT	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	1	16.82	38.82	429.60	134.56
12	LASER WELDER	1	47.54	172.10	2273.00	380.32
13	LEAK TESTER	1	5.84	19.00	260.50	52.56
14	HEAT TREAT EQUIP	1	0.07	0.36	1.80	0.07
15	PRESS	1	0.02	0.10	0.60	0.04
16	ASSEMBLE	1	0.00	0.00	0.00	0.00
17	FIXTURE	1	0.00	0.00	0.00	0.00
18	FORMING EQUIP	1	0.01	0.09	0.56	0.01
19	ASSEMBLE	1	0.08	0.30	1.52	0.08
20	OIL FILL	2	3.41	12.28	72.61	3.41
21	ASSEMBLE	2	0.02	0.11	0.64	0.02
22	BENCH TEST	8	36.31	54.80	330.80	72.62
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	0.72	2.93	16.75	1.44
25	LASER TRIMMER	1	0.19	0.63	2.70	0.19
26	DRIFT RACK	1	8.04	24.72	113.80	8.04
5	COLLECTION NODE	1	8.38	26.15	264.60	134.08
	TOTAL					787.44

CASE 16: INPUT INCREASED BY 50% WITH EQUALIZATION OF BATCH SIZE
2 SHIFTS AT LASER WELDER AND EXTRA FACILITIES
AT CLEANING EQUIP., LEAK TESTER, OIL FILL AND BENCH TEST

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	38	7.32	0.98	5.71	9.15	23	8
2	37	7.01	0.58	5.71	7.73	12	0
3	30	6.47	0.39	6.15	7.18	6	0
4	6	4.24	0.35	3.71	4.76	6	0

WEIGHTED AVERAGE 6.82

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	38	81.02	5.59
2	37	79.05	9.58
3	30	82.78	8.28
4	6	72.22	20.18

WEIGHTED AVERAGE 80.36

WAITING TIME

NODE NO	DESCRIPT	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	2	0.74	1.90	16.56	5.92
12	LASER WELDER	1	2.69	3.77	34.13	21.52
13	LEAK TESTER	2	3.87	7.29	62.83	34.83
14	HEAT TREAT EQUIP	1	0.33	0.72	3.63	0.33
15	PRESS	1	0.04	0.14	0.74	0.08
16	ASSEMBLE	1	1.49	9.34	64.14	1.49
17	FIXTURE	1	0.03	0.08	0.33	0.03
18	FORMING EQUIP	1	0.04	0.13	0.71	0.04
19	ASSEMBLE	1	1.22	4.07	16.49	1.22
20	OIL FILL	3	0.38	2.47	18.99	0.38
21	ASSEMBLE	2	3.06	12.73	63.89	3.06
22	BENCH TEST	12	0.12	1.16	16.26	0.24
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	0.62	2.46	16.73	1.24
25	LASER TRIMMER	1	0.74	3.06	15.74	0.74
26	DRIFT RACK	1	5.98	18.37	93.43	5.98
5	COLLECTION NODE	1	11.60	23.80	141.10	185.60
	TOTAL					262.70

CASE 17: INPUT INCREASED BY 50%
EQUALIZATION OF BATCH SIZES AND
2 SHIFT FOR THE ENTIRE LINE

LEAD TIME

PART TYPE	BATCH QUANTITY	AVERAGE WEEKS	STANDARD DEVIATION	MINIMUM WEEKS	MAXIMUM WEEKS	NUMBER OF LOTS COMPLETE	LATE
1	38	4.59	0.46	3.52	5.57	25	0
2	37	4.69	0.32	4.37	5.20	12	0
3	30	4.48	0.37	4.19	5.20	6	0
4	6	3.19	0.03	3.14	3.22	6	0

WEIGHTED AVERAGE 4.51

YIELDS

PART TYPE	BATCH QUANTITY	AVERAGE YIELD %	STANDARD DEVIATION
1	38	81.02	7.42
2	37	81.98	5.68
3	30	86.11	6.47
4	6	72.22	22.77

WEIGHTED AVERAGE 82.25

WAITING TIME

NODE NO	DESCRIPT.	NO. OF FACILITIES	AVERAGE TIME HRS	STANDARD DEVIATION	MAXIMUM TIME HRS	TOTAL TIME
11	CLEANING EQUIP	1	1.63	3.11	26.00	13.04
12	LASER WELDER	1	1.63	3.44	22.11	13.04
13	LEAK TESTER	1	0.54	1.37	11.04	4.86
14	HEAT TREAT EQUIP	1	0.18	0.34	1.21	0.18
15	PRESS	1	0.25	1.06	7.46	0.50
16	ASSEMBLE	1	0.05	0.22	1.22	0.05
17	FIXTURE	1	0.05	0.22	1.22	0.05
18	FORMING EQUIP	1	0.04	0.14	0.75	0.04
19	ASSEMBLE	1	0.26	1.20	8.40	0.26
20	OIL FILL	2	11.83	24.05	80.32	11.83
21	ASSEMBLE	2	0.06	0.32	2.11	0.06
22	BENCH TEST	8	.00	0.04	0.52	.00
23	OVEN	6	0.00	0.00	0.00	0.00
24	NGT COMPUTER	1	0.09	0.36	2.76	0.18
25	LASER TRIMMER	1	0.42	1.41	8.37	0.42
26	DRIFT RACK	1	13.65	33.74	143.90	13.65
5	COLLECTION NODE	1	5.91	12.82	87.68	94.48
	TOTAL					152.64

APPENDIX B

SAMPLE INPUT

1) SAMPLE DATA FORMS

2) SAMPLE DATA FILES - Copies of computer input files are included under separate cover.

PROCESS SEQUENCE

STEP # : 030

DESCRIPTION: LEAK CHECK PUMP & DIAPHRAGM

			FIXED TIME	UNIT TIME	
RESOURCES USED	1.)	MAN	5	2	(020)
	2.)	MACH	5	2	(100)

REPAIR TYPE: REINSERT AFTER BEFORE OPER 020 (CIRCLE ONE)

P/N	YIELD FACTOR	FRACTION REPAIRABLE	REPAIR TIME
0-4	.98	.50	20
5-9			
10-14			
15-20			

SPECIAL LIMITATIONS

1. PROCESS CANNOT START UNLESS FINISHABLE IN SAME SHIFT ____________

2. OTHER (SPECIFY)

3. REJECTS REINSERTED AHEAD OF OPER 020

PROCESS SEQUENCE

STEP # : 040

DESCRIPTION: HEAT TREAT PUMP & DIAPHRAGM

RESOURCES USED			FIXED TIME	UNIT TIME	
	1.)	MAN	10	1	(030)
	2.)	MACH	10	1	(180)

REPAIR TYPE: REINSERT AFTER BEFORE (CIRCLE ONE)

P/N	YIELD FACTOR	FRACTION REPAIRABLE	REPAIR TIME
0-4	100 %		
5-9			
10-14			
15-20			

SPECIAL LIMITATIONS

1. PROCESS CANNOT START UNLESS FINISHABLE IN SAME SHIFT

2. OTHER (SPECIFY)

APPENDIX C

SAMPLE OUTPUT

COPIES OF SAMPLE OUTPUT ARE INCLUDED UNDER SEPARATE COVER.

APPENDIX D

PROGRAM LISTING IS INCLUDED UNDER SEPARATE COVER.

END

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9-85

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