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USING SIMULATION TO SUPPORT IMPLEMENTATION OF FLEXIBLE MANUFACTURING CELL

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ABSTRACT

A simulation model was developed and tested using Taylor II to justify the implementation of a Flexible Manufacturing Cell (FMC). The current production capacity at the existing Continuous Flow (CF) assembly line must be increased and among other proposals, a FMC is highly recommended. Simulation models are developed, tested, verified, and the model sensitivity is evaluated. The simulation models provide valuable information about performance parameters, critical elements, and bottlenecks that may appear when the line capacities have been altered. Manufacturing line evaluation and assessment of the improvements from one layout to the other is accomplished by tracking performance parameters such as lead-time, throughput, work-in process, and resource utilization. The simulation models resulted in a more in-depth understanding of manufacturing parameters and clear understanding of the improvements achieved by switching to FMC. The FMC model showed a reduction in production lead-time, average WIP, the burn-in capacity, and the number of operators required.

1 INTRODUCTION

Today's manufacturing industry is facing problems that have been growing in size and complexity over the last several years. As a result, there is an immediate need for procedures or techniques in solving various problems encountered in today's manufacturing arena without extended shutdowns or expensive modifications (Clark 1996). Computer simulation is a powerful tool that allows experimentation with various manufacturing techniques and layouts without actual implementation.

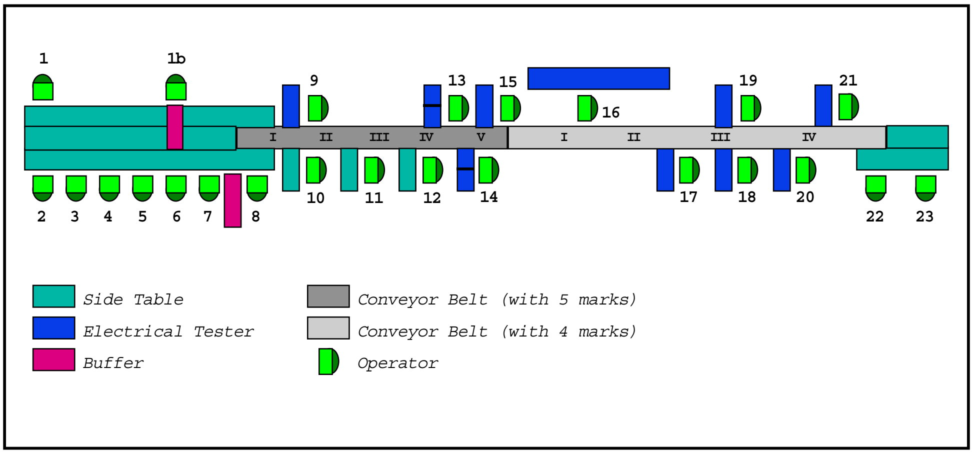
Application of simulation for solving manufacturing problems has been the cornerstone of the industry. Continuous flow assembly lines are most commonly used for mass production manufacturing, in which the processing and assembly workstations are placed along the product flow-line. With emphasis on reducing setup and flow times, inventory, and lead-time among other things, more companies are considering FMC as an alternative. FMC is composed of several workstations where similar parts from a family of parts are processed.

A discrete event system represented by either stochastic or deterministic models capable of simulating machine or workstation production on existing and new products and evaluating the performance measures related to the manufacturing goals of the company was developed. The model could be utilized for optimizing performance parameters and is capable of predicting systems performance resulting from interactions among system components and changes in the key parameters.

2 CONTINUOUS FLOW ASSEMBLY

Continuous Flow Assembly (CFA) Processes are most commonly used in assembly line production. With this type of layout, the processing and assembly workstations are placed along the flow-line of the product (Figure 1). The Work-In-Process is moved by conveyor or similar means from one workstation to the next. The product is progressively fabricated as it flows through the sequence of workstations.

An electronic device is manufactured in the Continuous Flow Assembly line shown in Figure 1. The electronic device is then inspected for performance specification and required physical finish. The model performance parameters include Throughput, Resource Utilization, In-Process Inventory, Lead-times, Travel Distances, and Percent Defects. These performance parameters could fully characterize the manufacturing operation (Farahmand 1994).



1. Manual Assembly #1
1b. Manual Assembly #1b
2. Manual Assembly #2
3. Manual Assembly #3
4. Manual Assembly #4
5. Manual Assembly #5
6. Manual Assembly #6
7. llumination Inspection
8. Visual Process Inspection
9. Electrical Repairing
10. Mechanical Repairing
11. Pre-Test
12. Cover Assembly
13. Parametric Tester #1 & #2
14. Parametric Tester #3 & #4
15. Parametric Tester #5
16. Burn-in Rack
17. & 18. Customer Check #1, #2
19. & 20. Customer Check #3, #4
21. Memory Verification
22. Final Inspection
23. Packing

Figure 1: Continuous Flow Assembly Layout

2.1 Description of the CFA Operations

2.1.1 Manual Assembly

Operations 1 to 8 are performed one after the other. Operation 1b feeds directly to operation 6 through a buffer. These eight positions are synchronized by green light bulbs which flash every 38 seconds and remain “ON” (to signal the operators to pass the product to the next position) for 2 seconds before the assembly begins.

2.1.2 Illumination & Visual Process Inspections

Illumination Inspection must detect any possible light leakage on the product’s trim plate, and inspect the process for poor assembly or possible missing or loose screws. For each position a certification is required.

2.1.3 Pre-Test

A final tuning of the product is performed before the encapsulation process is complete. Again a certified operator must perform this task.

2.1.4 Cover Assembly

At this position the operator places the top lid on the product to complete its mechanical assembly and place it in the next immediate available conveyor.

2.1.5 Parametric Testers

At this operation, a series of electrical tests are performed on the product, all controlled by a computer. The operator loads and unloads the product on the test fixture, and does some manual operations over the product guided by the computer via the monitor screen.

2.1.6 Burn-in Rack

It is a rack with capacity to hold up to 108 products. Each product will have to remain on the rack at least 60 minutes. One operator is in charge of placing the products on the rack and back on the conveyor after the 60-minutes cycle is over.

2.1.7 Customer Checks

At this position the operator performs a functional testing of the product. Because of the importance of this final functionality inspection, the operators must be fully trained and certified.

2.1.8 Memory Verification

At this operation a final memory verification of the product is performed via a computer.

2.1.9 Final Inspection

A final visual inspection of the product is performed by visual inspection.

2.1.10 Packing

The finished product is enclosed in a bag and placed in a box.

2.1.11 Electrical & Mechanical Repairing

Is in charge of any mechanical or electrical repairs.

3 CFA SIMULATION MODEL

As part of the model verification process, a simulation model was developed for the CFA process and the results of the simulation were compared to the actual production data. The focus parameters include WIP, throughput, lead-time, and machine utilization. These performance parameters proved critical in previous studies by Farahmand and Heemsbergen (1994) and Farahmand (1997) in manufacturing environment. The time study measurements are collected for all operations including the loading and unloading the product from the conveyor on to the fixture and back. The average operation times are used for the simulation model.

3.1 Work-In-Process (WIP)

Figure 2 shows the WIP inventory on the manufacturing line at different times (every half-hour) during the entire shift. The 1st proposal behaves very similarly to the current layout model (on its shape and trend), but with a much higher WIP (almost 40 pieces more on the average). This is basically because of the added stations to speed up the process and increase the capacity.

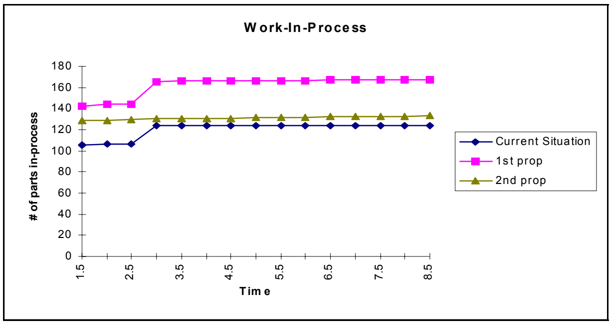


Figure 2: WIP Plotted Against Operation Times

The 2nd proposal shows a pretty stable WIP inventory levels after 1.5 hours of running the process. The WIP inventory levels are less even though the production capacities are much larger (almost 40 % more). The two contributing factors are: (1) the number of parametric testers were not increased, (2) the burn-in time was reduced to 45 minutes which decreased the number of products loaded onto the burn-in racks at this station significantly. The time spent by the products on the burn-in racks must be reduced as the process cycle time is increased.

3.2 Throughput (Production Rate in Pieces/Hour)

Figure 3 compares the simulation results for the proposal #1 and # 2 against the current layout. Both proposals generate the same production output. Naturally, this production rate is higher than the current layout production in order to achieve a higher capacity. It is also important to notice that the different number of workstations used in the two different proposals do not affect the production rates significantly.

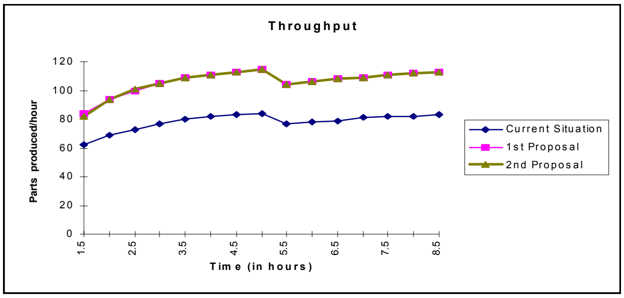


Figure 3: Throughput (production/hour) Results

3.3 Lead-Time

Figure 4 shows the results obtained from the simulation model for the proposal #1 and #2 along with the current layout. The peaks observed on the 1st and 2nd proposal lead-time curves are due to the 90% quality requirements (parts being sent back to repair station) applied to these two scenarios. For the current layout lead-time curve these peaks were erased to have a better visualization of the two curves under study. The curves for all three scenarios follow the same shape, but the 1st and 2nd proposal curves are shifted due to their higher output rate. It is also important to notice that the 1st proposal lead time curve switch between levels equals to the current layout lead-time and the 2nd proposal lead-time values, thus, making this option a very attractive one due to added production flexibility. The second scenario shows an average lead-time value of 17 minutes less than the other two scenarios. This is directly as a result of decreasing the burn-in time from 1 hour to 45 minutes.

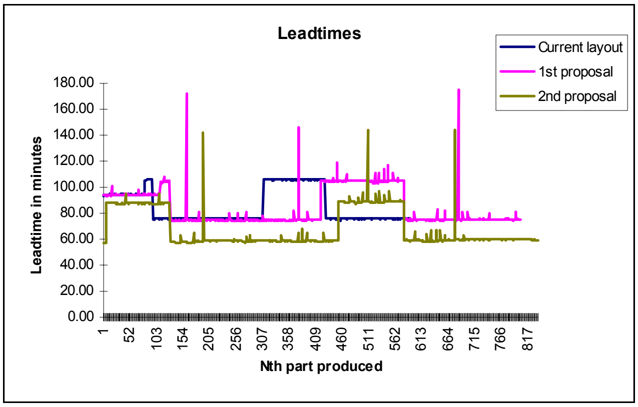


Figure 4: Lead Time Values

3.4 Machine Utilization

The machine percent utilization values determined for both proposals are higher than the values obtained for the current layout. Both proposals yield similar machine utilization. From the proposed scenarios for increasing the capacity to 800 pieces per day, the second one is selected. It resulted in a lower lead-time and a lower work-in-process inventory. The throughput is the same for both proposals. The number of operations and operators required has been reduced. The first proposal demanded a much larger burn-in capacity than expected which in turn affected the production rate and throughput through the system.

4 FLEXIBLE MANUFACTURING CELL (FMC)

The concept of a manufacturing cell consists of an automated process, which may include more than one processing capability or facility. The definition of a cell usually includes material handling or transfer capability. Robots are used to facilitate the movement of the product in combination with the human operator for loading and unloading the machines.

Cells are customarily arranged in a “U” or circular configuration so that the operator or robot can easily reach all of the machines. The chief advantage of a cell is the efficient movement of the work from one facility to the next, completing a cycle with minimal handling and delay resulting in short lead time and little work-in-process inventory (at least within the cell). (Turbide 1991)

A Flexible Manufacturing Cell (FMC) is a group of machines, working together to perform a set of functions on a particular part or product, with the added capability of being conveniently changeable to other parts or products. Figure 5 shows a FMC designed to consider the changeover requirements in the design of fixtures, capabilities, and programming.

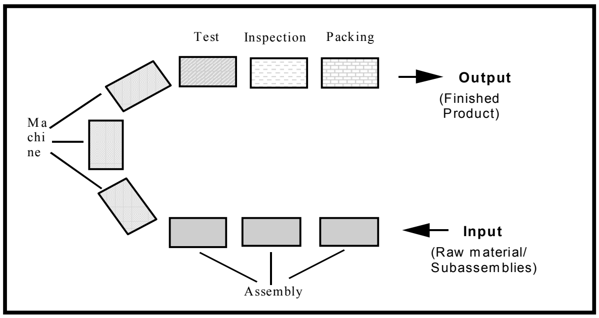


Figure 5: Typical FMC Arrangement

The actual layout of the flexible manufacturing cell is depicted in Figure 6. It shows the actual elements that influence the model based on the performance parameters: Throughput, Resource Utilization, In-Process-Inventory, Lead-Time, and Percent Defects.

4.1 Description of the FMC Operations

4.1.1 Manual Assembly

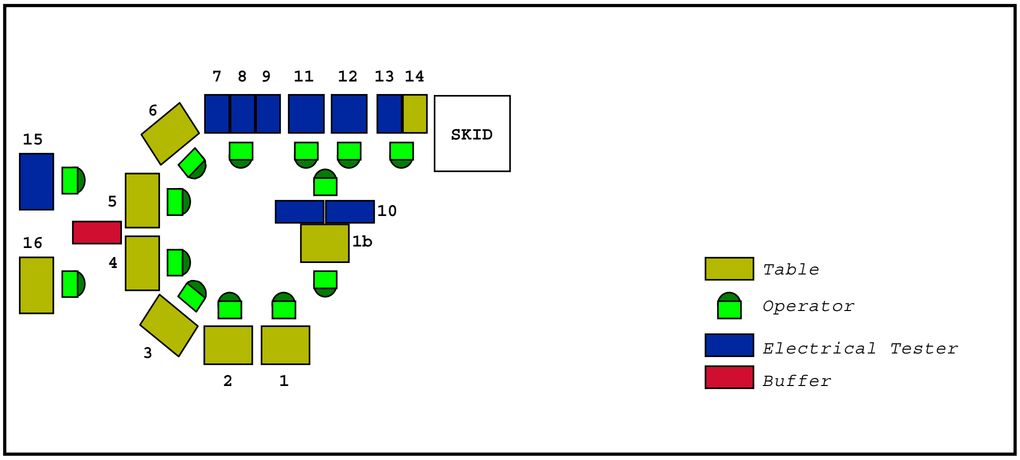
The assembly process starts in position # 1. Only positions # 1 and # 1b are synchronized by a green light bulb, which flashes every 63 seconds and remains on (to signal the operator to pass the product through to the next position) for 2 seconds. Position # 1b feeds directly to position # 4 through a buffer while position #1 feeds to the assembly position #2. The remaining positions are not synchronized by any light bulb. They pass their sub-assembly to the next position as soon as they finish their own assembly operation.

4.1.2 Manual Assembly # 4 + Visual Process Inspections

At this position the operator performs a manual assembly of the product and inspects it for possible poor assembly, and missing or loose screws. A certification for the operator is required to perform this task.

4.1.3 Pre-Test + Illumination Inspection

At this position a final tuning inside the product is performed before its final encapsulation. The operator also checks visually for possible light leakage on the products trim plate. Again, a certification for the operator is required to perform this task.



1. Manual Assembly #1
1b. Manual Assembly #1b
2. Manual Assembly #2
3. Manual Assembly #3
4. Manual Assembly #4 + Visual Process Inspection
5. Pre-Test + Illumination Inspection
6. Cover Assembly
7. Parametric Tester #1
8. Parametric Tester #2
9. Parametric Tester #3
10. Burn-in Rack
11. Customer Check #1
12. Customer Check #2
13. Memory Verification
14. Packing & Final Visual Inspection
15. Electrical Repairing
16. Mechanical Repairing

Figure 6: Flexible Manufacturing Cell - Physical Layout

4.1.4 Cover Assembly

At this position the operator places the top and bottom lids on the part to complete its mechanical assembly and sticks several control labels on it. Finally the operator stamps one of the labels and passes the product to the next position.

4.1.5 Parametric Testers

At this position a series of electrical tests controlled by a computer are performed on the product. The operator loads and unloads the product on the test fixture, and does some manual operations on the product guided by the computer via the monitor screen. One operator is controlling all 3 testers.

4.1.6 Burn-in Rack

It is a rack with capacity to hold up to 60 products. Each product will have to remain here at least 60 minutes. One operator is in charge of taking the products leaving from any one of the 3 parametric testers to the rack and, once they have been there for an hour, the operator passes the products to the next customer check tester available.

4.1.7 Customer Checks

At this position the operator performs a functional testing of the product. The operators for these positions are trained and certified because of the importance of this final product-functionality checking.

4.1.8 Memory Verification, Final Visual Inspection, and Packing

At this position a final memory verification of the product is performed via a computer. Once this verification is finished, the operator performs a final visual inspection of the whole product and then encloses it on a bag and place it on a box. A single operator performs these three operations.

4.1.9 Electrical & Mechanical Repairing

At these positions, repairing of the product due to mechanical or electrical defects takes place. When a defective part is detected at any of the stations, this is picked up directly by the quality auditor who takes it to the repairing position. Once that the part is fixed, it is placed on the buffer before the position #5 (Pre-Test + Illumination Inspection) to re-enter the normal process.

Electrical defects are detected by the Pretest + Illumination Inspection, Parametric tester, Burn-in Rack, Customer Check , and Memory Verification stations.

Mechanical defects are detected by the Visual Process Inspection, Illumination Inspection, Cover Assembly, Customer Check, and Final Visual Inspection stations.

4.2 Verification and Validation of the Model

The following aspects of the model were verified during the model coding:

- Cycle times of each element. Here the computer model code was verified to match the time studies tables gathered during the conceptual model development.
- Control of flows such as Routing. Visually, it was verified that the product was following the right path either when it was considered as good or when it was detected as defective. Here the visual display of Taylor II proved to be a powerful aid.

4.2.1 Computer Model Validation.

There is no such thing as general validity. A model is only validated with respect to its purpose. It cannot be assumed that a model that is valid for one purpose is valid for another.

4.2.2 Lead Time

In order to validate the lead-time obtained by the simulation model, first a theoretical calculation is performed. Table 2 shows this calculation, which is based on the individual process time of all the stations where the product passes through. Thus, the theoretical expected lead-time is 70.6 minutes or 71 minutes rounded.

Table 2: Lead Time Calculations

Average time (in seconds)	Reason
48	Manual Assembly # 1
60	Manual Assembly # 2
62	Manual Assembly # 3
55	Manual assembly # 4 + Visual Process Inspection
61	Pre-Test + Illumination Inspection
44	Cover Assembly
130	Parametric Tester
3600	Burn-in Rack
116	Customer Check
61	Memory Verification + Final Visual Inspection + Packing
4,237	seconds or
70.62	minutes of **Leadtime**

Next, the simulation model was executed for one shift (or 510 minutes). The initial conditions were to have 58 parts already loaded on the Burn-in Rack (as it happens normally) at the beginning of the shift. Figure 7 shows the result of the lead-time observed as each piece is produced throughout the whole shift.

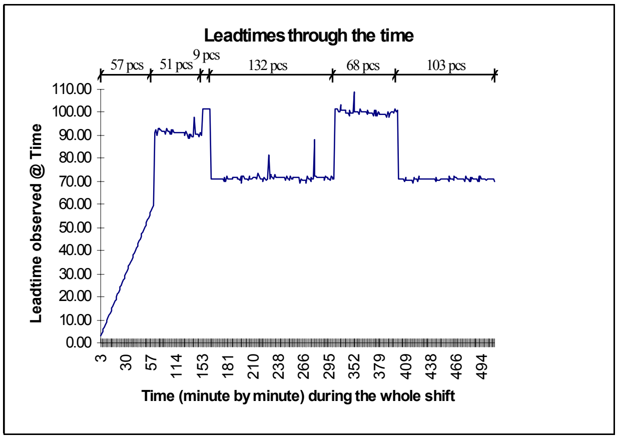


Figure 7: Lead Times Observed during a Complete Shift

4.3 Sensitivity Analysis

The model sensitivity was evaluated based on the need to increase the current FMC capacity by 25 % or more. Three proposals were to be considered for achieving the capacity increase. Computer simulation made it possible to measure how the performance measurements of the FMC (lead-time, throughput, work-in-process, utilization) are affected by increasing this capacity.

4.3.1 First Proposed Scenario

The first proposal focuses on speeding up the process by reducing the cycle time of the cell. This is accomplished by increasing the number of operations that represent a bottleneck to the new suggested cycle time. When dealing with the continuous line flow assembly line, there are just a few major bottlenecks such as: parametric and customer check. In the case of the FMC, the process is so well balanced that, if the capacity needed to be increased, it was also necessary to increase the number of operations for almost each segment of the process and not just the parametric and customer check positions. Table 3 shows the cycle-time suggested for each position, as well as the number of extra position required through the entire process to accomplish a capacity of 520 pieces/shift. This option required an investment for extra equipment and operators.

4.3.2 Second Proposed Scenario

The second proposal focused also on speeding up the process by reducing the cycle time of the cell. But the approach to accomplish this cycle time reduction was different. Instead of increasing the number of positions that represent a bottleneck to the new suggested cycle time,

Table 3: First Scenario Proposal to Increase Capacity Up to 420 Pieces/Day

Capacity >= **520** products/shift
FTQ = **97** %
Average leadtime = ??? minutes
Average Throughput = ??? products/hour
Avg Work-In-Process = ??? products

Description of Task	maximum cycle in seconds	# of positions	Total of people
Manual Assembly #1	50	1	1
Manual Assembly #1b	50	1	1
Manual Assembly #2	50	1	1
Manual Assembly #3	50	1	1
Extra-1 Manual Assembly	50	1	1
Manual Assembly #4 + Visual process inspection	45.5	1	1
PreTest + Illumination inspection	45.5	1	1
Cover Assembly	45.5	1	1
Extra-2 Manual Assembly	45.5	1	1
Parametric Tester	42	4	2
Burn-in Rack	3600	???	1
Customer Check	42.8	3	3
Memory verification + Final visual inspection + Packing	48	1	1
Total	**4,165**	**17**	**16**

the direction here was to focus on those bottleneck positions that could be improved by reducing process time (test and inspection, but not assembly), thus avoiding the need to increase numbers of operators or workstations.

Test process improvement could be achieved by testing only those parameters that were not quite under control. Table 4 shows the cycle-time suggested for each position, as well as the positions required establishing this new cycle time.

Table 4: 2nd Proposal - 420 Pieces/Day

Capacity >= **520** products/shift
FTQ = **97** %
Average leadtime = ??? minutes
Average Throughput = ??? products/hour
Avg Work-In-Process = ??? products

Description of Task	maximum cycle in seconds	# of positions	Total of people
Manual Assembly #1	50	1	1
Manual Assembly #1b	50	1	1
Manual Assembly #2	50	1	1
Manual Assembly #3	50	1	1
Extra-1 Manual Assembly	50	1	1
Manual Assembly #4 + Visual process inspection	45.5	1	1
PreTest + Illumination inspection	45.5	1	1
Cover Assembly	45.5	1	1
Extra-2 Manual Assembly	45.5	1	1
Parametric Tester	45.8	3	1
Burn-in Rack	2700	???	1
Customer Check	49	3	3
Memory verification + Final visual inspection + Packing	48	1	1
Total	3,275	**16**	**15**

4.3.3 Third Proposed Scenario

The third proposal differed from the first proposal by taking advantage of the current FMC layout with respect to equipment utilization. Table 5 shows the current utilization of the parametric testers.

Table 5: Current Parametric Testers Utilization

Position No	Position Name	Utilization (%)	Time Busy	Time Idle	Time Pause
14	URT # 1	70.99	362.06	87.94	60.00
15	URT # 2	60.17	306.89	143.11	60.00
16	URT # 3	44.50	226.94	223.06	60.00

The third proposal eliminated the need for an extra parametric tester without making an in-depth analysis of the current tests at the workstation. Table 6 shows the final requirements for this proposal.

Table 6: 3rd Scenario - 420 Pieces/Day

Capacity >= **520** products/shift
FTQ = **97** %
Average leadtime = ??? minutes
Average Throughput = ??? products/hour
Avg Work-In-Process = ??? products

Description of Task	maximum cycle in seconds	# of positions	Total of people
Manual Assembly #1	50	1	1
Manual Assembly #1b	50	1	1
Manual Assembly #2	50	1	1
Manual Assembly #3	50	1	1
Extra-1 Manual Assembly	50	1	1
Manual Assembly #4 + Visual process inspection	45.5	1	1
PreTest + Illumination inspection	45.5	1	1
Cover Assembly	45.5	1	1
Extra-2 Manual Assembly	45.5	1	1
Parametric Tester	42	3	1
Burn-in Rack	3600	???	1
Customer Check	42.8	3	3
Memory verification + Final visual inspection + Packing	48	1	1
Total	**4,165**	**16**	**15**

5 SIMULATION RUNS AND RESULTS

Considering the parameters such as Work-In-Process, Throughput, Lead-time, Machine Utilization, and Capacity, the results of each simulation model are presented here. Each of the parameters is reviewed and the current layout model is compared to the three proposed scenarios for increased capacity.

5.1 Work-in-Process

Figure 8 shows the results of the model execution for the proposal No 1, No 2, and No 3 along with the current layout. Figure 8 shows the work-in-process inventory on the flexible manufacturing cell at different times (every half hour) during the entire shift.

The 1st and 3rd proposal have the same WIP performance. And they both behaves pretty much like the current layout model considering shape and trend, but with a much higher WIP, almost 20 pieces more on the average. This is basically because of the added stations to speed up the process and increase the capacity.

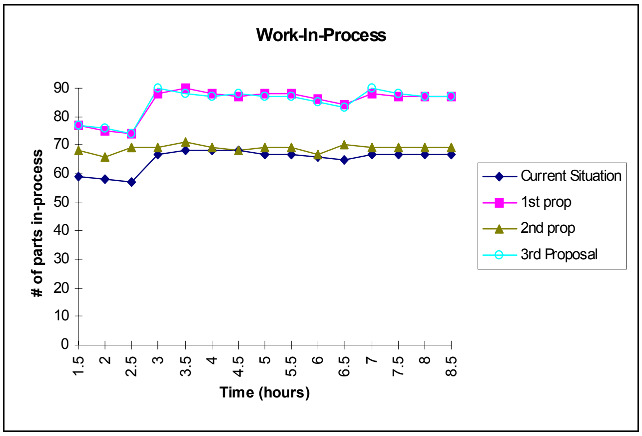


Figure 8: Work-In-Process Results

The 2nd proposal shows a flat WIP inventory after 1.5 hours, which is not much higher than the current. The main reasons for this is that burn-in time was reduced to 45 minutes causing the number of products being loaded at this station (burn-in rack) at any given time not to be increased significantly. Therefore, it is concluded that the factor contributing to major changes in calculating the WIP is the number of products being processed by the burn-in rack. In other words, in order to increase the line capacity without increasing the WIP inventory significantly, the time spent by the products on the burn-in rack must be somehow reduced as the process cycle time is decreased.

5.2 Throughput

Figure 9 shows the results of the simulation model for the proposal 1, 2, and 3 along with the current layout. Figure 9 shows the output rate (in pieces/hour) for the manufacturing cell at different times (every half-hour) during the whole shift. All the proposals show the same output rate performance. Naturally this output rate is higher than the one shown by the current layout in order to achieve a higher capacity. It is also important to notice that the differences in the number of stations between the proposals do not affect the output rate.

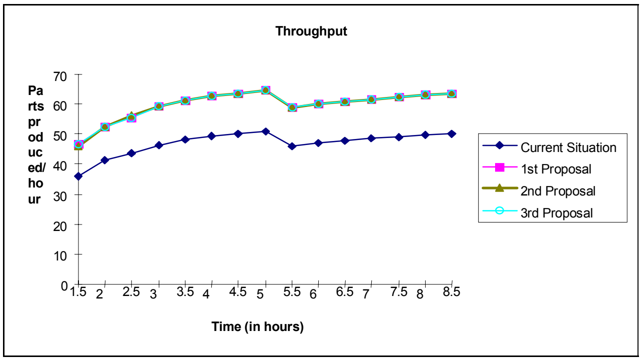


Figure 9: Throughput (production/hour) Results

Figure 10 shows the average throughput for each of the 4 scenarios. All proposals to increase the capacity show the same average throughput.

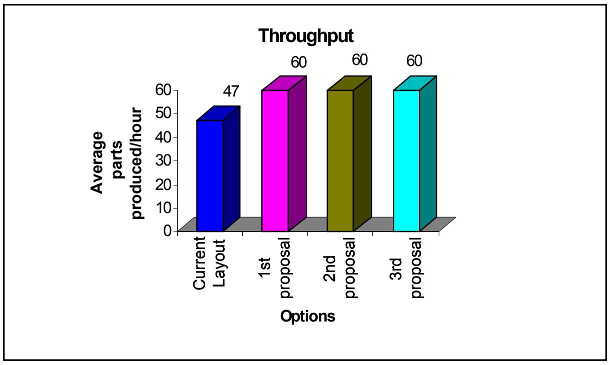


Figure 10: Average Throughput Results

5.3 Lead Time

Figure 11 shows the results of the simulation model for the proposal 1, 2, and 3 along with the current layout. The lead times observed for each of the parts being produced in all 4 scenarios are presented. The peaks observed on the lead time curves are due to the application of first time quality of 97%.

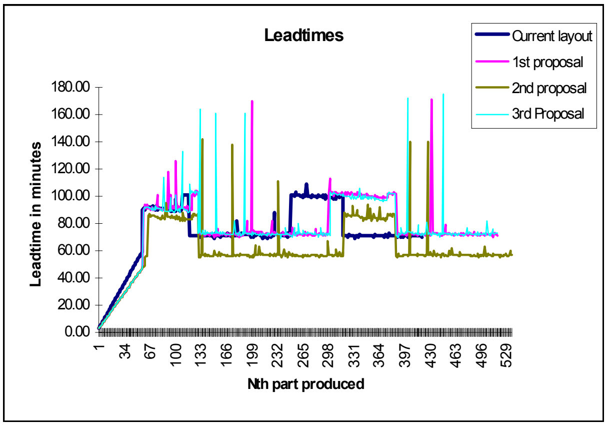


Figure 11: Lead Times Results

All curves present similar behavior, but the 1st, 2nd, and 3rd proposal curves are shifted to the right due to their higher output rate. It is also important to notice that the 1st and 3rd proposal lead time curves shift to levels equal to the current layout lead time curve, thus making this option much more attractive.

Figure 12 shows the average lead times obtained for each of the scenarios. The second proposal shows an average lead-time of 15 minutes lower than the other three scenarios. This is as a result of decreasing the burn-in time from 1 hour to 45 minutes.

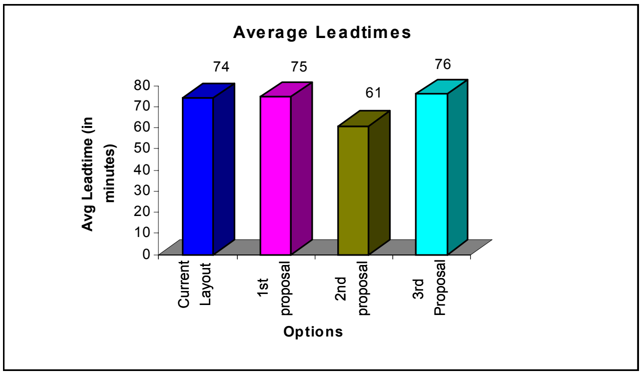


Figure 12: Average Lead Times Results

5.4 Machine Utilization

Table 7 shows the machine utilization values obtained from the simulation model for the proposal 1, 2, and 3 along with the current layout.

Table 7: Machine Utilization Results

Position		Current Layout	1st Proposal	2nd Proposal	3rd Proposal
No	Name	Utilization (%)			
2	Manual Assy #1	68.05	87.25	87.25	87.22
25	Manual Assy #1b	83.37	86.78	86.71	86.63
34	Manual Assy E1		87.00	87.06	87.12
4	Manual Assy #2	83.87	86.84	86.84	86.82
6	Manual Assy #3	86.93	86.71	86.68	86.66
8	Manual Assy #4	76.76	78.18	78.27	78.25
10	PreTest + Illumination	84.75	80.11	80.61	80.59
12	Cover assy	61.74	79.68	79.76	80
36	Manual Assy E2		79.54	79.70	79.75
14	URT # 1	70.99	73.62	70.24	79.29
15	URT # 2	60.17	67.26	62.19	75.15
16	URT # 3	44.50	55.02	44.36	69.47
37	URT # 4		31.95		
19	C. Check # 1	80.45	74.47	78.10	74.88
20	C. Check # 2	79.61	72.69	75.07	72.75
38	C. Check # 3		68.18	70.97	69.28
22	Packing Station	83.05	79.62	82.32	79.52
26	Electrical Repair	2.79	12.56	13.54	13.94
27	Mechanical Repair	2.95	3.87	6.32	8.13

Looking at Table 3, it can be noticed that the percent for most positions (except for the pretest + illumination, and customer checks) are higher given the proposals than for the current layout. Comparing the utilization between the proposals, only the 3rd proposal shows a higher utilization percentage on the parametric testers. Figure 13 shows a summary of the results for each of the parameters being analyzed for each scenario.

In order to increase the capacity to 520 pieces per day, the 2nd proposal looks promising. It shows a lower lead-time and a lower work-in-process inventory. The throughput is the same as the other two proposals. The number of positions and people is lowered. The burn-in capacity required is much lower than the 1st and 3rd proposals, and the same as for the current layout. It can be noticed that the third proposal (without adding an extra URT position) worked as well as the 1st one.

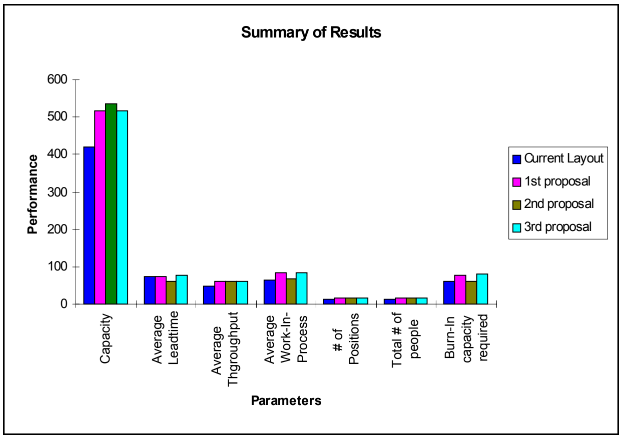


Figure 13: Summary of Results

6 CONCLUSIONS

The FMC model showed a reduction in production lead-time, average WIP, the burn-in capacity, and the number of operators required. The overall simulation study confirmed a better understanding of some of the concerns addressed earlier. These include:

- Critical elements or components were identified and relevant issues for the flexible manufacturing cell. Parametric tester, cycle time variability, and its effect on the process flow of the cell were investigated.
- The process of design of the FMC was made easier by visualizing the cell and evaluating the proposed solutions. The manufacturing process was modified until an optimum solution was at hand.
- Simulation was also an aid in planning future developments. The model provided a better forecasting of the proposed process performance and possible critical elements or weaknesses that may appear.

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