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ELECTRONIC MANUFACTURING CELL DESIGN USING PC-BASED MODELING AND SIMULATION TOOLS

Ravindra Gujar
Paul Desruelle

Department of Industrial Engineering
University of Wisconsin – Madison
1513 University Avenue
Madison, Wisconsin 53706

Randall Hammer

Delco Electronics
P.O. Box 471
Mail Station 1A20
Milwaukee, Wisconsin 53201

ABSTRACT

This paper describes the design of a high volume circuit board manufacturing cell using a set of PC-based modeling and simulation tools. The approach presented here allowed design, modeling and evaluation of the cell in a short time frame. The analysis consisted of six different steps. Rough cut analysis helped to narrow down the range of important decision variables in the operations of the cell. The analysis was performed using MANUPLAN II, a rapid modeling tool based on queuing theory. This tool was also used to perform a sensitivity analysis of the effect of breakdown factors. Simulation of the critical areas of the cell allowed to fine tune the buffer sizes and the number of machines. The simulation was performed using SIMAN, a discrete event simulation tool. Different layout alternatives were generated with MAC DRAW, a simple drafting program. Cost analysis was performed with EXCEL, a popular spreadsheet software. Multiattribute variate analysis was used to rate qualitative and quantitative factors to compare different alternatives. We believe that the progressive approach described in this paper can be applied successfully to similar projects in the manufacturing field as well as other areas.

1. BACKGROUND

A large corporation manufacturing electronic circuit boards for high volume consumer products has decided to shift from functional layout to cellular production organization to improve its manufacturing operations. Some of the problems faced by the management of the plant under consideration before the shift were:

- An average product flow time equal to about twenty times the total process time,
- A semi-finished product inventory of tens of thousands dollars ,
- A finished product inventory of several days maintained to be able to ship at customer request (shipments are made daily to several customers in the United States),
- Uncontrolled levels of scrapped products.

To resolve these problems, the company management made the strategic decision to drastically alter the current facility organized by process, and to regroup the equipment in autonomous manufacturing cells. Depending on the production volumes some of the manufacturing cells are dedicated to a specific type of product (one to three similar products) or to a family of products (several products with similar characteristics).The expected product life cycle is about five years. The rapidly changing electronic manufacturing technology makes current manufacturing processes obsolete for the new products. However, for part replacement it is sometimes necessary to continue to manufacture the product at a low volume for approximately ten years after the product life cycle is over. The company has consequently decided to implement the new manufacturing cell as new products enter production.

A team of faculty members and graduate students of the Industrial Engineering Department and the Manufacturing Systems Engineering Program at the University of Wisconsin - Madison (UW) was given an opportunity to analyze and design the new production organization. This paper, by two members of the team and one person from Delco Electronics, presents the design approach used by the team, and the benefits and experience gained by sequentially using appropriate modeling tools.

2. THE MANUFACTURING CELL DESIGN CRITERIA

The manufacturing cell analyzed is dedicated to two similar products, the main difference between them being the number of circuit boards. A forecasted demand of about one million units per year justifies the dedication to the two products. Another product is not expected to be manufactured in this module at least during the first five year.

Actual figures are withheld for confidentiality, but the following approximate figures can give the reader an idea of the size of the analyzed facility: initial capital investment of twenty-five million dollars, space utilization of fifty thousand square feet, personnel per shift of seventy-five employees.

Figure 1 presents a schematic view of the production process operations:

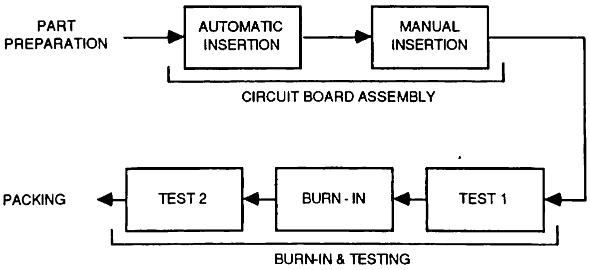

Figure 1. Production Process Operations

The operations involved were grouped in two main categories: circuit board assembly, and burn-in and testing. The average processing time, including the burn-in operation, was about 9.7 hours. Except for the burn-in operation, the production had a continuous flow pattern.Therefore, no need existed for grouping the products in lots. Every product is tested. If the test is successful the product proceeds to the next operation. If the test fails the product goes to a repair loop. Repair loops are dedicated to each testing operation and are integrated to the cell.

The company objectives were to operate the manufacturing cell in a just-in-time (JIT) mode. That is, to produce exactly the quantity needed by the customers and be able to react quickly to short term demand variations. The project goals and design criteria were established by the UW team after analyzing the company objectives, and discussing with the company's project contact the problems encountered with current operations on similar products.

The project goals and design criteria are listed below:

- Determine the necessary equipment and number of people,
- Determine the necessary supporting services and personnel,
- Develop an "efficient" layout,in order to:
  - Meet the required output,
  - Obtain an average flow time of less than eleven hours,
  - Minimize the work-in-process (WIP),
  - Minimize material flow inside and outside the cell,
  - Ensure autonomous cell operations (for instance location of the maintenance personnel inside the cell).

Team members were also especially concerned to design an environment facilitating personnel involvement and job satisfaction.

3. METHODOLOGY

Information obtained from the company relating to manufacturing operations (setup and cycle time) and workstation parameters (mean time to failure MTTF and mean time to repair MTTR) is used in the model. To design the manufacturing system in a short time frame, used a consistent set of modeling, analysis and design tools [Brown 1988; Shimizu and Van Zoest 1988] is employed which includes the following desk-top computer based packages : MANUPLAN II™., SIMSTARTER™, SIMAN™, MAC DRAW™ and EXCEL™. MANUPLAN II was used to perform rough cut dynamic analysis based on queuing theory. SIMSTARTER converts MANUPLAN models into SIMAN programs. SIMAN was used to simulate and compare different design alternatives. MAC DRAW was used to design different layouts of the facility. Cost analysis and multiattribute variate analysis was performed using the EXCEL spread sheet software. A diagram showing the different design stages is shown

The different design phases are given below.

1. Rough cut analysis: MANUPLAN II was used to get benchmark values of number of machines prior to detailed simulation analysis. The main concerns were to reduce WIP and flow time.
2. Sensitivity analysis: The MANUPLAN analysis pointed out bottlenecks in the system. Machines with high down time had large amount of WIP in front of them. This led to perform a sensitivity analysis to examine the effects of improvement in the machine characteristics on the system performance.
3. Detailed analysis of the critical stages: This phase of analysis was performed to get more insight into the operations of critical production stages. Automatic component insertion (two stages) and manual component insertion were the key areas of the system. A SIMAN model to simulate these production stages was created from the MANUPLAN model using the SIMSTARTER program. Final capacity planning was done on the basis of the simulation results.
4. Layout: Using simulation results and layout constraints a number of layouts were generated. MAC DRAW was used to draw the different layouts.
5. Cost analysis: Three configurations were selected from a number of alternatives generated during the layout stage. Cost analysis of these configurations was performed on the basis of information obtained from the company.
6. Multiattribute variate analysis and recommendations: From the earlier design stages many qualitative and quantitative factors had to be considered to evaluate alternatives. A multiattribute variate analysis method was used for this purpose. Finally the team made recommendations on the main aspects of manufacturing system operation to make JIT implementation successful.

4. ROUGH CUT ANALYSIS

This was the capacity planning phase. The minimum number of machines required was obtained from this analysis. The basic

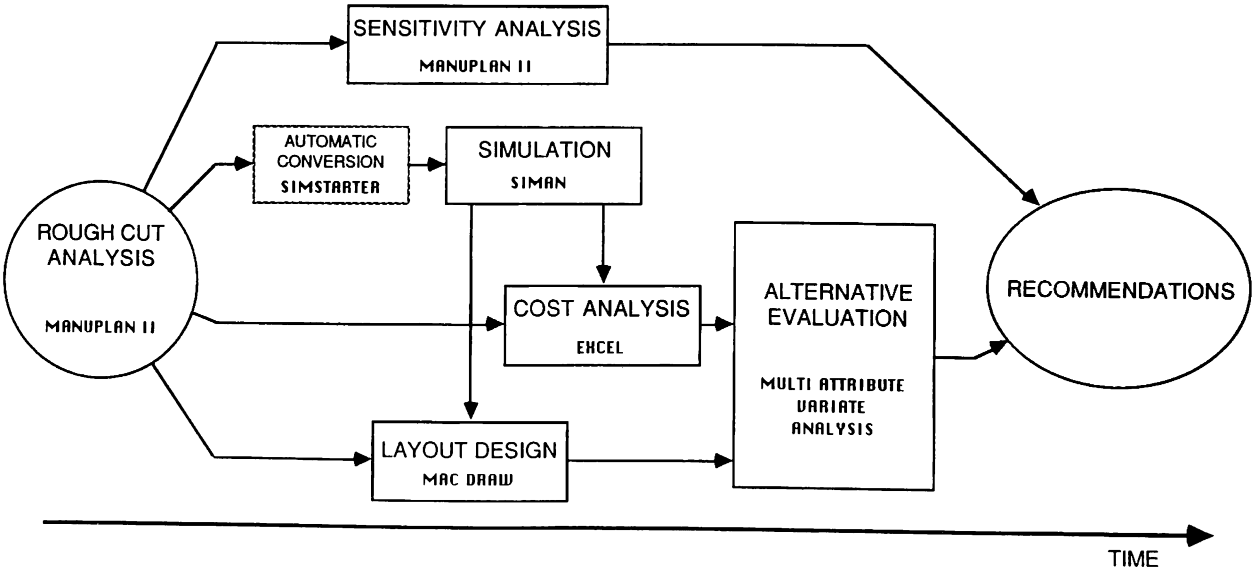

Figure 2. Schedule of design stages

data for modeling was supplied by the company. It consisted of machine parameters, annual demand, processing time, etc. The cellular configuration is expected to allow a JIT production strategy. A lot size of one unit was used for model building and analysis.

At this very first stage of the design the following requirements led to select a rapid modeling tool (RMT) [Suri 1988]:
1. Fast investigation of several design alternatives,
2. Ability to capture dynamics of the manufacturing system.

Static modeling using a spread-sheet package could not consider system dynamics, such as the effects of failures on WIP. Analysis using discrete event simulation is time consuming and would not permit evaluation of several alternatives in a short time frame.

The team selected MANUPLAN II for the capacity planning. MANUPLAN, a RMT could meet the above mentioned requirements : it is based on queuing theory, and it can consider interaction of different workstations [Suri, Diehl, and Dean 1986]. The MANUPLAN model runs take less than a minute to evaluate a particular system design. The following features of the software also made it more attractive:
1. PC-based,
2. Userfriendly (integrated with LOTUS 1-2-3^{TM}),
3. Quick model building.

A MANUPLAN model was built as per the specified constraints. MANUPLAN models give steadystate estimates of machine utilization, WIP and flowtime based on the dynamic analysis of the system. The minimum number of machines required to achieve the desired annual production were found from this stage. The workstation utilization and WIP with this system configuration is shown in Figure 3 and 4 respectively.

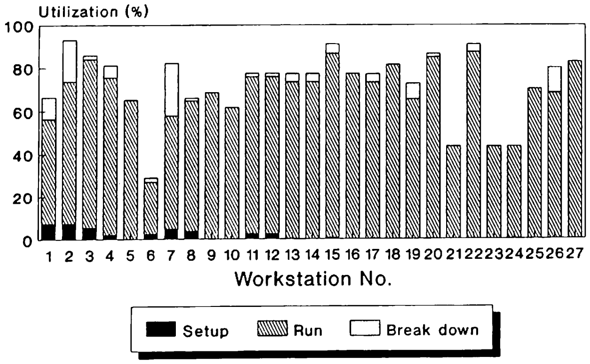

Figure 3. Workstation utilization (Rough cut analysis)

These figures clearly show very high WIP in front of machines having high downtime (e.g. 2 , 7) or high utilization (e.g. 15, 20).

The MANUPLAN analysis showed that though it was possible to achieve the production, the flow time was much higher than the desired value.

5. SENSITIVITY ANALYSIS

The rough cut analysis pointed out the bottlenecks in the system. The necessity to analyze the effect of machine performance improvements on the system parameters was felt.

To study these effects MTTF was increased from 0 to 100% (steps of 20%) and MTTR was reduced from 0 to 50%(steps of 10%). The effect of the individual parameters as well as combined effect of both the parameters were studied.

The what-if analysis was performed by making the changes in machine parameters only for critical machines (2, 7, 15, 19, 26). The quick response of the MANUPLAN model was a key factor of this study.

A graph of the combined effect of change in MTTF and MTTR on flow time (for the 1-board product) is given in Figure 5. The analysis pointed out the following interesting facts:
1. The required system performance is obtained only by the simultaneous improvement of MTTR and MTTF.
2. The initial rate of return on investment in maintenance program is the largest in terms of the system improvement.

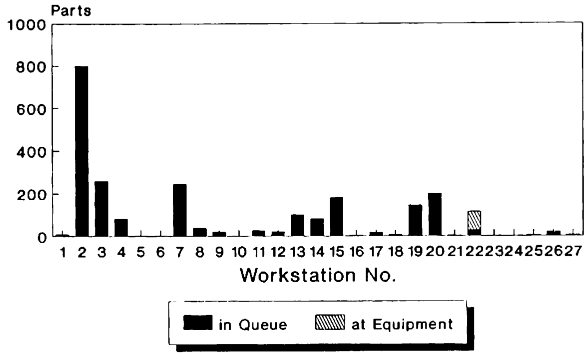

Figure 4. Work in process (Rough cut analysis)

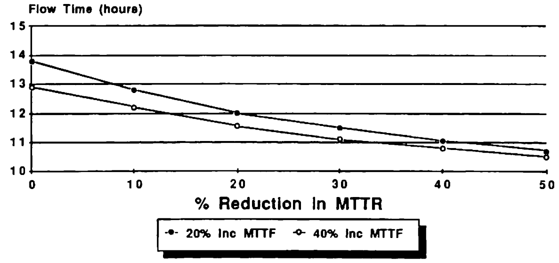

Figure 5. Combined effect of MTTR and MTTF improvement on flow time

The sensitivity analysis was the basis for most of the recommendations on the maintenance policy.

6. DETAILED ANALYSIS USING SIMULATION

The purpose of this step was to sharpen the MANUPLAN results and get more insight into the system performance. Rough cut analysis results showed that flow time and WIP were very sensitive to machine reliability and repair time. It also showed that a more detailed study of queue dynamics in front of the critical stations was necessary in order to determine appropriate number of machines.

Therefore the objectives of the simulation analysis were:
- To determine the required number of machines per station,
- To optimize buffer size between unlinked stations,

in order to meet the required output.

To simulate the system a SIMAN program [Pegden 1987] was created from a MANUPLAN model using the SIMSTARTER program [Suri and Tomsicek 1988]. The first three out of a total of four manufacturing stages (workstations 1 to 20) were the key areas of the system from the bottlenecks and the total investment point of view. The study concentrated on these areas of the system.

The simulation analysis progressed from confirming the rough cut analysis results to final capacity planning based on physical constraints. The details of the successive simulation models are given in Table 1. High level of buffer capacity refers to very large buffers and low level to limited buffers. Low level of MTTF and high level of MTTR refer to current machine parameters. High level of MTTF and low level of MTTR represent an improvement of 50% over existing conditions. Low number of equipment corresponds to the number of equipment resulting from the rough cut analysis, and high number of equipment represents final cell configuration.

Table 1. Simulated System Configurations

	Buffer Capacity	MTTF	MTTR	# of Equip.	Production Level *
1	High	Low	High	Low	84%
2	Low	Low	High	Low	75%
3	Low	High	Low	Low	88%
4	Low	Low	High	High	94%
5	Low	High	Low	High	97%

(*) The production level is expressed in percentage of the required output

The production level with different system configurations is shown in Figure 6.

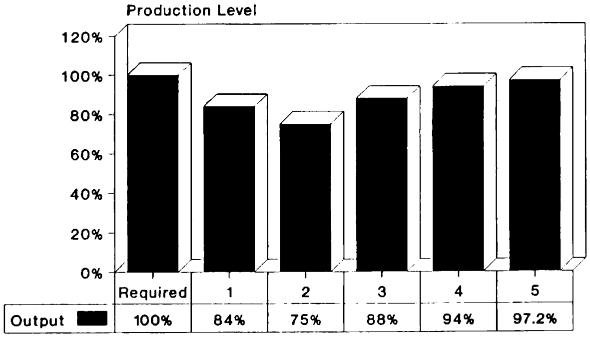

Figure 6. Simulation results

6.1 Results and Conclusions of the Simulation Analysis

The first system configuration attempted to model the system as seen by the rough cut modeling tool. Buffers in front of each station were set for infinite capacity. However buffer capacity in front of station number 2 and 7 was restricted to 100 to maintain the number of entities in the system below the maximum number of entities allowed by SIMAN. This restriction resulted in reduction in throughput by 16%. The second system configuration incorporated physical constraints into the model. This model considered limited buffersize between linked workstations. The restriction on buffersize between linked workstations was essential also to restrict inventory build up. This analysis shows that under these conditions the system production rate decreased drastically. This drop in output could be attributed to high level of blocking.

The initial phase of simulation analysis showed that the system parameters had to be improved in order to meet the required output under realistic queue constraints. The project team chose to investigate along two directions:
1. Improvement of maintenance conditions (50% increase in MTTF at and 50% decrease in MTTR at selected stations pointed out by the sensitivity analysis) and
2. Increase in number of equipment at bottleneck stations.
Thus a third configuration modeled the system with increased MTTF and reduced MTTR. A fourth system configuration modeled the system with improved number of equipment and a fifth one incorporated improvements in both the directions. The production with the final system configuration was within 3% of the required output and was considered satisfactory.

The simulation confirmed the bottleneck stations pointed by the rough cut analysis. It also confirmed that it was not possible to meet the required output without improved machine reliability and reduced repair time. Further it modified the number of machines for some of the bottleneck stations. Simulation results led to new layout alternatives.

7. LAYOUT DESIGN

One of the main expected outcomes of the project was several layout propositions for the manufacturing module.

Some of the constraints on the layout design were imposed by the company. Other constraints and additional criteria were considered by the team members. A list of these constraints and design criteria follows:

- Component delivery and finished product removal on the same side of the module but at different locations (no two-way traffic),
- Cell to be implemented in existing building (shape constraints, limited available floorspace),
- Implementation of all supporting services, personnel and equipment inside the cell:
  - * Location of the offices as central as possible,
  - * Distribution of the maintenance personnel in the cell and assignment to critical equipment components,
  - * Material flows to be kept as simple as possible.

Due to the short project time frame, it was decided to start the layout design before knowing the exact number of equipment components. Therefore the layout design phase overlapped with the simulation phase. The first layouts were designed based on the results from the rough cut analysis. Then the layouts were updated as the simulation results gave more insight about the final module configuration.

The team chose to use MAC DRAW, a simple drafting sofware package. It permitted to quickly test various options which could not have been considered otherwise.

As the simulation results were showing a need for an increased amount of equipment, it appeared more and more clear that the option of implementing the equipment in two separate modules had to be considered.

Three different alternatives were proposed:

- Two different cells, one being dedicated to one of the products and the other to the second product,
- Two similar cells, each producing half the required production,
- A single cell producing the total required output.

8. COST ANALYSIS

The objective of this phase was to determine and to compare among the proposed layout alternatives:

1. the total annual manufacturing cost ,
2. the manufacturing cost per product.

The company did not impose any limit in terms of capital expenditure or manufacturing cost per product. However, the project team was eager to verify that the analyzed options were cost effective. A cost analysis tool proved also to be helpful in comparing the different layout alternatives.

This phase started as soon as the first simulation results were obtained and the first layout was designed. As in the layout design phase, the project team has been able to provide to the company fast feedback on cost information. As more precise results were obtained from simulation and layout design, resulting costs could be refined.

EXCEL, a popular spreadsheet package, was used to compute the required costs from the individual cost information given by the company combined with the results from the simulation and layout design phases.

9. ALTERNATIVE EVALUATION

The final phase of the project was concerned with the evaluation of the different proposed alternatives on the basis of quantitative as well as qualitative information and aspects.

The team adapted a method from multiattribute variate analysis [Winterfeldt and Edwards 1986; Falkner and Benhajla 1986]. This method assigns a score to each alternative on the basis of weighted importance of decision factors. This analysis was performed with the EXCEL spreadsheet package for quick computation and easy updates. The decision matrix obtained after application of the method is given in Table 2.

Table 2. Decision Matrix

Factors	Weights	Individual Scores		
		Single Cell	Two Identical	Two Dedicated
Flow Time	21.0%	10	8.6	7
WIP	21.0%	10	8.5	7.5
Managability	13.7%	6	10	7.5
Emulation	8.4%	4	10	8
Overall Annual Cost	7.4%	10	8.5	8.6
Cost/Piece	7.4%	10	8.5	8.6
Quality of Work Life	6.3%	6	10	9
Breakdown Flexibility	5.3%	10	8	8
Demand Flexibility	5.3%	5	10	7
Space Utilization	4.2%	10	7	7.8
Total = Σ (Weight x Individual Score)		8.43	8.94	8.05

This method allowed the team to make meaningful recommendations to the company on the basis of comparative evaluation of quantitative as well as qualitative information.

10. CONCLUSION

A progressive approach for designing manufacturing systems using a set of modeling and simulation tools was presented. The different phases of the approach applied to the design of a circuit board manufacturing cell were detailed and the results reported. Benefits of using this methodology along with the corresponding tools were presented.

It is believed that the approach and tools presented in this paper could be applied successfully to similar projects particularly in the manufacturing field, and could also be adapted to other projects in different fields.

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