*Proceedings of the 1987 Winter Simulation Conference*
A. Thesen, H. Grant, W. David Kelton (eds.)

# A METHOD FOR PLANNING ANALYSIS AND DESIGN SIMULATION OF CIM SYSTEMS

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*Abstract*

**Analytic models (AM) that combine a network of queues with resource reliability parameters are currently being applied to strategic planning analysis and design simulation of manufacturing systems. These models estimate the dynamic interaction between resources and production inventory in a manufacturing system computing the time each item being produced spends at each resource. These models predict the production rates and equipment utilization.**

**Recent advances in modeling have resulted in models of factories that require a minimum amount of data input, give results quickly, and approximate real conditions. Often, such models are used to study a factory before its construction in order to select the most efficient alternative configurations for further consideration. In the application described here, an analytic model has been applied to a proposed printed circuit board (PCB) manufacturing test cell to assist in making the strategic decisions required to design a manufacturing line for a new product. Lot size and process quality were studied and optimum conditions determined for each. The use of the model can help reduce the investment cost in expensive test equipment required to test products containing Very Large Scale Integrated (VLSI) circuits.**

## I. INTRODUCTION:ANALYTIC MODELING AND DISCRETE/CONTINUOUS SIMULATION

### 1. Discrete-Continuous Simulation (D/C)

Discrete/Continuous simulation models can be made extremely accurate and realistic. They use Monte Carlo techniques to achieve a life-like representation of a real system with statistical and random variation of the system's operational parameters. However, D/C simulation models require an enormous amount of detail that sometimes results in costly computer runs and rigid conformance on the user.

### 2. Analytic Models

An Analytic model that combines a network of queues with reliability parameters area series of mathematical equations that represent the behavior of a system. Such a model is used to study the dynamics of a system such as competition for equipment, machine failures, variations in arrival time and probability of rework. It can predict production rates and equipment utilization.

Analytic models give results for steady state conditions only and are not suitable for estimating the transient behavior that occurs during startups or recovery from machine breakdown. Because of their long time horizon (weeks, months, etc.), they cannot be used to make short term decisions e.g., which lot to load next or the sizes of buffers between process steps etc. However, analytic models can quickly provide the user with much valuable insight into the behavior of the aggregate system.

Unlike discrete/continuous simulation, the use of analytic modeling requires no specialized training of the user. The interface employs manufacturing terminology and requires a minimum amount of information about the process. Since the models are easy to use and require little time to run, users are free to use their imagination to investigate many alternatives in a short period of time. The computer-based model used for the analyses described in this paper is called MANUPLAN, MANUPLAN and MANUPLAN II are trademarks of Network Dynamics Inc., Cambridge, MA.

It has the following input requirements and output characteristics:

- **Input Requirements**
  - Number of hours of operation
  - Number of machines, with their reliability parameters
  - For each workpiece: part number, demand, and lot size
  - Routing data, including operation and equipment group assignment
- **Output Characteristics**
  - Production summary, including rates and quantity of scrap
  - Flow time, average WIP, equipment utilization, and time used for repair

### 3. Application of Queuing Theory

The analytic model (AM) is based on recent developments [16] in the solution of equations used in classical queuing theory and makes possible the analysis of large manufacturing systems. The capabilities and features of this model are:

- Can model large systems--many lots, many machines;
- Features easy to solve, extremely efficient algorithms;
- Results obtained from AM on real systems are within 0.1 to 15% of the mean values obtained from D/C simulators, the traditionally accepted modeling method [17].

The analysis of manufacturing system performance is achieved by the evaluation of four variables. To illustrate, using a single server queuing system, [5] the variables are:

- T = Observation Period
- A = The number of lots arriving during T
- B = The amount of time the system is busy
- C = The number of completions during T

The relationships derived from the quantities A, B, C and T are:

- $\lambda$ = A/T, the arrival rate (jobs/second)
- X = C/T, the output rate (jobs/second)
- U = B/T, system utilization (x 100 = %)
- S = B/C, mean service time per job (sec)

If $\lambda$ is greater than S, a queue (storage) area is required for the arriving jobs.

Work-In-Process (WIP) can be calculated from Little's Law [10]. The amount of inventory contained in the system at any time can be estimated from $\lambda$ and time in the system or flow time (F).

$$\text{WIP}=\text{F}\lambda \quad \textit{(Little's Law)}$$

4. Application of Reliability Theory

The frequency of failure and the time to repair for a machine have an effect on the capacity of a manufacturing system. Therefore, the addition of reliability parameters to the model enhances the validity of the system performance parameters that are obtained. The reliability parameters included are:

- MTTF = Mean time to failure
- MTTR = Mean time to repair

The mean time required to bring the machine back into service, MTTR, can also be defined as the utilization of the machine for repair, instead of for production.

## II. MODELING A PCB TEST CELL

### 1. Manufacturing Test Cell Description--A Scenario

In order to illustrate the feature of the AM analysis tool a hypothetical manufacturing test cell will be analyzed. This example is based on an actual PCB test cell has been modified to illustrate the results that can be obtained with the tool.

The objective of the anaylsis was to develop a successful test strategy that arranges the various testers in the circuit board manufacturing process so that a lot size one concept and a 95% first pass test at each inspection point in the process for Product(X) can be determined. The variables that affect the test strategy are assigned as follows:

- Number of operating days/week = 5 , Number of Shifts/day = 2
- Forecasted production rate= 5K boards/year.
- Product(X) will consist of 3 printed circuit boards.
- Component and Process Quality --The real process average based on products currently manufactured = 50-70%.
- To reduce test time, testability feature will be included in the design.

Other factors that influence the test cell configuration:

- Product(X) is currently in the planning phase and real statistics are unavailable. The manager of product assurance has been asked to implement a new Q95 policy on Product(X). This policy requires a 95% yield at each process step.
- The *yield* has been found to be an important parameter for determining test strategy and test equipment. Achieving 95% yield at each process step implies a significant manufacturing test cost savings.
- A start up yield of 50% is assumed for Product(X) and the new circuit and packaging technology used will, as the product matures result in a continued yield improvement.
- A 24 hour burn-in of each PCB is required.

### 2. Cell Configuration and Features

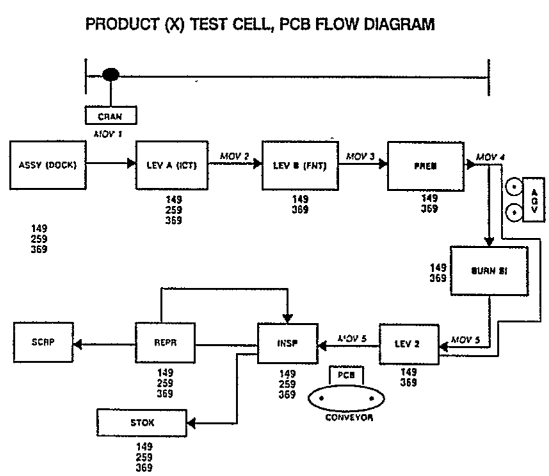


**Figure II-1:** Diagram of Test Cell

Figure II-1 shows the conceptual organization for the Product(X) test cell studied. The abbreviations used in the figure are:

ASSY: Assembly
LEV #: TESTER
PREB: PRE-BURNIN TEST
INSP: INSPECTION
REPR: REPAIR
SCRP: SCRAP
AGVS: Automatic Guided Vehicle System
CRAN: Overhead Carrier

149,259, 369: ASSEMBLY NUMBERS FOR PRINTED CIRCUIT BOARDS

Among the factors to be investigated in the study are:

- The effect of various product quality levels on test resources.
- The effect of equipment reliability (MTTF) and repair time (MTTR) on production rates.
- The effect of various production demand and lot sizes on test resources.
- The proportion of resources required for test and repair.
- A material handling system that includes an overhead crane, conveyor and automatic guided vehicle (AGV).

3. Validation

Prior to the test cell design analysis , studies were made to determine the correlation between the results obtained from AM and a discrete event simulation of the system [13]. The results obtained are in good agreement with those of Haider et. al on their "Factory of The Future Project" [6]. Thus the results obtained from AM can serve as a validation for a discrete event simulation model. [16].

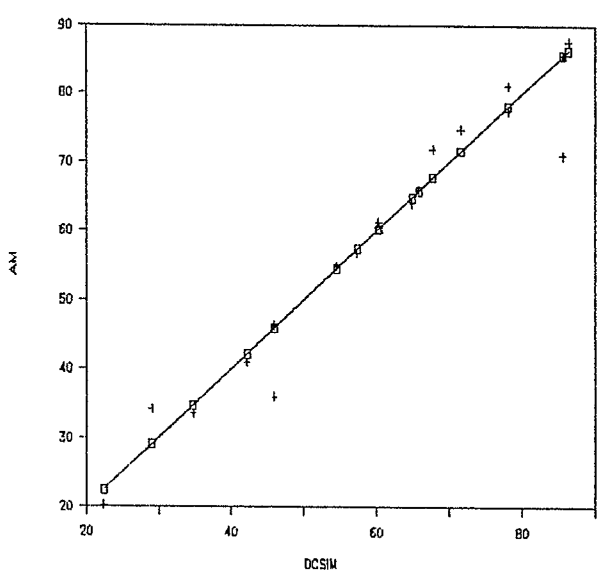


**Figure II-2:** Comparison of Utilization- AM vs D/C Models

Figure II-2 illustrates the results obtained from the validation study for the values of Utilization obtained by the analytic model and the discrete event simulator. Figure II-3 show the results for Work-in-Process.

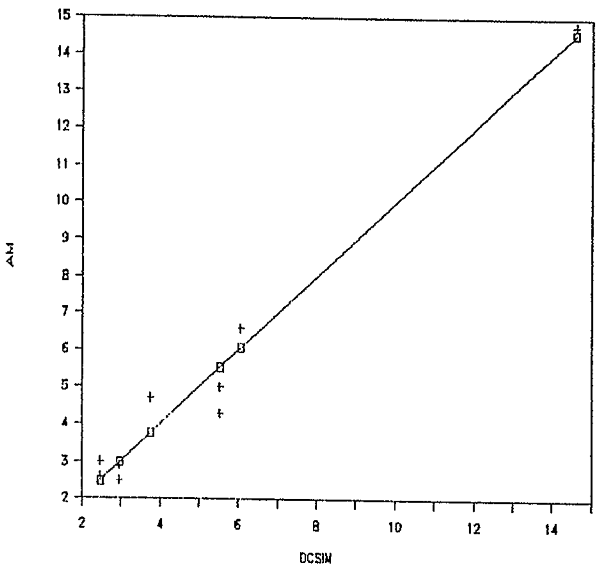


**Figure II-3:** Comparison of WIP for AM vs D/C

4. Effect of Lot Size

The effect of lot size on tester resources is shown in Figure II-4. The results show that the set up time for each product has an influence on the overall equipment utilization. The smaller the lot size the higher the equipment utilization. There is a corresponding shorter flow time and lower work-in-process when the lots are smaller. In order to achieve production for a process average quality level of 50%, an additional shift for the ICT and CRAN operations are required. Figure 4 shows the utilization of the ICT, FNT, LEV2 INSP and AGVS operations.

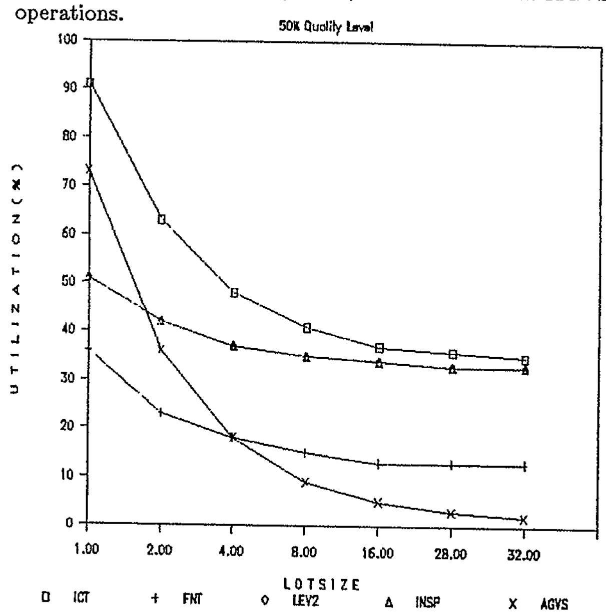


**Figure II-4:** Lotsize vs Equipment Utilization

Utilization [%]

| | Q50 | | Q95 | |
|---|---|---|---|---|
| LOTSIZE | 1 | 28 | 1 | 28 |
| EQUIPMENT | | | | |
| ICT | 91 | 36 | 91 | 36 |
| FNT | 59 | 17 | 59 | 17 |
| PREB | 67 | 24 | 67 | 24 |
| LEV2 | 36 | 13 | 28 | 10 |
| INSP | 51 | 33 | 42 | 27 |
| REPR | 19 | 19 | 1.5 | 1.5 |
| AGVS | 73 | 3 | 73 | 3 |
| FLOW(DAYS) | 1.7 | 3.8 | 1.8 | 3.3 |
| WIP | 88 | 207 | 94 | 174 |

TABLE 1: Utilization vs Quality Level

TABLE 1 shows the utilization of resources for the assumed start-up quality level (Q50) and the target quality level (Q95). A Q95 process has reduced repair and inspection cost only. The utilization of all resources except INSP and REPR are independent of quality level.

5. Flow Time

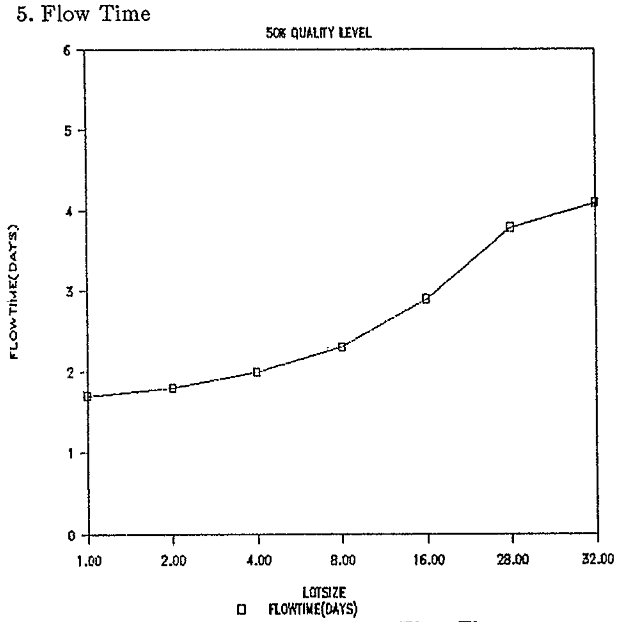


**Figure II-5:** Lot Size vs Flow Time

Figure II-5 shows the effect of lot size on flow time. For minimum flow time, a lot size of 2 to 8 IS optimal for the cell configuration studied. Smaller lots will also provide more production capacity and quick turn around.

Several factors must be considered in selecting an optimum lot size such as cycle time, utilization of equipment, and work-in-process inventory. The optimum condition will also depend on the mix of operations with lot setup time and operations without lot setup. The expense associated with storage and handling of small lot size must be considered in the aggregate decision.

6. Level of Testability and Manufacturability

If testability can be quantified as test time and set up time, the AM can provide information about the amount of testability and manufacturability required to optimize the manufacturing process. Minimizing setup times and test time of assemblies during the product design cycle have significant effects on the flow time achieved.

7. Tester Workstations for Product Test and Repair

Workstation and operator assignments can be quickly determined using AM. Changing product mix and product delivery requirements can be evaluated and used to forecast changes in resources or their activity. For example, a reduction in the group number will increase the utilization of the equipment but an increase in flow time will also result.

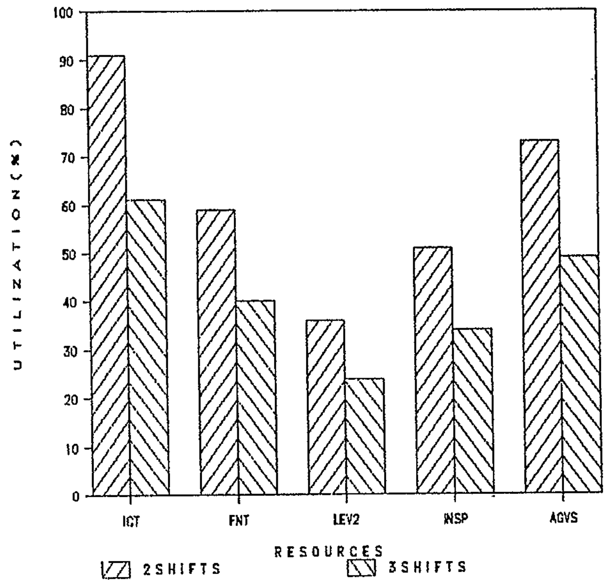


**Figure II-6:** Resource Utilization vs Period

Figure II-6 shows the resource utilization for both two and three shift operation. These results were obtained by altering the time per period (minutes per day) parameter in the model. The utilization of equipment is reduced by 30% when production extended over three shifts. The model allows the user to selectively change overtime factors for individual resources of the system. The user has the capability to evaluate many options during the analysis.

8. Material Handling

The variation in delivery and machine processing can be altered in AM. The best estimate buffer size and other constraint limited variables require simulation. AM does permit the inclusion of material handling delay parameters in the analysis thus providing realism to the analysis. For example breakdowns of the CRAN and AGV will effect the system performance.

9. Equipment Reliability and Maintainability

The availability (MTTF and MTTR) of the test cell's resources can be altered and the result on the test cells performance measured. Availability parameters for new equipments can then be assessed to determine their contribution to process improvement. Insertion of the availability parameters of proposed machines and testers of new technology, can aid in determining specifications for new equipment.

## III. A PRECURSOR TO SIMULATION

Building, debugging, verifying and validating a D/C simulation model is time consuming. It is not always possible to incorporate proposed design changes or insert new technology into the system without building a new model. Thus the analyst or planner is discouraged to using the tool during the planning and design stages for new plants and manufacturing systems. Experience currently shows that using AM before building a simulation model saves time and provides the flexibility for rapid evaluation of new manufacturing and test technology.

| MODEL | D/C-SIM (hrs) | AM (hrs) |
|---|---|---|
| 1 | 24 | 2 |
| 2 | 640 | 6 |
| 3 | 2.5 | 0.5 |
| 4 | 20 | 2 |

TABLE 2: COMPARISON OF MODELING TIMES

TABLE 2 shows typical model development times for both the analytic model and a discrete event simulation model. Included in the time are:

1. model development;
2. verification (model is right);
3. validation (the right model);
4. some feedback for model refinement.

Data collection was not included since this task, started before the modeling began, and was performed concurrently in the tasks.

Other benefits obtained from the test cell modeling and analysis project are:

- Modeling is a team effort that involves people in various departments of the organizations. Problems are discussed with objectivity.
- Validation and verification requires a minimum of two people.

## IV. CONCLUSIONS

An analytic model has been used to evaluate a new manufacturing test strategy. Its ease of use aided the study of the issues relevant to achieving optimum cycle times and production efficiency, including lot size and process quality. AM is a good tool to use before simulation to examine in a consistent way as many design or policy alternatives as possible. Its feature allow:

- Obtaining baseline perfomance of actual systems (Validation);
- its use throughout the entire life cycle of the plant or process;
- planning for new technology insertion into product and process;
- its application to the economic justification of a system.

For the manufacturing test cell studied, the following was observed:

1. a Q95 process results in the lowest inspection and repair cost;
2. small lot sizes result in lower work-in process cost and maximum equipment utilization. Optimum lot size for this test cell is between 2 and 8;
3. a further reduction in set-up time will be required in order to increase the test capability;
4. AM is a good precursor to simulation.

During the operational phase, the AM can provide information on workload balancing and resource capacity for dynamic changes in product manufacture. It can also be used to assess the insertion of new technology before the actual changes are made. This minimizes the risk in making commitments of resources and revenue for changes or enhancement to the manufacturing operation.

## ACKNOWLEDGEMENTS

The author acknowledges the invaluable participation of Mr Ralph Renner and Ms. Betsy Malloy in the analysis and preparation of this paper.

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