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SIMULATION OF ELECTRONICS MANUFACTURING AND ASSEMBLY OPERATIONS: A SURVEY

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ABSTRACT

This paper will provide an overview of simulation applications in various manufacturing scenarios, including wafer fab production, printed circuit board assembly, surface mount technology lines an other electro-mechanical assembly operations. The survey will illustrate how simulation can be used in design analysis and in the scheduling of operations. Of particular interest are the scheduling applications. This presentation will demonstrate the important points of these applications using real time animation and real world case studies.

1. INTRODUCTION

With increased emphasis on the more precise modeling of manufacturing facilities, simulation and scheduling have become premium tools for modeling manufacturing systems. Often times however, there is confusion between these two techniques and their role in the modeling and the optimizing of manufacturing systems.

In this paper we would like to clarify the use of these two systems for electronics manufacturing. We will first identify a set of problems for which simulation is most appropriate. Then, we will analyze the importance of each of these problems in the following functional areas of electronics manufacturing.

1. Wafer fabrication
2. Device manufacturing and assembly
3. Printed Circuit Board (PCB) assembly
4. Product Manufacturing and assembly
5. Testing Operations
6. Packing, shipping, warehousing, and other inventory related functions.

To further clarify the use of simulation, we would like to point out the pressing scheduling problems within each functional area. Please note however, that scheduling is a day-to-day management function and is not a generic modeling tool. It is recommended specifically for short term execution related issues. Hence, our focus will be on the role of finite capacity scheduling in the functional areas above and its relation to simulation.

We will start by identifying a short list of issues which probably account for 95% of the simulation problems in the electronics industry, today. The list of simulation problems is given below:

1. **Capacity Analysis:** Refers to analysis of the primary manufacturing resources such as machines, heat treatment equipment, ovens etc. In most simulation studies, either the amounts of the machines are fixed and simulation is done to estimate the possible production quantity and bottlenecks within the given configuration. Or, one may be interested in finding out the required amount of resources needed to provide a specific production volume.

2. **Operator Requirement Analysis:** Is similar to capacity analysis but deals with manual labor.

3. **Material Handling Design and Analysis:** Deals with the automated and/ or manual material handling aspects of electronics manufacturing. It may include the design of transporter networks, conveyor specifications, the number and/or size of material handling equipment, etc. In most cases, simulation is done to see if a given material handling configuration is sufficient enough to provide a certain specified output of the simulated system.

4. **Process Improvement and Automation Analysis:** In most cases, electronics manufacturing operations can be improved by either reducing steps or by switching to more automated equipment. Therefore, simulation analysis is used to view the impact of various process improvement ideas and automated equipment.

5. **Machine and Equipment Selection:** Refers to cases where more than one alternative machine may be selected for a given operation. Because of the competitive nature of the equipment for electronics manufacturing, there is more than one alternative most of the time. Therefore, simulation analysis can be used to choose the most appropriate equipment for a given system.

6. **Tools and Other Secondary Resource Requirement Analysis:** Refers to other secondary but constraining resources such as tools, fixtures, containers, etc. Secondary equipment, although most of the time cheaper to obtain and maintain than primary equipment, may have an important impact on the profitability of the manufacturing system. Therefore, in most cases it can be analyzed through simulation.

2. SIMULATION IN WAFER FABRICATION

The characteristics of wafer fab production from a simulation modeling point of view can be summarized as follows: Operations are essentially similar to a series of batch processes. In a wafer fab facility, a batch of wafers go through a specified sequence of cleaning and electrochemical reactions which are performed by highly automated equipment and ovens. The use of operators is also essential, even though the operations are highly automated.

Traceability and other technical requirements require the use of secondary resources in a wafer fab facility. Therefore, it is essential to have more than one shared resource among the different equipment. Combining this with other possible alternative routings and a large number of process steps which may be repeated on the same equipment, makes wafer fab manufacturing very complicated for simulation modeling.

In addition, there is usually a high level of in-process inventory in the system. This means that at any given time during a simulation run, there may be a large number of active entities. The time accuracy in such an environment may be varied but in most cases, it is within minutes. What makes things more complicated however, is the use of time windows for certain operations, due to temperature and/or other chemical requirements.

The data requirements of wafer fab are also very intense. This is because of the number of steps and possible variations required in production times.

Simulation is a very appropriate tool for studying certain issues in wafer fabrication. The following is a list (in order of importance) of where most simulation modeling and analysis applies in wafer fab production.

1. **Capacity Analysis:** This is probably the most studied issue using simulation. In most cases, a capacity analysis study also includes combining the other resources because of the high level of dynamic interdependence in wafer fabrication.

2. **Operator Requirement Analysis:** In a waferfab facility, usually only one operator attends to multiple automated equipment. Therefore this issue is typically included in a simulation model that addresses capacity planning issues.

3. **Material Handling Design and Analysis:** Material handling design and analysis in a wafer fab facility closely follows other material handling design and analysis problems. What makes this task more interesting however, is the use of an operator also as a transporter in most systems. Therefore the detailed modeling of the operator and of the material handling equipment is also a necessary part of most capacity analysis models.

4. **Machine and Equipment Selection:** This is usually important during the system design phase.

5. **Tool and Other Secondary Resource Requirement Analysis:** Some secondary re-

sources such as robots and containers are also important in waferfab operations and they should also be included in the capacity analysis models.

The two most pressing scheduling issues today are order release scheduling and the detailed finite capacity scheduling of resources. The latter problem also includes lot sizing issues and is a bona fide scheduling problem which must be addressed by proper tools. We defer discussion of these two scheduling problems until the last section of this paper. At this point however, we would like to note that open loop near optimal order release scheduling policies may be determined by using simulation. To do this, one can run multiple replications of different order release scenarios under varying production floor conditions and can determine proper order release policies to satisfy production criteria specified by management.

3. SIMULATION IN DEVICE MANUFACTURING AND ASSEMBLY

Device manufacturing involves the mounting of chips onto electronic components. The final product of this process is referred to as a device. Device manufacturing is mostly automated because of high product variety and production volume. Once the chips are separated, they are fed into flexible assembly equipment which can be programmed. This flexible equipment is capable of producing high volumes of different products. The major problems that can be approached by simulation in this phase of production are:

1. **Machine Selection:** Most important application during the design phase.

2. **Capacity Analysis:** In most cases, it surfaces in the form of bottleneck analysis.

3. **Process Improvement and Automation Analysis:** This issue is becoming increasingly popular because the current emphasis on JIT (Just-In-time) and CFM (continuos flow manufacturing)

4. **Operator Analysis:** Usually included in capacity analysis or process improvement and automation analysis.

Again, detailed finite capacity scheduling problems are valid problems which must be addressed by proper scheduling techniques.

4. SIMULATION IN A PRINTED CIRCUIT BOARD (PCB) ASSEMBLY

At this stage, the similarities between electronics manufacturing and other manufacturing facilities become more clear. Like other manufacturing operations, a PCB assembly operation may involve manual, semi-manual, stand alone machines or may involve a totally automated assembly line. Most of the time the former operations are related to through hole component mounting whereas the latter operations mostly correlate to surface mount technology (SMT) lines. Most of the issues that relate to the analysis of assembly lines and operations are also valid for PCB assembly.

PCB assembly operations are totally integrated with test operations most of the time. However for the purpose of clarity, we will consider all test operations in a separate section of this paper.

Another important aspect of simulation models in a PCB assembly is that of cellular manufacturing operations and/or continuous flow manufacturing (CFM), i.e. a term which is equivalent to just in time (JIT) in manufacturing. Therefore, batch sizing and work in progress related issues are important in approaching PCB assembly design and operational issues. The most important problem list includes:

1. **Material Handling Design and Analysis:** This issue becomes more important as one goes into the direction of SMT and automated lines.

2. **Capacity Analysis:** Especially important in manual and semi-automated operations.

3. **Operator Requirement Analysis:** In most semi-automated operations, operators are used to transport parts between the different component insertion machines as well as between test operations. Therefore, operator analysis may also include material handling analysis.

4. **Process Improvement and Automation Analysis:** The dominant scheduling problem at this stage is batch sizing. Due to an increase in independent job shops like PCB assembly, a host of other scheduling problems come up. For example, in a made to order PCB assembly shop there is usually high variety and low volume. Therefore, due date scheduling is very important in such a shop. As in other manufacturing operations, the characteristics of scheduling problems are very case specific.

5. SIMULATION IN PRODUCT MANUFACTURING AND ASSEMBLY

Electronic products are assembly products with large numbers of components. Usually more than one of the same component is required for the product. Depending on the manufacturing organization, the products may include a number of subassemblies. Automated assembly is a valid option in electronics assembly operations but manual assembly is still very dominant in modern practice. Manual assembly lines can be organized with automated material handling equipment, in most cases with conveyors.
In a batch mode operation, several cells may serve each other. Continuous flow manufacturing is becoming very popular in this area. Another characteristic, the kitting of components is also interesting. We will discuss kiting issues in a later section of this paper. The list of problems is still very similar to our previous list with one addition which is, component inventory related problems.

1. **Capacity Analysis:** It is still valid in this phase of electronic manufacturing. However, it is more of a design and planning related issue.

2. **Operator Requirement Analysis:** This problem is also relatively important in manual assembly operations.

3. **Material Handling Design and Analysis:** Mostly for the analysis of conveyor systems or operations which carry different components or subassemblies to and from operations.
4. **Process Improvement and Automation Analysis:** Automation is a valid strategy for electronics assembly. Therefore, models dealing with automation analysis are common.

5. **Tool and Other Secondary Resource Requirement Analysis:** Tooling problems may surface as pallet and fixture planning problems

6. **Material Planning, Component Inventory Analysis:** Refers to the analysis of lot sizing and ordering decisions.

The dominant finite capacity scheduling problem in this phase is Material Scheduling. In most cases, the subassemblies feeding into the operations create the scheduling problems. Therefore, operation due date and batch sizing related issues become more important. Another important issue for scheduling at this phase is the scheduling of change-overs.

6. SIMULATION FOR TESTING OPERATIONS IN ELECTRONICS MANUFACTURING

We separated this as a different type of operation in electronics manufacturing because of several characteristics. In an electronics manufacturing environment, tests are usually performed on expensive test equipment. Test equipment may be manual, meaning that each piece may be loaded manually and an operator may have to be present to determine the results of the test. Alternatively, it may be totally automated, where a batch of units can be loaded for testing and the test results automatically recorded to some media.

Regardless of the method of testing however, testing is especially important in electronics manufacturing because of the characteristics and design of the products. Most test equipment is expensive or specifically designed for the operations. Therefore, modeling efforts for testing operations are very important in manufacturing environments. For example, a direct labor reduction of 10% is not uncommon because of improvements in testing operations.

Another aspect of testing in electronics manufacturing versus other manufacturing environments is that of multi level rejects. A rejected unit at the end of a test operation may be corrected manually or may be sent to a different level of a previous manufacturing or assembly step. These units may be considered totally new products when they arrive for the new operations because of their disassembly, component test and replacement procedures. In most electronic manufacturing environments there is also a great need for component traceability, which further complicates the modeling of test operations. Our list here still remains the same with a different emphasis as follows:

1. **Capacity Analysis:** This is still an important issue in regards to the amount of test equipment required.

2. **Operator Requirement Analysis:** This is a part of capacity analysis most of the time.

3. **Material Handling Design and Analysis:** In most cases this is not a primary problem. It may accompany one of the other problems.

4. **Process Improvement and Automation Analysis:** This is extremely important in the testing of electronic equipment. The possible difference in this area is well worth even the most difficult modeling.

5. **Machine and Equipment Selection:** It is mostly integrated with process improvement and automation analysis.

6. **Tool and Other Secondary Resource Requirement Analysis:** It is no different than the previous discussion regarding product manufacturing and assembly.

The finite scheduling problem in regards to test operations may be considered part of the capacity related problems. If the same test equipment is used for more than one product line however, there may be some machine scheduling issues which are similar to other manufacturing problems.

7. SIMULATION OF PACKAGING, SHIPPING, WAREHOUSE AND INVENTORY RELATED PROBLEMS

This set of problems is not very different than those of other manufacturing environments, so we are not going to go into great detail. One problem however, is almost case specific regarding its characteristics; that is the kitting problem.

Kitting refers to a collection of all the subassemblies and components which are required in an assembly of a given number of units. Such a set of components and subassemblies is called a kit. In a traditional electronics assembly scenario, a kit is processed at different steps of the assembly. Obviously, kitting requires additional operations by a number of resources. The advantage of kitting includes better traceability, avoidance of part shortages, etc. The disadvantages of kitting include; additional operations as well as quality related problems resulting in work stoppages at different departments. This is an area where simulation modeling can make a extremely important difference.

Because of space limitation we are not going to discuss each of the problems that are also applicable to this area. The importance however changes very much from one organization to another and is similar to their counterparts in other manufacturing areas.

8. FINITE CAPACITY SCHEDULING AND SIMULATION IN ELECTRONICS MANUFACTURING

As has been seen in our previous discussion, there are more related finite capacity scheduling problems in addition to our list of simulation problems. This is not only valid for electronics manufacturing but is also valid for other manufacturing systems as well. We would like to devote the following section to a discussion of the differences in approaches between finite capacity scheduling and simulation modeling. The characteristics are summarized below:

Finite Capacity Scheduling is Mainly a Deterministic Tool Whereas Simulation is a Stochostic Tool: Most finite capacity scheduling models or systems do not consider randomness explicitly. The rework and reject loops and probabilistic routings between operation steps are not considered in Finite Capacity Scheduling.. FCS models use deterministic process times, set-up times, and transport times whereas simulation almost invariably uses probability distributions for process times, set-up times, and transport times. Some of this is due to the aggregation of different products or different units into an "entity" in simulation models. Most of the variability however, is valid variability however, is valid even for each product. For example, the assembly times in an assembly line may be different from one assembly to another.

Finite Capacity Scheduling Addresses Shorter Horizons Whereas Simulation Addresses Longer Planning Horizons: At least the current use suggests that simulation is a valuable tool for addressing long term design and planning problems whereas finite capacity scheduling is an excellent tool for addressing short term and on-line execution problems.

The Degree of Detail is Different in Finite Capacity Scheduling and Simulation: We do not mean that finite capacity scheduling models are more detailed than simulation, but because the purpose of these two modeling tools are different, the degree of detail is different. Scheduling systems have a more detailed representation of the real part numbers, product types and routing steps whereas simulation models are much more representative in the probabilistic routings and in the modeling of secondary and additional resources. For example, in a simulation model, an operator and a machine may be modeled for the loading and unloading of parts whereas only a machine may be required in-between. In a scheduling model it is not uncommon to specify an operator as a secondary resource with a 50% requirement. This illustrates that although they are inherently similar, the different tools of simulation and scheduling are essential for electronics manufacturing. These tools may be integrated however, for better use of data and to reduce modeling time.

9. CONCLUSIONS

We have identified several problems which can be addressed using simulation for electronics manufacturing. As can be seen from the list, capacity analysis in the form of machine and operator requirement analysis, tops the list. This is because of the concurrent utilization of different resources in electronics manufacturing. These resources may include machines, operators, and other tools and devices. The other important element in our list is the high variety. Therefore problems stemming from these issues include: Batch Sizing, Component and Subassembly Requirements, and Material Handling Systems.

In our analysis we have indicated that most scheduling problems, although very similar to simulation related problems, require a different level of detail. Combined with other factors in regards to the probabilistic and planning issues, a different framework is required for solving scheduling problems. We highly recommend an integrated approach which may reduce data entry operations for the users of size systems. Such an approach would promote rapid modeling and therefore, better effectiveness of both types of systems.

By applying the proper integrated techniques, we believe that the amount of performance increase in an electronics manufacturing facility would exceed all management expectations, greatly.

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