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A FLEXIBLE SIMULATION FRAMEWORK FOR EVALUATING MULTI-LEVEL, HEURISTIC-BASED PRODUCTION CONTROL STRATEGIES

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ABSTRACT

Operational flexibility can be used to great advantage in many manufacturing and assembly environments. This operational flexibility can be in the form of flexible workstations or cells, flexible planning and control strategies, or some combination of both. Effective evaluation tools are needed to help in the development of these flexible control strategies (FCSs). In some environments, due to the large number of scenarios that require examination, it is necessary for the evaluation tools themselves to maintain a great deal of flexibility. In this paper, a flexible simulation framework is described.

The effectiveness of the framework is tested in the development phase of a heuristic-based, three-level FCS. The production basis for this experimentation is a mixed technology printed circuit board assembly plant. The performance of the flexible framework is discussed with a focus on the advantages and limitations of the approach in this challenging environment.

1. INTRODUCTION

Flexible control strategies (FCSs) can be used to advantage in many manufacturing and assembly environments. While they may be advantageous, they may also be very difficult to develop and implement. This is especially true at the operational level, where a number of factors can interact dynamically to rapidly change system status. Perhaps equally as difficult is the development of evaluation tools to determine the benefits and restrictions associated with using a particular FCS. This paper focuses on the development of an effective evaluation tool to support FCS development in a difficult environment.

2. BACKGROUND INFORMATION

The evaluation tool presented in this paper is used to support the development of a heuristic-based, dynamic FCS in a flexible assembly system (FAS) environment. This FCS is described in detail in [Taylor 1990]. The FCS makes use of a natural control hierarchy composed of three levels, taking advantage of flexibility in product mix determination at the system level, product routing flexibility at the cell level, and flexibility in buffer sequencing at the machine level. At each of the three levels, control strategies are evaluated for use as stand-alone operational control elements and as members of integrated multi-level FCSs. Although production data for the research in [Taylor 1990] is obtained from several sources in North America, Europe, and Asia, the primary production basis and test facility for the research is a mixed technology printed circuit board assembly plant in Connecticut. This facility provides actual production data and serves as a valuable validation source for solution approaches. It is described in more detail in [Taylor and Graves 1990]. The complex FCS structure and difficult operating environment presented in [Taylor 1990] and [Taylor and Graves 1990] make the development of effective evaluation tools a difficult task in several ways.

One source of difficulty is the inherent dynamic nature of the operational control problem in a FAS. Each processing center and each product in the system provide a source of random events. Product mix and process availability contribute dynamically to the creation of system level and cell level bottlenecks. The evaluation tool selected must be able to successfully capture the effects of random events.

Another source of difficulty arises when a large number of scenarios must be evaluated in FCS development. Heuristic-based solution techniques often require the examination of a large number of scenarios. This is especially true in the test case presented in this paper because heuristic solutions are employed at multiple levels. The FCS also makes use of interfacing heuristics between the three control levels employed. The examination of each scenario requires that changes be made to evaluation tools. It is desirable to minimize these changes as the effects of various heuristic solution approaches are explored.

Finally, it may be said that the electronics industry presents a difficult operating environment. The industry is characterized by rapid changes to product structures and process technologies. In printed circuit board assembly, rapid changes to component packaging technology have led to much greater product variability than previously encountered, and product life cycles are increasingly shorter. Assembly processes are also rapidly changing, and manufacturers are attempting to build flexible processes that are capable of assembling a wide range of mixed technology products as the product evolution continues.

Suri [1985] has divided evaluative models for flexible manufacturing systems into five categories; static allocation models, queueing network models, simulation models, perturbation analysis, and Petri-nets. Each of these modelling techniques have advantages and disadvantages. Buzacott and Yao [1986] suggest that analytical models may be superior to simulation models but claim that analytical approaches are not practical in many cases due to their slow development and degree of abstraction from reality.

3. SOLUTION APPROACH

In spite of inherent difficulties, it appears that there is no better evaluation tool than discrete event system simulation for evaluating the FCS problem in electronics assembly. No other modeling tool provides the ability to accurately quantify the effects of using various FCS scenarios in a highly dynamic environment. The extra development work is justifiable in this case.

At the core of the solution approach is a flexible simulation framework (FSF) that helps to minimize the set-up time associated with the transfer between alternative scenarios. Other authors have suggested similar solution approaches and have offered helpful ideas. Shroer and Tseng [1987] develop general purpose simulation generators to represent assembly stations, manufacturing cells, and inventory transfer functions. These components can be liked together to model many manufacturing systems. Ben-Arieh and Moodie [1987] describe a knowledge based routing system (KBRS) which consists of a static data base, a dynamic data base, behavioral knowledge, procedural knowledge, and a simulation driver.

Their approach is to tune the KBRS as suggested by observed system behavior.

As in [Shroer and Tseng 1987], the approach in this paper breaks the simulation task into component parts linked together to create a scenario. The solution approach is also similar in several ways to the work described in [Beh-Arieh and Moodie 1987]. The primary driver is discrete event system simulation using the SIMAN language. A static data base maintains key processing parameters. Dynamic data such as work in process information, queue length status, machine status, and product attribute information are managed through the combined use of SIMAN and FORTRAN. The heuristics which control operational decision making explicitly include procedural information such as the ability to determine which alternatives are feasible. Additionally, the heuristics implicitly include behavioral knowledge and attempt to make decisions based on expected behavioral improvements in the FAS as a result of the decision. As in [Ben-Arieh and Moodie 1987], observed behavior is used to tune the heuristics in each of the experimental scenarios based on current and historical information.

Figure 1 presents the simulation model architecture in more detail and indicates that the actual modelling methodology may be broken down into four major components; the SIMAN model frame, the SIMAN experimental frame, FORTRAN subroutines, and external data files. At the heart of the simulation architecture is the station code which resides in the SIMAN model frame and represents each process in the manufacturing environment. The SIMAN experimental frame contains information defining system experimental conditions, specifying replication data, and stipulating that the statistical output be routed into data files for subsequent examination using the SIMAN output processor. The flexible control heuristics range from quite simple to very complex depending upon the scenario and reside primarily in interchangeable FORTRAN subroutines.

4. PERFORMANCE OF THE FLEXIBLE MODEL

The performance of the FSF is tested in a variety of FCS scenarios. Initially, a baseline model which is characterized by a total lack of processing flexibility is examined. This scenario provides a basis of comparison for scenarios featuring some degree of flexibility in operational control. The baseline makes use of a fixed product mix, first-come-first-served sequencing, and one routing per product. The most difficult feature of the baseline model from a simulation viewpoint is the inclusion of finite-sized, blockable machine buffers in the presence of multiple products with different routings. Fortunately, the station code in the FSF contains enough flexibility to allow for this feature. Station release information is carried as an entity attribute in the FSF. In this way, at any particular work station, it is possible to release or block any of several machines which may have been the immediate assembly predecessor station for any particular workpiece.

The addition of system level control heuristics to regulate product mix adds to the complexity of the simulation task, yet the FSF performs well. In spite of the complexity of the mix task which includes the loading problem (which products to input), the release problem (when to input), and the lot size problem (how much to input), the FSF allows most scenarios to be examined with relative ease by simply exchanging scenario specific heuristic coding in the subroutine labeled "mixer code" in Figure 1. The coding changes are somewhat more difficult for scenarios involving "pull" processing or hybrid "push/pull" processing environments instead of the baseline "push" strategy. In these scenarios, additional changes must be made to the system controller in the SIMAN model frame to help initialize the system with work in process.

The utility of the FSF is further demonstrated by examining the effects of adding inter-cell routing flexibility. This flexibility refers to the ability to conduct assembly operations in alternate sequences, but does not extend to the ability to use alternative resources for specific assembly operations. The cell level controller in the FSF, labeled "router code" in Figure 1, recognizes routing decision points for each product based upon precedence constraints and provides the opportunity to make routing decisions based on a variety of different heuristic procedures.

One major difficulty associated with using the FSF must be overcome when a high degree of routing flexibility is avail-

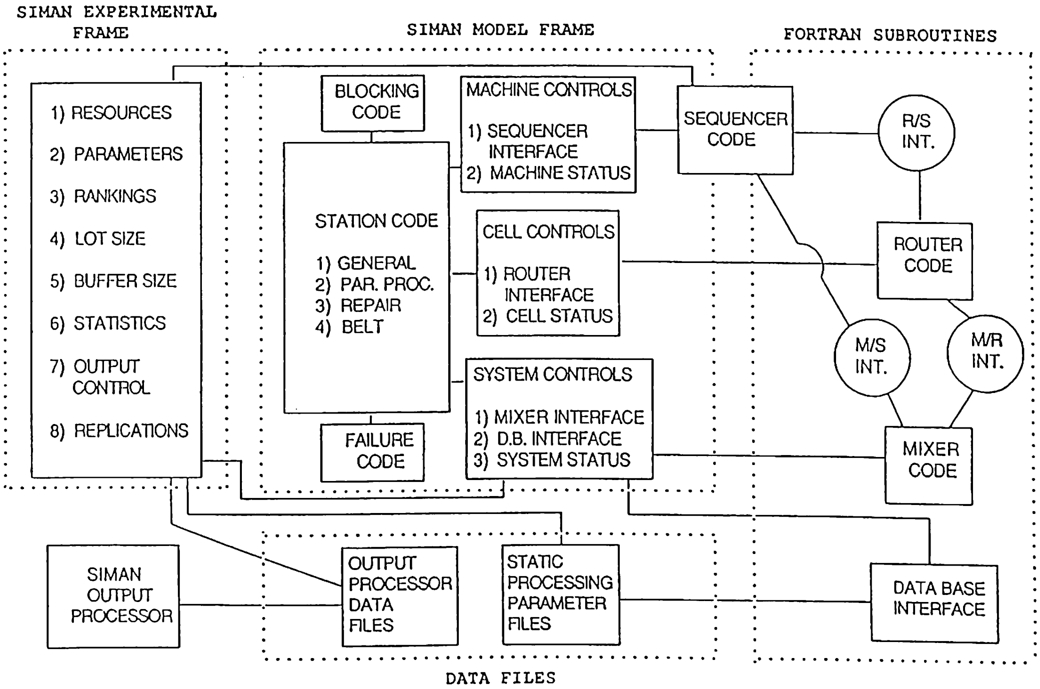

Figure 1. Simulation Model Architecture

able. As previously mentioned, the basis FAS is characterized by a finite queueing strategy with blocking, and the simulation code specifies that machine releases be based upon product attributes. With alternate routing sequences, it is possible in rare occurrences that two blocked cells or stations can hold the release attributes for each other, resulting in a "gridlock" effect that eventually paralyzes the entire assembly system. Additional rules must be included in the router code to prevent this phenomenon while using the FSF.

The FSF performs especially well when evaluating scenarios which make use of machine level sequencing heuristics to manage the selection of jobs from individual machine buffers. Figure 1 shows that a combination of SIMAN and FORTRAN is used for the sequencing task. This allows the FSF to make use of certain features available in the SIMAN language to make the programming task to incorporate different sequencing strategies less complicated. For example, the SIMAN RANKINGS block can be used in the experimental frame in combination with product attribute manipulation in the SIMAN model frame and FORTRAN subroutines. Other scenarios make use of the SEARCH and REMOVE blocks to select jobs from individual queues based upon a particular condition or product attribute.

The FSF receives more rigorous testing when scenarios which make use of flexible controls at multiple levels are examined. The FSF strategy of providing an interface between heuristic policies at each level in the control hierarchy appears to be an effective one.

Consider the scenario which includes flexibility in both cell level routing and system level product mix determination. As stand-alone policies, the router and the mixer have different and sometimes conflicting goals. These differences can be managed effectively using the FSF. Integrating heuristic code, residing in a FORTRAN subroutine, is called at periodic intervals to determine what action is required based upon a dynamically maintained data base which receives input from both system and cell level sources. Scenario changeover time using this approach is quite acceptable, requiring only the exchange of substitutive subroutines.

In other multi-level control scenarios, a different approach to integration may be pursued using the FSF concept. Instead of providing actual interfacing subroutines, it is possible in some cases to coordinate the heuristic decision making at each level by ensuring that complementary policies are guiding decisions at each level. This strategy is justified when more direct integration attempts result in a model that is an abstraction of reality. Consider, for example, the scenario which includes flexibility in cell level routing and machine level sequencing. It is certainly possible to use a common machine buffering concept where jobs could be selected from a central location by a number of different processing steps as machines become available. The jobs could be selected using any sequencing criteria deemed appropriate. Since a number of potential processes would be pulling jobs from this queue based upon specific precedence constraints, the routing problem and the sequencing problem would be solved concurrently. Although this approach is a viable method of solving a routing/sequencing problem, it violates the assumption that only finite sized individual machine level buffers exist in the basis facility.

When scenarios are examined making use of flexibility at all three levels in the control hierarchy, the true utility of the FSF is recognized. Since it is desirable to examine a number of different heuristic alternatives at each control level, and because a number of alternatives are available for integrating those heuristics, then a large number of permutations exist. Therefore, it is extremely beneficial that the FSF permits the use of interchangeable control and integration subroutines. The FSF described in this paper standardizes, as much as possible, the inputs and outputs required by these subroutines to ensure that they are interchangeable. The result is that a large number of alternative control scenarios are able to be examined using the FSF in a short amount of time.

In addition to providing the ability to easily examine the effects of changes to system policies, the FSF is designed to facilitate the examination of changes to system conditions such as input lot size, buffer size, set-up times, etc. Sensitivity analysis is performed using data from the basis facility to test the ease of using this feature. Generally, all sensitivity analysis can be performed by changing input parameters in the SIMAN experimental frame or static data base files.

5. CONCLUDING REMARKS

As pointed out by Pritsker [1987], it is difficult to evaluate the worth of a model because measurable criteria are generally not available to quantify the value. However, the FSF described in this paper tremendously reduces changeover time between scenarios and allows the rapid examination of multiple heuristic alternatives. Through the inclusion of specific interfacing mechanisms between control subroutines, and through standardization of inputs and outputs to those subroutines, the FSF helps to isolate operational control problems and helps to minimize the management task associated with operational flexibility. This feature is especially important as additional operational flexibility is made available.

Additional research could focus on the further standardization of inputs and interfaces in an effort to make control and integration subroutines even more interchangeable. One of the key limitations associated with the current approach is that exotic scenarios may require changes to the subroutine input/output, perhaps resulting in significant coding changes elsewhere. Although SIMAN and FORTRAN are used with a great deal of success in this study, perhaps other tools would be equally or perhaps even better suited for additional work.

This approach shows the advantages of seeking flexible, creative solutions in the development of new evaluation tools for flexible environments. The FSF approach has proven to be effective for use in the test environment of flexible electronics assembly. Furthermore, it appears that this approach may be valuable in a variety of related manufacturing and assembly situations that require the examination of a large number of scenarios.

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