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SBDSS - A SIMULATION BASED DECISION SUPPORT SYSTEM

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ABSTRACT

Factory managers compare different financial and operational strategies based on their own objectives. These objectives are often conflicting and hard to evaluate merely in a quantitative way. SBDSS (Simulation Based Decision Support System), based on simulation, DSR (Dynamic Sequencing Rule), and the AHP (Analytic Hierarchy Process) method enables the decision maker to arrive at the optimum decision by taking into account all of the relevant quantitative and qualitative information.

1. INTRODUCTION

Manufacturing modeling and simulation techniques [Anderson and Diehl 1988, 1989; Suri 1988; Law 1982, 1988] provide an accurate and effective means to forecast the effects of different operations as well as financial strategies. One of the most difficult problems in any complex manufacturing organization is scheduling. Often, simulation is applied to search for an answer to the following common question, "What is the optimal decision rule to use in scheduling?" That is, given a backlog of orders at an operation, which local scheduling rule will yield the best results? But what is meant by the best results?

A factory manager usually has different (possibly conflicting) objectives in mind. Among these goals are:

- *Minimize WIP (Work-In-Process)*
- *Balance the plant-wide work load (avoid higher utilization for one machine and lower for the other)*
- *Achieve on-time delivery performance*
- *Maximize throughput*
- *Minimize overall operation costs*

Scheduling literature [Blackstone et al.1982] offers some well established rules that perform best relative to a specific measure of performance. However, when several response measures are of concern, then a definitive knowledge of what is the "appropriate rule" is hard to establish. For this reason, decision makers usually prefer one strategy over another based on the closeness of the outcomes to their own objectives. Often, it is very difficult to evaluate these objectives in a quantitative way. Therefore, alternatives must be negotiated so that the ultimate decision can reflect the desires and compromises of the decision makers.

In this paper, we introduce SBDSS, which is a valuable tool for considering and evaluating simultaneously the tangible and intangible criteria during the operational decision-making. SBDSS consists of three main modules: Simulation, Sequencing, and MCDM (Multiple Criteria Decision Making) [Saaty 1977]. Using SBDSS, decision makers can make a better and more carefully weighed decision by combining the results generated from the MCDM module and scores achieved by the candidate alternatives from the Simulation and Sequencing modules.

The organization of this paper is as follows. In section 2, we describe the SBDSS framework and general architecture. In section 3, we discuss the functionality of different modules of SBDSS, including the user interface. In section 4, we present an example to demonstrate how the system works. Finally, in section 5, we conclude the paper with some final remarks. To understand the concepts and methodologies that are utilized by SBDSS, the user is encouraged to study the example presented in section 4.

2. THE SBDSS FRAMEWORK

In manufacturing, it is often the case that certain criteria should be fulfilled and different options are available to meet them. For example, given a number of orders with different due dates and process plans (in a job shop), one might be interested in meeting all of the due dates while maintaining a low (WIP) level, high machine utilization, and short flow times. These objectives are basically conflicting and it is difficult to apply an operational strategy to result in an optimum level for each one of them. Therefore, it is important to understand the trade-offs and construct a policy based on the relative importance of these criteria.

SBDSS, is a decision-making aid that provides the user with the optimum operational discipline based on the plant conditions, product characteristics, and management objectives. Figure 1, illustrates the overall architecture of the SBDSS and the interactions between its different modules.

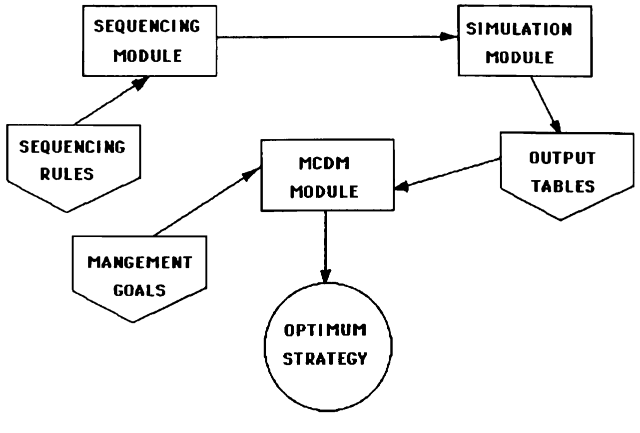

Figure 1. The Architecture of SBDSS

As shown in Figure 1, SBDSS consists of three main modules:

- *Simulation Module*

Using the simulation module and given the manufacturing model, different scenarios can be quickly simulated and the outcomes can be saved for later evaluation.

- *Sequencing Module*

This module enables the decision maker to formulate optimum sequencing rules (by utilizing DSR [Shahraray 1988]) based on the specifics of the plant and products and the objectives of the management.

- *Multiple Criteria Decision Making (MCDM) Module*

This module is based on the AHP method and allows the decision makers to realize the relative importance of their goals.

The functionalities of these modules are discussed in section 3.

3. THE SBDSS MODULES

3.1 Simulation Module

The discrete event simulation software used in this module is SIMAN. As shown in Figure 2, SIMAN is one of the components of RSPE (Rapid System Prototyping Environment). RSPE is an integrated set of tools that enables the analyst to rapidly investigate the decisions in all stages of the design and operation of manufacturing systems. The other components of the RSPE (in addition to SIMAN) are: MANUPLAN, SIMSTARTER, and CINEMA. The functionality of each component is briefly discussed below (for more information about RSPE refer to [Anderson and Diehl 1988, 1989; Suri 1988]).

- *MANUPLAN* is a rough-cut analysis tool for studying the dynamics of manufacturing systems through analytical modeling. Using this tool, decision makers can build models quickly and perform some preliminary what-if studies.

- *SIMSTARTER* allows almost instantaneous conversion of the analytical model into SIMAN simulation code. It greatly reduces the time required to develop the discrete event simulation model.

- *SIMAN* offers detailed simulation modeling abilities to industrial users. Using SIMAN, the models generated by MANUPLAN and SIMSTARTER can be fine-tuned and studied in detail.

- *CINEMA* provides the analyst with the life-like representation of the system. Using CINEMA, the manufacturing model can be visualized and the accuracy of the assumptions can be examined.

Note that RSPE utilizes manufacturing data (such as orders, process plans, maintenance, reliability, etc.) that could be stored in a manufacturing data base. The manufacturing data base can be easily updated to reflect changes in the manufacturing plans and parameters.

SBDSS assumes that a valid simulation model of the manufacturing application is available (by RSPE). Given this valid manufacturing model, the goodness of different sequencing rules can be examined by the simulation module. Each simulation run results in a performance table that contains the following response measures.

- *Length of the simulation run*
- *Number of orders completed*
- *PDD (percent due dates met)*
- *ACT (Average cycle time)*
- *MU (Average machine utilization)*
- *Average WIP*
- *Average lateness*
- *Average earliness*
- *Total lateness*

The performance tables are then saved, to be utilized later by the MCDM module in its comparisons.

3.2 Sequencing Module

The Sequencing Module contains a collection of sequencing rules that can be selected. Sequencing decisions involve dispatching, which includes routing of orders through certain work centers and the determination of the sequencing of the orders at each work center. Because of contingencies arising from randomness (machine breakdown or maintenance, job mix, random arrival of new orders, etc.) queues of orders waiting to be processed usually form at the work stations. Therefore, selection of a proper sequencing strategy can be crucial to the overall performance of a production environment. Performance of different sequencing rules vary depending on the type of the factory, specifics of the products, and the goals set by the management [Blackstone et al. 1982].

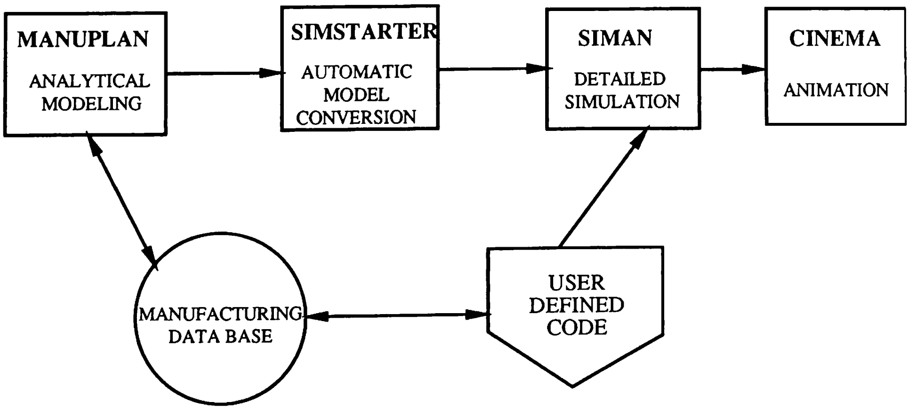

Figure 2. Rapid System Prototyping Environment

The Sequencing module offers a set of well known sequencing rules such as:

- *FIFO (First In First out)*
- *SPT (Shortest Processing Time)*
- *LPT (Longest Processing Time)*
- *EDD (Earliest Due Date)*
- *SRPT (Shortest Remaining Processing Time)*
- *LRPT (Longest Remaining Processing Time)*
- *MNOR (Most Number of Operations Remaining)*
- *LNOR (Least Number of Operations Remaining)*
- *RANDOM*

These rules, as established in the literature, might perform well in terms of one response measure and not so well in terms of another. For example, while SPT guarantees the minimization of the average cycle time, EDD promises the most number of jobs completed on time. For this reason, in addition to the above rules, the Sequencing Module also offers DSR (Dynamic Sequencing Rule [Shahraray 1988]).

DSR is a combined priority function of weighted decision factors. Using DSR, optimum sequencing strategies can be formulated based on the specifics of the plants and products and the goals of the decision maker. This is done by modifying the coefficients that define the relative weighting or importance among the decision factors in the rule. Therefore, DSR allows the decision maker to include all relevant decision factors in the priority rule and assign desired weights to them.

Selection of the decision factors for the priority function is a judgmental matter which rests upon the decision maker's assessment of the relevance of alternative factors to his/her production environment. Some possible factors for inclusion are due date, imminent processing time, order value, customer value, operations remaining, WIP value, release date, total processing time, machine status, scheduled maintenance, and machine idle time look-ahead.

3.3 MCDM Module

Using the MCDM Module, the decision maker can select the best sequencing rule that results in the optimum production performance. Furthermore, the MCDM Module allows a group of decision makers to work together and reach a consensus on the best sequencing alternative. This is a significant feature since, in a manufacturing environment like any other organization, decisions might be made by several managers who might have conflicting objectives. The decision makers, Through interactive sessions, can prioritize their goals and reevaluate the performance of different sequencing rules (provided by the Sequencing and Simulation modules) based on their own preferences, experience, and knowledge. The MCDM Module, by utilizing the AHP methodology and the inputs from the decision makers, assigns ranks to the selected sequencing rules and recommends the best one. To clarify the role of the MCDM module, we present a brief background on the AHP methodology. (more details on AHP can be found in [Saaty 1977, 1980; Forman 1983])

AHP is a theory of measurement for dealing with quantifiable and/or intangible criteria that has found abundant application in decision theory, conflict resolution, and in models of the brain. It is based on the principle that, to make decisions, experience and knowledge of people is at least as valuable as the data they use. The philosophy behind the three major components of the AHP (*analytic, hierarchy, and process*) are briefly described below.

- *Analytic*. Simply put, the AHP uses numbers (mathematical/logical reasoning) to describe a decision.

- *Hierarchy*. The AHP structures the decision problem in levels that correspond to one's understanding of the situation: goals, criteria, subcriteria, and alternatives (as shown in Figure 3). By breaking the problem into levels, the decision maker can evaluate smaller sets of decisions and complex situations can be handled easily.

- *Process*. Any real decision problem involves a process of learning, debating, and revising one's priorities. In the case of group decision making, solutions often need to be negotiated to satisfy the requirements of all the members of the group.

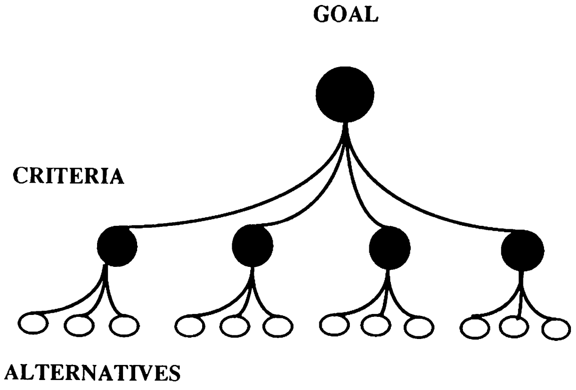

Figure 3. The AHP Hierarchical Structure

In AHP, evaluation of a structured decision problem (such as the one shown in Figure 3) is carried out based on the concept of paired comparisons. The elements in a level of the hierarchy are compared in relative terms as to their importance or contribution to a given criterion that occupies the level immediately above them. This process of comparison yields a relative scale of measurement of the priorities or weights of the elements. That is, the scale measures the relative standing of the elements with respect to a criterion independent of any other criterion. These relative weights sum to unity. The comparisons are performed for the elements in a level with respect to all the elements in the level above. The final or global weights of the elements at the bottom level of the hierarchy are obtained by adding all the contributions of the elements in a level with respect to all the elements in the level above. This is known as the principal of hierarchic composition. While there is an infinite number of ways of synthesizing the weights of the alternatives and the weights of the criteria, the additive aggregation rule of the AHP has the advantage of intuitive understanding of the apportionment of the whole into its parts. The result not only shows the ranking of the alternatives but also provides a meaningful (ratio scale) measure of the differences between them.

In the context of SBDSS, *GOAL*, *CRITERIA*, and *ALTERNATIVES* can be defined as;

- *GOAL:* Improving productivity, minimizing the overall cost, or maximizing the profit.
- *CRITERIA:* Smaller WIP, higher machine utilization, shorter average cycle time, maximize the throughput, on-time deliveries, minimize earliness.
- *ALTERNATIVES:* Different sequencing rules such as FIFO, SPT, EDD, etc. or sequencing rules that are formulated using the DSR mechanism.

The example presented in section 4 illustrates how, in SBDSS, the criteria and the sequencing rules based on each criterion are compared. Furthermore, this example demonstrates how the final scores for different rules are computed and the rule with the highest score is recommended.

3.4 SBDSS User Interface

The DM's (decision maker) interaction with SBDSS is through different menus. A typical SBDSS session consists of the following steps.

1- SELECT A MODEL: Here the DM can select a specific manufacturing model to examine. SBDSS assumes that the manufacturing models are provided by RSPE and that they represent the true dynamics of the production line.

2- *SELECT THE SEQUENCING RULES:* The DM can select one, some, or all of the sequencing rules that are available. He/she can also formulate unique rules using the DSR capabilities. This is done by assigning appropriate disjoint or overlapping weights to different DSR indexes to form a priority rule based on the user's preferences. For example, the user can formulate a rule named *DSR1* in the form of *EDD-SPT-FIFO*. This means that *EDD* is applied as the primary rule, then *SPT* as the secondary rule, and finally, *FIFO* as the tie breaker.

3- *RUN SIMULATION:* This option invokes the simulation program to simulate the manufacturing model of interest and establish the effectiveness of the selected sequencing rules. The resulting performance tables are stored for future reference by the MCDM Module.

4- *GENERATE PERFORMANCE TABLE:* Using this option, the DM can specify the criteria of his/her concern and obtain a summary evaluation table (from the simulation runs) to investigate the effectiveness of the selected rules based on these criteria. Note that the DM might be interested in one, some, or all of the available criteria.

5- *RUN MCDM:* This option enables the DM to make the final decision on the best sequencing rule. The comparisons of the rules and criteria are carried out in two stages. In stage one, the results generated from the simulation runs are presented to the DM to allow him/her to compare different rules against different criteria. The DM might choose to confirm the simulation results (the higher the better for example in the case of the on-time delivery rate) or he/she might want to score the results based on the information that is only available to him/her. To explain the latter, suppose the DM (say, from experience) knows that the optimum machine utilization level is 75%. Now, if one rule results in 80% machine utilization and the other one in 72%, the DM might prefer the second one because overutilizing machines might create costly maintenance problems.

In stage two, the DM is asked to compare the criteria pairwise to communicate the relative importance of them to SBDSS. For example, missing the deadlines might be more expensive than maintaining a low machine utilization. SBDSS, based on the inputs provided by the DM (in stages 1 and 2), recommends the best sequencing rule. Note that if there are multiple decision makers, stages 1 and 2 will be repeated for every person. This way, the final decision suggested by SBDSS reflects the preferences of all the members of the group.

6- *EXIT:* the DM can terminate the session when a satisfactory solution is found. Note that the DM can repeat steps 2, 3, 4, or 5 until he/she is satisfied with the result.

The example in section 4 provides more details about SBDSS commands and menus.

4. A MANUFACTURING DECISION MAKING SCENARIO

Suppose that the production control manager (*Ms. PCM*) of the *PCB TEST CELL* is interested in investigating which operational strategy results in maximum profit. From her five years of manufacturing experience, she believes that the most important criteria that contribute to the profit margin are: PDD, ACT, and MU (defined in section 3.1). *Ms. PCM* decides to use SBDSS to evaluate three different sequencing strategies (FIFO, DSR1, and DSR2) and implement the most effective one. Figure 4 illustrates the hierarchical structure of the *PCB TEST CELL* problem.

The interaction of *Ms. PCM* with SBDSS, in order to arrive at the final decision, is summarized below.

- *Ms. PCM* selects the *PCB TEST CELL* simulation model (which is available to SBDSS). The complete description of the model (product mix, process plans, and equipment reliability information) can be found in Anderson and Diehl [1989] paper. For the sake of this example, we assume that *Ms. PCM* chooses to study the behavior of the system after 28800 simulated minutes (one 8 hour shift per day 210 working days per year). Furthermore, we assume that the products have fixed due dates equal to two times their lead times (lead time is defined as the total processing time without waiting time).

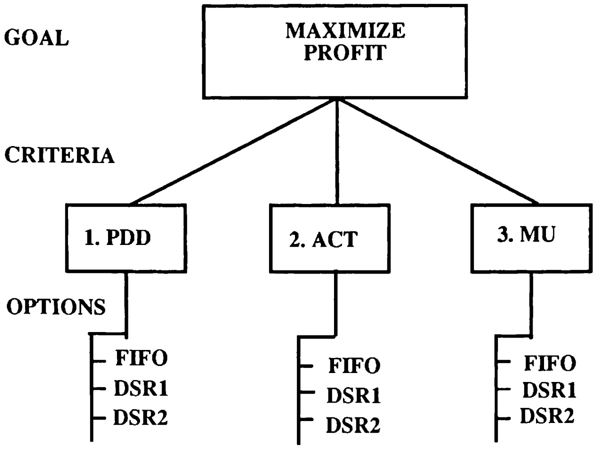

Figure 4. The Hierarchical Structure of the PCB TEST CELL Problem

- *Ms. PCM* identifies the following three sequencing rules to be examined, each with one performance criterion in mind.
  - FIFO (maximizing MU)
  - DSR1, in the form of SPT-EDD-FIFO (minimizing ACT)
  - DSR2, in the form of EDD-SPT-FIFO (maximizing PDD)

Note that we have already explained (in sections 3.2 and 3.4) how sequencing rules such as DSR1 and DSR2 can be formulated.

- *Ms. PCM* next invokes the GENERATE PERFORMANCE TABLE option. As a result, three simulation runs, one for each selected sequencing rule are performed and the results are listed in Table 1.

Table 1. Summary Performance Table

CRITERIA		PDD	ACT	MU
	FIFO	93.31	1273.35	0.65
RULES	DSR1	93.42	1251.08	0.64
	DSR2	94.30	1261.90	0.64

- Finally, *Ms. PCM* attempts to make the decision on the best sequencing rule by invoking the MCDM module. At this stage, *Ms. PCM* is asked to rank (from 1 to 10) the performance of each rule based on each criterion. Ms. PCM, by checking Table 1 against her knowledge about the optimum performance levels of the criteria, ranks the sequencing rules (demonstrated in Table 2).

Table 2. Ranks of the Sequencing Rules

CRITERIA		PDD	ACT	MU
	FIFO	5	2	7
RULES	DSR1	7	7	6
	DSR2	9	5	6

Next, *Ms. PCM* is asked to make a pairwise comparison of the criteria to communicate their relative importance to the MCDM Module. At this stage, she is asked to use Saaty's ratio scale [7,10] from 1 (two elements equally important) to 9 (one element absolutely dominant over the other). The results are presented in Table 3. Note that in table 3, diagonally opposite elements are reciprocals. The principal eigenvector of the resulting reciprocal matrix is a measure of the relative weight given to each of the criteria.

Table 3. Pairwise Comparison of the Criteria

How much more does criterion (row) than criterion (column) contribute to your final goal?	**PDD**	**ACT**	**MU**	**WEIGHTS**
PDD	1	4	6	**0.691**
ACT	1/4	1	2	**0.204**
MU	1/6	1/2	1	**0.105**

At this point the MCDM module, using the information provided in tables 2 and 3, computes the final scores of the sequencing rules and illustrates the results in Table 4.

Table 4. The Final Decision

The final scores for the selected sequencing rules

RULE	**SCORE**
DSR2	7.869
DSR1	6.895
FIFO	4.598

DSR2 Yields the best result.

As shown in Table 4, the MCDM Module recommends **DSR2** as the best rule. Here, we briefly discuss why **DSR2** is a reasonable choice for the PCB TEST CELL problem.

From the formulation of DSR2, we know that the EDD term has the largest weight. Therefore, we expect that DSR2 performs the best in terms of PDD. In fact, Table 1 shows that DSR2 outperforms both FIFO and DSR1 in terms of PDD, yields a smaller ACT than FIFO, and achieves comparable MU to DSR1 and FIFO. On the other hand, from Table 3, it can be seen that *Ms. PCM* assigns the highest weight to the criterion PDD and the second highest weight to ACT. Therefore, the above argument supports the choice of **DSR2** as the best operational strategy for this problem.

As mentioned before (section 3.3), often, in a manufacturing environment, decisions must be negotiated to fulfill the requirements of several mangers (possibly with conflicting goals). For example, suppose in our hypothetical study, in addition to *Ms. PCM*, the Inventory Control Manager (*Mr. ICM*) is involved. Then the comparison steps in the MCDM module should be presented to *Mr. ICM* as well as *Ms. PCM*. This is because the objectives and preferences of *Mr. ICM* and *Ms. PCM* might be different (and indeed they are) and the recommendation of the MCDM module should reflect these differences (and indeed it does!).

5. FINAL REMARKS

In this paper, we have shown that SBDSS can facilitate operational decision making in manufacturing environments by helping the decision maker:

- organize complexity
- incorporate quantitative information as well as knowledge and intuition based on years of experience
- consider trade-offs among competing criteria and/or alternatives
- synthesize to determine the best alternatives
- communicate the rationale for selecting a strategy to others

SBDSS can be used to supply an effective operational strategy every time there is a change in the objectives of the decision makers and/or the conditions of the production line or characteristics of the products.

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REFERENCES

Anderson, K.R. and G.W. Diehl (1989), "Rapid Modeling: In the Design of a New PCB Manufacturing System," *In Proceedings of the 1989 Winter Simulation Conference*, 818-827.

Anderson, K.R. and G.W. Diehl (1988), "Rapid Modeling: Implications for Business Planning," *In Proceedings of the 1988 Winter Simulation Conference*, 691-696.

Blackstone J.H. Jr., D.T. Phillips, and G.L. Hogg (1982), "A State-of-the-Art Survey of Dispatching Rules for Manufacturing Job Shop Operations," *International Journal of Production Research* 20, 1, 27-45.

Forman, E.H. (1983), "The Analytic Hierarchy Process as a Decision Support System," *In Proceedings of the IEEE Computer Society*.

Law, A.M. and M.G. McComas (1988), "How Simulation Pays Off," *Journal of Manufacturing Engineering* 100, 2, 37-39.

Law, A.M., and W.D. Kelton (1982), *Simulation Modeling and Analysis*, McGraw-Hill, New York, NY.

Saaty, T.L. (1980), *The Analytic Hierarchy Process*, McCraw-Hill, New York, NY.

Saaty, T.L. (1977), "A Scaling Method for priorities in Hierarchical Structures," *Journal of Mathematical Psychology* 15, 3, 234-281.

Shahraray M.S. (1987), "Dynamic Sequencing Rule Applied to Job Shop Scheduling," *In Proceedings of the Simulation and AI in Manufacturing Conference*, 249-260.

Suri, R. (1988), "RMT Puts Manufacturing at the Helm," *Journal of Manufacturing Engineering* 100, 2, 41-44.