DETERMINATION OF MACHINE REQUIREMENTS VIA SIMULATION

Roderick R. Reasor
Tennessee Eastman Company
Robert P. Davis
Virginia Polytechnic Institute and State Univ.
David M. Miller
The Ethyl Corporation

ABSTRACT

This paper presents an approach to machine requirements planning which employs simulation as an experimental tool to examine the effects on system performance of varying the number, type and operating characteristics of machines in a production system. A normative mathematical model is employed to guide the determination of variations in machine configurations and operating characteristics, and to identify a minimum cost production system design. An illustration is included to describe model construction and application.

I. INTRODUCTION

One of the most fundamental facilities design issues is that of defining how many machines to have on hand. In general, this "machine requirements problem" can be defined as the specification of the number of each type machine required for a production system in each period during some planning horizon. There are a limited number of procedures for analyzing the machine requirements problem which have appeared in the literature. These approaches differ in how they formulate the problem, but all are fairly limited in the degree and scope of complexities explicitly considered.

Most of the approaches reported in the literature are deterministic, static analyses using a descriptive rather than normative model. In general, these approaches are concerned with a single work center, single product, single operation situation. However, Apple [1] and Francis and White [3] explicitly consider a multiple work center machine requirements problem. They use a static approach that considers as deterministic quantities: production output requirements, machine output rates, machine scrap factors, machine efficiency factors, and available work time. Their models yield fractional machine requirements that must be subjectively rounded to integer quantities. No interactions with other components of the production system are considered. The underlying process is implied to be a fixed, serial routing system. Apple's approach implies a single product system while Francis and White explicitly consider multiple products. With proper recursive definition of the parameters involved, however, Francis' and White's approach can be shown to be equivalent to Apple's.

There have been a few probabilistic approaches to the machine requirements problem reported in the literature. Morris [5] considers a single work center and treats production requirements, operation performance time (to include machine run time) and machine effectiveness (to include down time, scrap, etc.) explicitly as random variables. However, he does not develop the explicit form of any of the distribution functions involved.

Reed [7] also presents a descriptive analysis of a static, multiple work center, serial flow system from a probabilistic standpoint. The objective of his analysis is to find the overall number of machines to meet prespecified production requirements (in terms of operation cycles). He also partially accounts for the interrelationship between the machine requirements problem and the shop's inventory system with a lot size parameter.

The only normative approach reported in the literature is that by Morris [6]. Morris develops a single work center, static, probabilistic model based on a linear cost criterion and no constraints. The cost components are machine investment and operating cost, and overtime cost. A more detailed description of the above approaches may be found in Miller and Davis [4].

All of the analytical approaches to the machine requirements problem reported in the literature assume a relatively simple view of the underlying production system. Little consideration is given to the interrelationships between the number of machines used and such system components as in-process inventories, scheduling rules, product quality, available space and production time. In addition, the dynamic nature of the underlying production system is not considered. Another shortcoming of existing approaches is the lack of consideration for the competition among various work centers for scarce resources involved in the production system. Resources such as investment capital, operating funds, floor space, and overtime are consumed by the various work centers, thus creating interdependencies between work centers that should be accounted for. Finally, existing approaches concentrate on fractional results rather than integer decisions. The tradeoff between excess machine capacity and lost opportunity cost verses overtime and subcontracting costs is left to subjective consideration.

The analytical approach used to solve the machine requirements problem depends upon the scope of its definition; this is, the degree of interaction between the machine requirements problem and other facilities design issues and production planning decisions explicitly considered. The model presented here attempts to eliminate many of the inadequacies found in past approaches. The probabilistic nature of the production system, the interaction with other facilities design issues, and constraints imposed by management, introduce obvious analytical complexities in the determination of machine requirements. The approach presented here attempts to accommodate consideration of these dynamic system characteristics through simulation. It is our belief that simulation represents a more tractable analytical approach to machine requirements planning than strict mathematical modelling when a number of stochastic interactions can be defined for the system under investigation.

II. SYSTEM DESCRIPTION

The specific definition of the machine requirements problem depends on the nature of the production processes being used, as well as management objectives and constraints imposed on the decision problem. The system under consideration in this paper is a multiple work center, multiple product, serial production system. A serial production system is defined here to be a system which has no rework cycle and no convergence or divergence of product components. A fixed, identical routing for all products in the system is not required. A work center is defined to be a group of similiar machines, all performing identical functions. The operating characteristics of the machines at each work center are not necessarily identical. Three main classes of machines are considered in general. These are manual, semiautomatic, and automatic machines. Each class of machines is assumed to have a single operating rate.

Associated with each work center is a queue of in-process products awaiting processing. Three service disciplines are included in the model. These are first come - first serve, service in random order, and shortest operating time serviced first. It is not necessary that each machine in the work center be able to process any product in the queue. When a machine completes processing of a job, it selects a job from the queue that it is able to process, according to the service discipline specified. If the job selected from the queue is of the same "family type" as the job which just completed processing, the machine undergoes a minor tooling setup. If the job selected is of a different "family type", the machine must undergo a major tooling setup.

As noted earlier, the possibility of a rework operation has not been explicitly modelled. However, the queueing operation described above provides the ability to apply the model to a production facility where rework occurs. The rework operation simply becomes another work center, where "good units" are processed on a machine which has a zero processing time, and defects are processed on a rework machine.

The capability to constrain the length of the in-process queue has also been provided. If the queue associated with any work center reaches its maximum length, then any machine at the preceeding work center, that has completed processing of a lot of product and desires to output that lot into the queue, shuts down until space becomes available. Note that only the machine or machines in the preceeding work center desiring to output finished product into the queue are shut down when the queue is at its maximum length, not the entire work center.

A typical work center is illustrated in Figure 1.

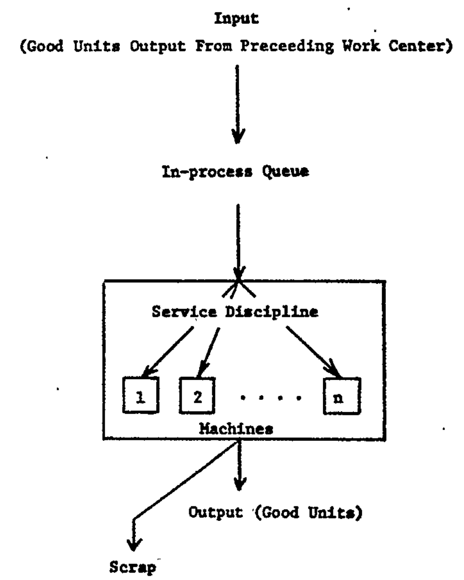

Figure 1: Diagram of a Typical Work Center

III. MODEL DESCRIPTION

The simulation model is a next event simulator, programmed using GPSSV. GPSS was chosen as the simulation language because of its ability to represent the dynamic activities of manufacturing processes and their stochastic interactions in time. The system is modelled as a series of work centers. Associated with each work center will be a queue of products awaiting processing. The servers are the machines located at that work center. Note that since different classes of machines (manual, semiautomatic, automatic) can be considered, the service time distributions for servers at the work center are not all necessarily identical.

The simulation model interfaces with a normative model that considers the cost of competition among various work centers for scarce resources involved in the production system, and the trade-offs between excess machine capacity verses insufficient machine capacity. Specifically, it considers the interrelationships between the number of machines used, their operating characteristics and such system parameters as in-process inventories and floor space requirements. The normative model is designed to employ only integer results for the number of machines required and to represent the dynamic nature of the production process.

The objective of these models is to determine machine requirements such that the total costs required to achieve given target production quantities is minimized. The simulation model is used as an experimental tool to evaluate different combinations of system characteristics. The system characteristics (e.g. number of machines at each work center, machine operating rates and characteristics, scheduling disciplines, etc.) are strategically varied and the simulation model evaluated to experimentally determine the optimum set of system parameters.

AN EXAMPLE

A common set of machine requirements decision issues is the number of work shifts that machines should be operated and the operating rates (manual verses automatic) for those machines. Using data obtained from a department in a medium sized manufacturing facility, the above described experimental approach was employed to determine optimum machine requirements with respect to these decision variables.

The department consists of multiple work centers that serially process multiple products in a job shop fashion, independent of other manufacturing departments at the facility. The department consists of 14 work centers and processes 15 products. This system was analyzed under the assumptions of infinite queue length and a first come - first served service discipline. The department's operations were simulated for a period of 2 years and average annual cost of production was computed. The department requires a six week lead time on orders; therefore, the demand for the department was considered to be all orders arriving 6 weeks prior to the end of the 2 year period. Data on scrap rates, machine efficiencies, major and minor setup times, and product demand was collected and fitted to distributions. Cost components considered were: machine burden rates, labor rates, setup costs, machine and operator idle costs, and scrap costs. The existing work center configuration is given in Table I.

Table II below highlights four system configurations from which operating cost improvements were identified. Key factors in identifying the system characteristics to be varied were: excess (or insufficient) machine center capacity, in-process inventory levels and scrap quantities produced. These variations in operating characteristics, although by no means an exhautive list, are included to indicate the manner in which the models can be employed to iterate toward a more cost-effective system design. Configuration 1 is abnormally high in cost. It is used as a base point, existing configuration which is capable of meeting demand; and, frequently all three shifts are utilized to reduce backlogged demand.

TABLE I - EXISTING SYSTEM CONFIGURATION

		Number of Machines	
Work Center	Description	Manual	Automatic
1	Blanking	-	1
2	Forming	-	2
3	Milling "A"	-	1
4	Milling "B"	-	1
5	Milling "C"	-	1
6	Milling "D"	1	-
7	Punch Press	3	-
8	Broach "A"	2	1
9	Countersink	2	-
10	Deburr	2	1
11	Milling "E"	2	-
12	Broach "B"	1	2
13	Broach "C"	3	1
14	Milling "F"	2	-

TABLE II - ALTERNATIVE SYSTEMS

Configuration No.	Description	Cost ($) per unit produced
1	Existing System, 3 shifts/day Operation.	0.52
2	Existing System, 2 shifts/day Operation.	0.30
3	Replace 2 Manual Machines with One Automatic Machine at Work Center 8, Operate 2 shifts/day.	0.32
*4	Add One Automatic Machine at Work Center 2, Operate 2 shifts/day	0.30

*Note: 1% improvement in productivity over configuration #2.

The ranking procedure developed by Dudewicz and Dalal [2] is used to isolate optimum system characteristics by ranking the results of simulation experiments in which the above design characteristics are strategically varied.

IV. THE GPSS MODEL

The GPSS model consists of a general sequence of blocks stored in a MACRO that describes a typical work center. The model is expanded to represent the production facility under consideration by repetitions of the basic MACRO. A block diagram of the MACRO is given in Figure 2. Product routings and machining times are stored in matrices. Demand distributions, major and minor setup distributions, scrap distributions and machine efficiency distributions are stored in functions. A generate block is supplied for each product or part number considered. Order arrivals are generated each day, where a day can be defined to be 1, 2, or 3 eight hour shifts. Associated with each product is a probability distribution for order quantity. Each order (transaction) is assigned an order quantity given by this distribution. Orders for zero units are immediately terminated.

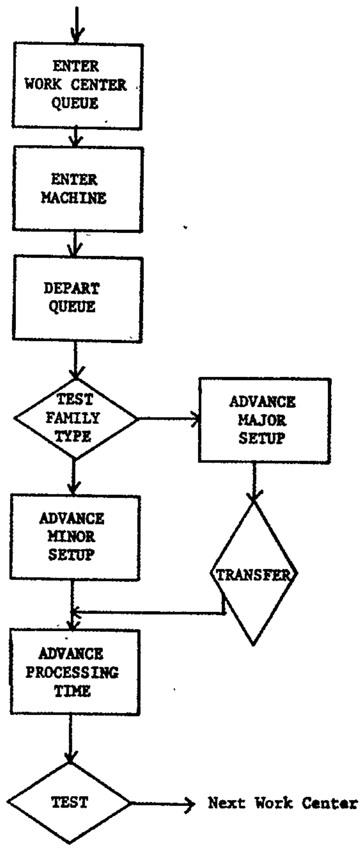

Figure 2: Block Diagram of a Typical Work Center

V. USE OF THE SIMULATION MODEL

The simulation model is designed to determine the optimum number of machines required by the production process in order to meet target production quantities. However this decision is depenent on interactions with other facilities design issues. Therefore, the model can be used to determine the effects of varying such system operating and environmental characteristics as:

1. queue service disciplines
2. changes in such system parameters as: scrap rate, machine efficiency, in-process inventory space
3. changes in levels of scarce resources such as: operating and investment capital, plant floor space, production time.
4. changes in demand or product mix
5. variable operating rates for machines.

VI. CONCLUSIONS

The simulation approach presented in this paper attempts to eliminate many of the inadequacies found in past approaches to machine requirements planning. The approach presented here provides a basis for evaluating the impact of production system design variations on productivity and system cost effectiveness. Further, the simulation model described in this paper can be used to estimate production costs and evaluate design alternatives for new production facilities, and can be modified to accommodate systems with non-serial structures.

VII. REFERENCES

1. Apple, James M., Plant Layout and Materials Handling, The Ronald Press Company, New York (1950).

2. Dudewicz, Edward and Dalal, Siddhartha R., "Allocation of Observations in Ranking and Selection with Unequal Variances", Sankhya, ser B, Vol. 37-1 (1975).

3. Francis, R. L. and White, J. A., Facility Layout and Location: An Analytical Approach, Prentice-Hall, Inc., New Jersey (1974).

4. Miller, D. M. and Davis, R. P., "The Machine Requirements Problem", awaiting publication in The International Journal of Production Research.

5. Morris, W. T., Engineering-Economic Analysis, R. D. Irwin, Inc., Illinois (1976).

6. Morris, W. T., "Facilities Planning", Journal of Industrial Engineering, Vol. 9, No. 5 (1958).

7. Reed, Ruddell, Jr., "A Probabilistic Model for Machine Determination", Proceedings Seventeenth Annual Institute Conference and Convention - AIIE, New York (1966).

8. Schriber, T. J., Simulation Using GPSS, John Wiley & Sons, New York (1974).