CHAPTER 13

FUTURE METALWORKING ANALYSIS

Harry M. Markowitz and Alan J. Rowe

It has been several years since the authors performed the analyses described in the preceding chapters, and (extrapolating from current activities) it will be at least as long before either of us actively engages in this area again. We would, however, like to devote a few pages to what seems to us to be a promising next step in the analysis of metalworking capabilities. Specifically, we wish to point out some potential applications of simulation techniques to the analysis of economy-wide capabilities.

We first discuss the nature of simulation, and its current use in manufacturing analysis. Afterwards we consider some of its potential contributions to the understanding of the metalworking industries as a whole.

SIMULATION TECHNIQUES

In the area of metalworking, simulation techniques are increasingly being applied to problems of manufacturing analysis. Simulation techniques are like optimization techniques (such as linear programming) in that both require a description of technological possibilities. Simulation differs from optimization, however, in that the former does not necessarily arrive at a best way of using production possibilities. A simulation analysis, rather, tries out different plans of action proposed to it—works through one or more "histories" using each proposed plan of action—and reports how well each plan scores with respect to a number of measures of performance. Since an analysis which can economically find a best strategy is generally preferable to one which simply evaluates specified proposals, optimization techniques are generally preferred to simulation techniques when the former are feasible. Simulation techniques, on the other hand, can be applied to problems which, at present, are hopelessly beyond our abilities to optimize.

We may visualize a simulation analysis in terms of what the human analyst gives the electronic computer, what the computer does with this information, and what the computer gives back to the analyst by way of results. In simulating a shop the computer must be given: a description of the shop; decision rules which prescribe shop action under all circumstances; and a description of orders to be processed by the shop. Let us consider each of these inputs in turn.

DESCRIPTION OF THE SHOP TO BE SIMULATED. The more advanced computer programs for shop simulation require an analyst to supply information such as the number of machine types, the number of labor classes, the number of machines of each type, the number of men in each labor class each shift, the possible assignments of types of men to types of machines, the basic hourly wage of each labor class, the premium for each shift, the length of each shift, etc. The simulation program allows these shop parameters to be varied from run to run.

DECISION RULES WHICH PRESCRIBE SHOP ACTION UNDER ALL CIRCUMSTANCES. Most shop simulation programs require a dispatch rule. Such a rule answers the question, "Suppose that a given man or machine can turn to one out of two or more different jobs; which of these alternatives should be selected?" Among the more commonly analyzed dispatch rules are:

First come first served.
Do the quickest job first.
Dispatch according to due date.
Do the most expensive job first.

In addition to dispatch rules the more complex manufacturing simulators may require decision rules in other areas, such as overtime rules to determine under what conditions labor should work extra hours, and alternate routine or alternate sequencing rules, to decide among the available options with respect to machine selection and operation sequencing. Such rules formalize actual or proposed operating procedures for running the shop.

DESCRIPTION OF ORDERS TO BE PROCESSED BY THE SIMULATED SHOP DURING A PERIOD OF TIME. In some simulation programs order information is read in, order by order, in the sequence these orders are released to the simulated shop. Information about each order includes routings and process times, and sometimes alternate routing, alternate sequencing, priority, and cost information. In other simulation programs the analyst supplies parameters of probability distributions from which the computer randomly generates order information as needed. For shops which make only a few standardized products, the routings and process times are supplied at the start of the simulation; then, during the course of simulation, the computer reads in orders by quantity and type, using the previously supplied information to determine routings and process times. Thus, in one manner or another, the analyst must characterize the jobs to be accomplished by the shop, including routings and process times, and any alternate routing or alternate sequencing possibilities which the shop may use.

The computer simulates by running the specified orders through the specified shop in accordance with the specified decision rules. At the beginning of a simulated shift it assigns men and machines to orders in accordance with the dispatch rule. As it makes these assignments it notes how long the order is to be processed and at what time processing is to be finished. When simulated time reaches this value the computer removes the order from its machine, sends it on to its next queue (or notes it as being completed) in accordance with its routing information, and allocates the man and machine (not necessarily to each other again) in accordance with the dispatch rule. This same working of the system through time could be done with pencil and paper. A human analyst could, in principle, keep track of the status of each item in the shop, applying the prescribed decision rules whenever a new action had to be decided upon, as he advanced the hands of the simulated clock to the point in time when the system next changed. Such simulation by hand is extremely tedious and time-consuming even for quite small shops. The computer, however, can trace the flow of large numbers of such orders through complex shops with fairly reasonable requirements for computer time.

As the computer (more precisely—as the simulation program directing the computer) moves the system through time, it keeps track of information concerning machine utilization, labor utilization, lengths and values of queues, the use of overtime or alternate routine, and the performance of the shop with respect to meeting its due dates. At the end of the run it labels and prints out this information, e.g., by simulated week and for the run as a whole.

To apply simulation successfully to a manufacturing problem, the analyst must conscientiously carry out a number of related analysis operations. Most, if not all, of these supplementary analysis operations were considered part of good practice even before the advent of simulation. In the analysis of the equipment selection problem for a new plant, for example, the analysis team must estimate typical operational requirements for various kinds of products within the product line, and one or more levels and mixes of possible demand. The analysis team must also design a good first guess as to a shop that could adequately handle such demands upon it. Before simulation, a static load analysis—which compared total demands for men and machines with total supplies of each—was used to judge the adequacy of the proposed shop. Since it was well-known that a shop cannot operate satisfactorily with a static load of 100% of capacity, judgment or "reasonable load" factors were applied. Even with the availability of simulation techniques the static load analysis provides useful information, particularly in forming the initial shop plan.

The static load analysis, however, frequently misses important dynamic interactions, and hence lets certain potential troublespots slip by undetected. A typical example is the following: Product A uses more of machine X than Y. Product B, on the other hand, uses more Y than X. Based on estimated total annual demand for A and B the static load analysis concludes that the shop is amply supplied with machines X and Y. But this may be an error, since at any one time the shop may be producing only A (with considerable idle time on machine Y), or only B (with considerable idle time on X). If both A and B are in the shop, their requirements for X and Y may dovetail—but to what extent? In actual shops the picture is further complicated by a multitude of types of work which route in various patterns through a variety of machines, perhaps to rendezvous with matching parts to route as subassemblies and assemblies. How, in such a maze of possible interactions, can we tell whether the available resources will keep work moving in a steady flow rather than in disrupted eddies and spurts? These are the questions to which simulation addresses itself.

A simulation analysis typically involves a number of computer runs. In equipment selection, for example, the first run would test the initial shop design against a likely level and mix of orders. This might show that the proposed shop had serious weaknesses even if the likely happened, and hence must be modified. The number of machines of various kinds would be altered in light of the queue and utilization experience of the first run. Perhaps, even after these corrections, the second run might reveal difficulties which suggest further modifications and further runs. It is not enough, however, to find a shop which works well for the likely level and mix of demands. It is important for the shop to remain manageable if possible alternate levels and mixes of demands hit it. Hence, further runs are required to test the flexibility of the shop. There is no assurance (in fact, no presumption) that this process reaches an optimal shop. It simply evaluates alternate proposals under a variety of conditions until—in the light of costs of analysis, need for a timely decision, and the apparent acceptability of the best solution thus far—it seems advisable to terminate the analysis.

When a simulation model is constructed for an existing facility the initial model can be run using approximately the actual shop configuration, decision rules, and orders for some past period of time. The results of this run can be compared with shop performance for the same period to see if the model reproduces the real world in important aspects with reasonable accuracy. For a complex shop the first runs of such a model frequently reveal some systematic error in data or some neglected aspect of shop performance that should be further investigated and incorporated into the model. Typically, after half a dozen or so runs, the model is deemed sufficiently accurate and is directed towards policy questions such as changes in shop configuration or operating procedures. In simulating a completely new facility, however, such testing of the model is not possible. Reliance on experience with similar plants, the use of somewhat conservative productivity estimates, and the use of the model itself to test its sensitivity to certain magnitudes are the principal means of treating this difficulty in modeling new facilities.

PROCESS ANALYSIS APPLICATIONS

The increasing application of simulation models to practical manufacturing problems should contribute to data and concepts needed for broader scope, industry-wide models. Not that the proper method for analyzing the metalworking industries is to build a detailed simulation involving 60,000 establishments. Rather the availability of simulation models permits us to test hypotheses concerning how such establishments can be characterized and thence aggregated.

One area in which simulation can contribute is that of static analysis with substitution. In the last chapter we presented a linear programming analysis describing direct substitution possibilities among machine tools. This analysis rested on the fact that the same task can be accomplished in more than one way. We can imagine more general linear programming analyses based on the fact that alternate sets of tasks can accomplish the same transformation of materials, or that alternate materials can be transformed into products serving the same ends. All such analyses have this in common: They portray substitution possibilities due to changes in actual, direct inputs per unit output. There is another major source of substitution among "requirements," however, which has to do with the extent to which various resources are fully utilized. Even if there were no substitution possibilities among direct inputs the actual use of resources by establishments would be effected by shift and overtime policy and by the ratios of load to availability for various resources. What we need is some way of characterizing substitution possibilities resulting from these sources. We need to know whether such substitution possibilities are substantial or negligible in magnitude. We need to know whether they can be characterized by relationships which, hopefully, could be incorporated into a linear programming analysis. Towards these ends simulation can serve as a laboratory in which to experiment with different shift and overtime policies, and with different ratios of availability to load. Just as the detailed simulation model can serve the manufacturing analyst in testing alternate shop configurations, it can also serve to test hypotheses of the analyst who seeks to characterize metalworking capabilities under a variety of circumstances.

Another area in which simulation can contribute is that of the *dynamics* of changing levels and compositions of output. It can do more than trace the effects of changing output levels in the production shop. Just as it is used to trace the flow of materials through various stages of production, it can also be used to trace the flow of pieces of paper through the preliminary steps of requisition engineering, drafting, tool design, and production and materials procurement.