The structure of a comprehensive control system for the fabrication and assembly industries is outlined.

The system consists of several major functional components that are interconnected as an integrated whole.

Component functions are described and relevant methodologies mentioned.

Fabrication and assembly operations

Part I The outlines of a control system

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In large part, modern industry is comprised of fabrication and assembly processes. For several reasons, these processes, which produce our airplanes, automobiles, machine tools, etc., are often difficult to control. They frequently exhibit a high degree of dimensionality; systems involving thousands of variables are common. These variables are discrete, taking integral values only, and are subject to substantial random fluctuations. Moreover, since a product can often be manufactured in more than one way, the processes are not unique. Despite these difficulties, control systems must be devised.

This part of the paper describes a comprehensive operation control system structure for fabrication and assembly industries. As an introduction, some pressing control problems are listed that could benefit from an application of the system described.

There exists, first of all, a need for the efficient utilization of production resources. Optimum trade-offs among setup, inventory, subcontract, and premium labor costs are desired; production plans should take into account seasonal cycles and model innovations. The typical resource utilization problem starts with a desired schedule of production. This may be either a forecast or a schedule of contractual commitments. Plant management then decides upon a production schedule (which is generally different from the forecast) for the most effective use of the available manpower, raw material, semifinished goods, and capital equipment. Plant management must consider whether the plant capacity should be adjusted to changing loads by hiring, layoffs, overtime or subcontracts, by building up the inventory prior to the actual need, or by negotiating changes in delivery dates.

An accurate prediction of future production resource requirements is important since money, material, labor, and equipment generally cannot be made available instantaneously. Plant management also needs an assurance that the final delivery dates for their products will be met without unexpected production costs.

Calculations of a delivery date should be based upon a firm methodology. At present, many manufacturers do not know the precise impact of an order on their plants. They do not, for example, have the means of foreseeing bottlenecks at various stages of production. Hence the selection of a promise date based upon experience and judgment alone is often in error. The actual production performance of a plant must be compared with the promised delivery schedule. Dynamic (time dependent) priorities should be generated for the proper selection of work to be done at every stage of production. There is also a need for quick response to changes in production schedules. A plant must react swiftly and smoothly to changes in the market. If a customer cancels his order, changes the size or specification of his order, or postpones the delivery of his order, the plant must react promptly to avoid the use of plant resources on the wrong tasks.

Manufacturing management must be able to assess the effects of proposed policy changes (minimization of inventories, stabilization of the work force, reduction of overtime, etc.) upon the operation of their production systems. Although the qualitative nature of these consequences may be understood to some degree, the existing quantitative descriptions of these consequences are presently not accepted by management as a basis for action. One useful consequence of comprehensive control systems for fabrication and assembly processes would be the capability of accurately assessing the effects of such policy changes.

When new products are put into production, their accompanying production data must smoothly enter the plant's data processing system. Although this is a transient phase of production operations, it is a normal event and the data handling system must be designed to accommodate it efficiently. Failure to provide such accommodation can result in costly delays and confusion during the introduction of new products.

Industrial management frequently wishes to determine which combination of their products can be produced most economically in a particular plant. Plant management has fixed amounts of production resources available that are capable of producing many distinct products, each product having different resource requirements. These resources can be combined to produce many product combinations.

Industrial management must be able to calculate the benefits and additional requirements to be expected from new capital equipment. Additional plant capacity may be needed, and labor requirements changed. Capital requirements must be evaluated with regard to the resource requirements of the manufacturer's products. If the most economic combination of resource requirements can be determined, the evaluation of alternative resource capabilities and technologies is readily possible.

control system

An important task in the development of an operation control system for fabrication and assembly processes is the creation of suitable manipulatable abstract representations or models of the production processes. This task requires the identification and clear definition of all important variables that define these processes as well as a practical means of expressing the interrelationship of these variables. A system of this type depends heavily on an effective evaluation of the existing conditions in the national economy and product markets. Certain criteria of cost and performance must be optimized, whereas others are used as boundary values.

system components

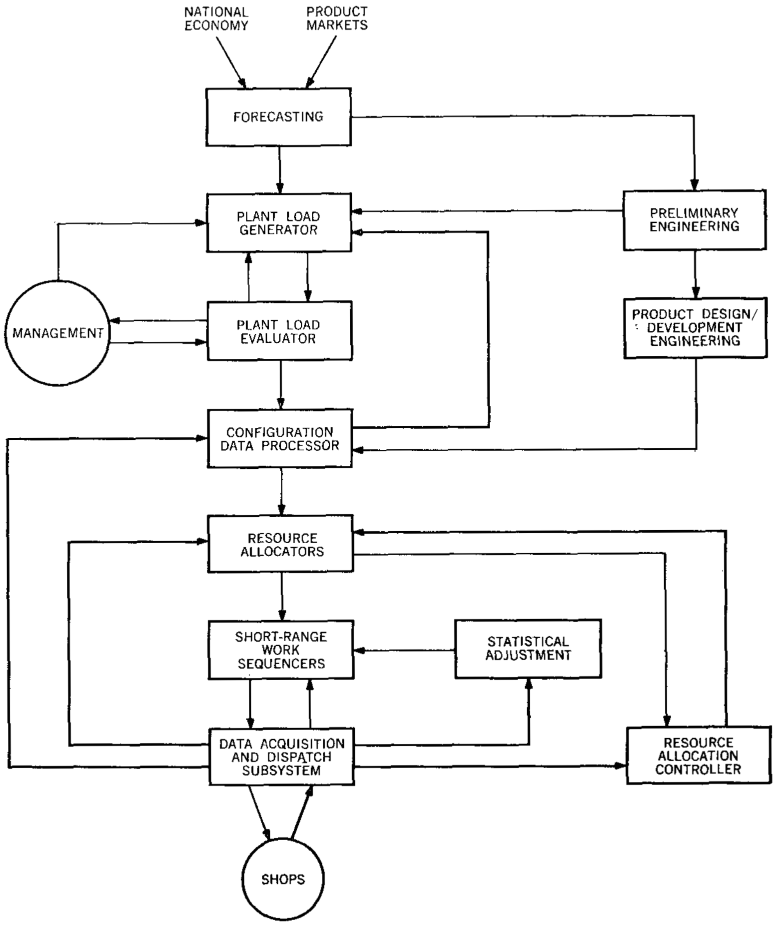
In defining an overall operation planning and control system, the major functional components of the system must be identified first. Their functions must be determined and interconnections among them defined. Figure 1 is used in describing this process.

Forecasting is a functional component which evaluates information describing the state of the national economy and the product markets, plus such specific product-related data as anticipated demands generated by a sales compaign. Today, a considerable amount of methodological development effort is directed toward forecasting problems. These theoretical methods are augmented by judgments and opinions of sales management. Depending upon the type of fabrication and assembly business, the forecasting function may be formal and analytical, informal and empirical, or some combination of the two.

The output of the forecasting function, a statement of expected sales quantities, is frequently prepared without reference to the productive capacity of the factory. Therefore, this forecast is insufficient as a base for the planning of production schedules. Two other functional components, the plant load generator and the plant load evaluator, compare the raw forecast with the production capacity of the factory.

The *plant load generator* provides an aggregated representation of the productive capacities of a fabrication and assembly plant. The generator includes a formal expression of certain management policies that are essential for resolving work activity conflicts with respect to the use of production facilities. The techniques of a plant load generator are closely related to the PERT/CPM[1] techniques that have been widely used in the armed forces and construction industries. These techniques, described in Part II of this paper, employ empirical methods to enforce resource constraints across several activity arcs and to accommodate the processing of many project

Figure 1 Operation planning and control system



networks simultaneously. These two properties are not available in the usual PERT/CPM formulations. Although the finished products are represented by networks as in PERT, the data in the activity arcs consist of the total number of processing hours required of each of the major groups of production resources in the plant.

The result of these computations is a very crude, highly aggregated production plan, which provides a gross overall representation of the plant's ability to respond to a particular proposed arrangement of production activities. However, the plan does not provide any detail with regard to part numbers, man numbers, and individual processing facilities, etc.

The *plant load evaluator* prepares a quantitative evaluation of the various alternative production plans that are generated by the plant load generator. This evaluation involves consideration of the plant's delivery performance, the size of the plant's workforce and skill mix, charges for premium labor, accumulated inventory charges, and various other related charges of concern to plant management. The technique of these evaluations is based on the modern applied mathematical methods of linear programming which are described in some detail in Part II of this paper. The output of the plant load evaluator is a single aggregated production plan that can be turned over to plant management for implementation with assurance that it is within the aggregate capacity and resources of the plant to implement this plan.

The combined output of the plant load generator and the plant load evaluator results in a preliminary solution to the problem of planning the production in a fabrication and assembly plant. At this point, we are in a position to proceed with more detailed computations to implement this plan. We develop details in terms of part numbers, lot sizes, work force sizes, hours of overtime, etc., necessary to provide explicit orders to the lower echelons of the factory. This detailed solution is actually given to the factory for implementation.

The *configuration data processor* embodies several different data processing functions that lie at the center of a fabrication and assembly plant's data handling system. In this discussion, we are concerned with but one of the processor's several functions: that of developing the net, time-displaced requirements for parts and assemblies used in the production of the finished products. To perform this function, the configuration data processor must receive inputs from the plant load evaluator and data on the inventory status of all the parts and assemblies in the system. The techniques for the efficient processing of these data are described in Part III of this paper.

The discrete production *resource allocators* make important detailed economic decisions for each of the various shops in a fabrication and assembly plant. Determined are such factors as the size and composition of the work force, additional subcontract support, and optimal amount of overtime work required. The resource allocators also provide the actual production schedule for parts and assemblies considering the latest due dates as well as economical operation of the production facilities. These decisions minimize the total variable cost of the shop's operations. An optimal balance among the various cost components in the production shops (setup costs, inventory carrying charges, and premium labor charges) is computed. A detailed exposition of the theoretical considerations is given in Part IV of this paper.

The next functional component in the system is the *short-range work sequencer* for fabrication as well as assembly shops. Processing the resource allocation programs, this component computes detailed sequences for individual work activities. Without neglecting lot sizes and constraints on delivery and resources, as imposed by the resource allocator, the calculations take into consideration the requirements for work already in progress in the shops. The type of methodology used, similar to that of the plant load generator, is related to PERT/CPM techniques. Details of this metholodogy will be described in a subsequent issue. The frequency of recomputation in the short-range work sequencer varies widely with the processes.

As requests to bid upon special custom-designed products are received, they are taken from the forecasting function to preliminary engineering. The output from this activity—the preliminary engineering production requirements—go directly to product design/development engineering and to the plant load generator for futher evaluation. Plant management, informed by the plant load evaluator, also can enter data for policy changes to the plant load generator. As the products are designed, the engineering data are dispatched to the configuration data processor where these product specifications are maintained.

The basic source of control data is the shop, which reports its activity to the data acquisition and dispatch subsystem. The shop performance is transmitted from the subsystem in summarized form to various other components of the system. The actual shop status data are reported to the short-range work sequencers where they are included in the periodic computations of the preferred work sequences. The various shop performance parameters (such as average idle time, work-in-process inventory, average throughput time, and similar measures) are reported to the *statistical adjustment* function for periodic recalculation of the decision-rule parameters in the short-range work sequencer. The actual performance costs are supplied to the resource allocation controller as explained earlier. Other control data are supplied from the data acquisition and dispatch subsystem directly to the resource allocators. These data include the reporting of capacity committed to current production so that the resource allocators can plan production for the available uncommitted resources. Completion of individual work activities is reported to the configuration data processor where this information is accumulated according to the product structure. This arrangement makes it possible to report the completion of the various major components of final products to the plant load generator. The procedure ensures that the plant load generator has an accurate representation of the shops' status at the generator's level of aggregation, allowing a realistic computation of the plant loads with reference to actual shop status.

conclusion

The discussion has considered those logical functions of greatest import in the construction of an operations control system. We have described the feed-forward flow of production planning data and the feedback of production control data that characterize the system. Subsequent parts of this paper will describe methods for implementing the various functions of the system.

FOOTNOTE

1. PERT (Program Evaluation and Review Technique)/CPM (Critical Path Method).