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OPERATIONS SEQUENCING SIMULATION
IN A PROCESS INDUSTRY

by

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ABSTRACT

Operations sequencing is a computer simulation technique used to assign production activities to equipment. This technique is applied to the computer-aided scheduling of production of biochemicals at a plant of Eli Lilly and Company. Through involvement of the potential user community, a model was developed which is comprehensible, flexible, fast, and which meets management's expectations. Various scheduling strategies, model options, and parameters are described. A case study shows the potential effects of using some common scheduling strategies.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS AND FIGURES

INTRODUCTION

Construction of the Tippecanoe Laboratories of Eli Lilly and Company began in 1951, and production began in 1954. The facility currently produces some 150 biochemical products for use in pharmaceutical, antibiotic, and agricultural chemical products. Biochemical production is currently done in three chemical manufacturing buildings, designated as T-17, T-27, and T-28.

Biochemical production operates under conditions typical of a "process industry". All production occurs in chemical batches, with varying process (or cycle) times and varying effective yields of the desired product. Products are organized into process chains, so that each product may be the input for one or more higher-level products. Conversely, each product may require one or more biochemical input products. The term "yield" has a particular meaning in process industries as opposed to piece-part industries. In a piece-part industry, "yield" usually means the percentage of items which meet manufacturing standards, each piece being inspected on a pass-fail basis. In a process industry, "yield" means the amount of material resulting from a successful manufacturing operation. The material is considered in terms of "lots" or "batches"; the entire lot must meet manufacturing standards as measured by chemical assay, or the entire lot is rejected. If the material is rejected, it will be held until chemical analysis determines if the material can be reworked or if the material must be scrapped.

Chemical production occurs in equipment known as a rig. An actual rig usually consists of a still, receiver, two brine pots, and a holding tank. While a "standard rig" is used for plant capacity planning, the actual configurations, capacities and capabilities of the rigs in use vary widely. To increase processing efficiency, rigs can be run "in parallel", which means that some component of a particular rig can be physically connected through piping to components of another rig.

Two other considerations are worthy of mention. Material cannot be released for further production until the Technical Services Group has determined that the material meets Company and Federal Government specifications. The chemical assay period normally lasts 3 to 6 days.

The second consideration is the equipment "setup", which involves cleaning the equipment after the previous product run is finished and checking the equipment to determine if it is serviceable. For example, acidic reactions are normally run in glass-lined rigs. As a part of each setup for a glass-lined rig, a "spark test" is made. This test determines if pinholes or cracks have occurred in the interior glass surface of the rig; if so, further acidic reactions may allow the solution to reach the metal jacket of the rig and cause extensive damage. After the check is completed, the rig must be connected to the proper material flow lines, gas lines, steam lines, and solvent lines before processing can proceed.

Conventional assembly-line balancing techniques do not apply to chemical processing at the Tippecanoe Laboratories. Since material must be produced in batches, the usual method of splitting lots to balance work-center load is not applicable. The planning process is further complicated by the differing cycle times, physical yields, and next-step input requirements. At the present time, the corporate material requirements planning (MRP) system does not extend to the level of biochemical production at Tippecanoe.

Since the plant began functioning, a key problem has been scheduling biochemical production. In the beginning, scheduling was easier due to the small number of required products and equipment. In recent years, the Tippecanoe Laboratories has made a much wider variety of products for corporate applications. In the 26 years since the facility was constructed, there have been four plant expansions, with a fifth scheduled for the 1980-1981 period. Management has recognized the urgency of developing a method of scheduling production to meet demands while operating within the constraints of production capacity, operating budgets, and waste-treatment capacity.

Initial inquiries into a computer-aided scheduling system were begun in 1962, with the conclusion that existing methodology and computer capacity were inadequate to solve this complex problem. In 1969, a consulting firm was asked to examine the problem; the firm concluded that the problem was still beyond the realm of technical feasibility and would remain so for the foreseeable future (1).

In January, 1978, corporate management began discussing the in-house development of a computer-aided scheduling system. This issue surfaced again because of the rapidly growing load on the Master Scheduler. Up to this point, the scheduling of biochemical production was done by one individual using pencil-and-paper methods.

In June, 1978, a management scientist from the corporate Information Systems Group was assigned to the task of developing a model of the scheduling process. The management scientist formulated an optimization problem with the objective of maximizing priority-weighted production; the "priority" was the "urgency of need" indicated by the corporate marketing group. A working computer model was produced after a period of eleven months. This model consisted of a 0-1 integer-programming formulation, with a constraint set which was designed to describe the limitations on inventory usage, production targets, and equipment setups, as well as describing the time-dependent features of the problem (2).

The integer-programming model produced a problem with 20,000 0-1 variables for a typical 90-day scheduling horizon. Because a problem of this size could not be solved in a reasonable amount of time, a decomposition methodology were developed which broke down the scheduling horizon into a series of short runs, each of which scheduled 6 to 15 days' worth of production. These shorter runs generated subproblems of only 3000 variables and 3000 constraints, and were within the capability of the available software and hardware. Run times varied widely from one job step to another, with a usual range of 2 CPU minutes to 175 CPU minutes. The total time to generate a feasible schedule for a 90-day scheduling horizon varied from a minimum of 25 clock hours to a maximum of 82 clock hours. The model consumed 2 megabytes of real core storage and 60 cylinders of direct-access data storage.

A strategy used to reduce the run times was to stop when the first feasible integer solution was obtained. Efforts to determine the advisability of further work to reach the optimal answer showed that it generally took as long to reach the second feasible integer solution as it did to obtain the first one, and that this relationship tended to hold for subsequent solutions.

Although the integer-programming formulation of the scheduling problem leads to an optimal solution, the computer package which resulted was not readily accepted by plant management or by the Master Scheduler. Plant management had expected to obtain a methodology for generating feasible initial schedules, for facilities planning, and for forecasting production costs and "absorption" (the cost-accounting method by which production of material recovers equipment and labor costs). The integer-programming package did provide feasible schedules, but required a number of approximations which removed the solutions from a close parallel with actual plant operations.

The integer-programming formulation and method were not understood by management or by the Master Scheduler. The general reaction was that "a monster has been created." Although the operation of the model was eventually automated by using computer system software, the process of setting up the data and initiating the model required persons with mathematical programming background--in effect, a high priesthood who served the model.

Another problem was the single-objective nature of the formulation. In actual practice, there are a number of goals which management is trying to achieve. For example, maximizing priority-weighted production results in too many equipment setups, which increases shop personnel workload and creates high production cost.

The initial reaction of plant management illustrated Millen's concept of "acceptimization". In essence, management often cannot translate "optimal" solutions into operational policy or procedures (3). The integer-programming methodology also presented a problem to management in that there was no opportunity for interaction between decisionmakers and the model. In the present case, neither the managers nor the Master Scheduler could easily modify the model results. Any changes to the decisions made by the model required another complete execution of the procedure. As Bishop points out, managers prefer to be able to modify the model's results to compensate for factors beyond the scope of the model, or to exert a sense of control (not leaving decisionmaking to the computer) (4).

The very long run times for a typical problem using the integer-programming package also precluded another management goal--the ability to examine the results of various scenarios, or "playing what-if games". Because the computer run usually consumed the available computer resources for at least an entire weekend, there was no opportunity to use the model as a tool for evaluating various changes in requirements, equipment configurations, or priority schemes. Although the model was designed to allow these uses, the size and execution time for one problem meant that whatever the model produced had to be accepted, because generating an alternative solution was impractical.

A final and very serious objection resulted from the policy of the Company related to production goals. Eli Lilly and Company is proud of its traditional role as a full-line pharmaceutical producer. This means that the Company is committed to producing pharmaceuticals as long as there is demand for them, particularly in the case of a "life-sustaining" drug. In terms of the scheduling problem, the result is that "you must make some reasonable amount of everything for which there is demand." Using his manual methods, the Master Scheduler could adjust production levels of various compounds as he neared the end of the scheduling horizon, in order to be sure that at least part of the various production quotas would be met. This is a form of "slack-rule" scheduling, or "minimizing the maximum scream" (5). The model as developed has no provision for this sliding-priority scheme, and often the resulting schedules showed that a large number of low-priority products had no production at all.

Surveys of the available literature showed that problems of this type have been addressed in a variety of ways. Glover et. al. have developed the notion of "Generalized Networks" to address a number of situations where the restrictions of pure-network solution procedures preclude their use; the main advantages are speed of solution, compact computer storage, and the ease with which network problems can be visualized and explained to management (6). Prokop and Votruba address a scheduling problem for fermentation products, but assume an objective of profit maximization with no restrictions on equipment availability, and are satisfied with continuous (non-integer) solutions (7). Talbot et. al. enhance the integer programming solution procedure with network cuts to reduce solution times; this method is limited to 30-50 variables and three resource types (8). Perhaps the closet parallel to the present situation comes from that reported by Jain, who describes the simulation approach to sequencing 1000 rolls of steel on 40 machines on a daily basis, together with the data and file management software required to efficiently use the system (9).

Given that the existing scheduling model fell far short of its goals, it was necessary to try a new approach. This approach is built around a time-progressive deterministic computer simulation model with a heuristic method for assigning products to the combinations. This heuristic is a simplified spinoff of the integer programming formulation, and is specifically designed to meet the goals of Company management.

DESIGNING THE HEURISTIC MODEL

> HOARE'S LAW OF LARGE PROBLEMS:
> Inside every large problem is a small problem struggling to get out (10).

Before proceeding to the discussion of the structure of the heuristic simulation model, it is appropriate to describe the actual process of designing the model and obtaining the criteria used in that design.

After recognizing the need for an alternative to the integer-programming model, all persons at the plant site who had strong interest in obtaining a functional scheduling model were interviewed. These interviews were conducted to determine if management perceptions and (possibly) goals had changed as a result of the modeling effort to date. The interviewees ranged from the Master Scheduler through the management chain to the Vice-President for Biochemical Operations. As a result of these interviews, the following list of criteria for a biochemical scheduling model was developed:

- The model must execute quickly and fit into the normal data-processing job stream, so that a number of runs could be made during the normal working day. This would allow plant management to examine a number of alternatives before selecting a particular schedule.

- Within the constraints of the situation, the model must examine the largest possible number of alternatives in determining a schedule.

- The model can be operated by a "naive" user, one without in-depth knowledge of biochemical scheduling, mathematical programming, or computer systems operation. This attribute is important if the Master Scheduler is not available to assist in the scheduling process, and would allow the model to be of value to a very broad user community.

- The model should be flexible, able to be run with possible variations in a number of parameters, and easily modified to reflect new conditions or to be used at other plant sites. The model should also be capable of expansion to encompass a planned increase in the number of products and rigs at Tippecanoe.

- The model should satisfy the information needs of groups not directly involved in biochemical production. For example, the Accounting group would be able to forecast the recovery of labor and equipment costs, inventory holding costs and unutilized equipment costs. The purchasing department would be able to generate time-phased purchased raw material requirements. The waste treatment facility would be able to forecast types and quantities of waste streams resulting from biochemical production.

Another, unarticulated goal was quickly identified: the model must be comprehensible. The model must explain what is happening and must faithfully reproduce the working environment, meeting the decisionmaker's objectives in a way he can understand and use (11), As a recent study notes,

> The critical task at this point was to identify a model that exhibited a useful degree of realism, in view of the decision objectives, yet which was efficiently solvable. The early history of Management Science applications contains numerous examples of elaborate decision-making systems which were designed to solve the wrong problems or designed to solve the right problems, but which utilized a model structure that could never be solved with existing solution technology. In addition, the interpretations of these models and their outcomes were often completely opaque to anyone other than the highly technical "experts" who designed them (12).

It was concluded that the potential users of a scheduling model represented diverse groups with a number of shared and distinct goals, and that no single criterion would satisfy all users. Further, a simple analog model which described the biochemical scheduling milieu accurately, but which contained no overt optimization methodology, would meet management's objectives. Thus, "satisficing" would be preferable to optimization. As Wallenius notes, managers prefer an unstructured approach over more sophisticated methods, due to ease of use and a lack of constraint on the decisionmaker (13). The final objective became to build a simple intuitive model to give a reasonable explanation of the scheduling environment, together with identifiable reasons for model results.

The key factor in implementing the model successfully was obtaining the cooperation and approval of the Master Scheduler by incorporating his insights into the resulting model. From the Master Scheduler's point of view, the model should automate the tedious bookkeeping and calculation tasks which are a large part of his job, and should produce an initial schedule he could modify to remove "poor" decisions made by the model. A necessary prerequisite to this was the development of several report-generation programs which were reproductions of formats the Master Scheduler was currently using. The best example is a graphical report which generates a scheduled production report replicating a blueprinted format used in manual scheduling.

Extensive interview sessions were conducted with the Master Scheduler concerning the biochemical environment and the scheduling process. Capturing the Master Scheduler's mental process for scheduling was a challenge. A decisionmaker often cannot specify his needs in advance, and while the user is expert at doing his job, he is often not facile at explaining how he does it (14).

The goal-specification process led to consideration of a "vertical-loading" operations sequencing simulation model. The operations sequencing technique is a time-progressive deterministic simulation. The term "vertical loading", as defined by Lankford, means considering all potential jobs simultaneously, loading the highest priority operation, with the possibility for priority override of an operation already in progress (15). This structure was selected because it would allow a flexible model whose internal workings could be easily described and monitored as necessary, which could be tailored to fit specific situations, and which would permit the incorporation of a wide variety of policy alternatives.

This type of model has a considerable advantage in such scheduling problems. As Ramsey observes,

> Computer systems and human schedulers offer quite different, and highly complementary, capabilities for solving complex scheduling and resource allocation problems such as those found in typical logistics management applications. Modern mathematical programming and general-purpose heuristic algorithms allow very large problems to be addressed, but are quite restrictive with respect to the range of constraint types which can be modeled in the context of a large problem. Human schedulers, on the other hand, are capable of considerable insight, and can successfully deal with soft and complex constraints and multiple objective functions, but, if unaided, are limited to relatively small problems. The solution of problems which are both large and

> logically complex appears to require a cooperative union of these capabilities (16).

Another consideration led to the selection of a time-progressive simulation model. The processing or "cycle" times for the individual chemical products vary from 5 to 260 hours, requiring any analytical model to account for a wide range of time-phasing to accurately represent the scheduling problem. The simulation approach synchronizes the cycle times by monitoring model status at fixed time increments, as discussed below.

It was hoped that the model would gain acceptance by this process of involving the user in the model development process and by capturing the user's knowledge and insights. The user community's perceptions of "what the model can do" were expected to evolve as a result of this continuing interaction, resulting in newly articulated desires for additional model features.

The simulator was implemented on the existing DEC timesharing system using FORTRAN as the simulation programming language. The timesharing system is available on a 24 hour basis, 7 days per week, allowing the users to run the scheduling system whenever they wish. The simulation program has four levels of "debug" output ranging from a brief summary of results to a minutely detailed account of every decision made by the model; in a timesharing environment, the user can trace the progress of the model to determine what is happening and why. The user community at Tippecanoe is familiar with the capabilities of the DEC system and has a high-speed terminal available for use. Using the timesharing system would thus increase the likelihood of user acceptance of the model. FORTRAN was selected rather than a more sophisticated simulation language because many company programmers have used FORTRAN on the timesharing system, allowing the eventual transfer of maintenance programming tasks for the simulation model. The use of FORTRAN also avoided expenditures for leasing a simulation language compiler.

To maintain model integrity while incorporating new features, a highly structured, modular approach was used in developing the coding. Detailed programming notes were included in the code, identifying the purpose of and method used in a particular block of code. Without this "document-as-you-go" strategy, one quickly loses track of the structure of the coding and has a great deal of difficulty effectively integrating new coding into the existing model. In short, the development process for the heuristic model was built around the desire to be "elegant" rather than "sophisticated" (17).

MODEL OPTIONS AND PARAMETERS

This chapter presents the options and parameters presently incorporated into the operations sequencing simulation model. The model parameters are specified through a set of control files modified by the user with the aid of a "front-end" program. This program utilizes man-computer interactive dialogue to set up model runs without any specialized computer systems knowledge on the part of the user.

1. The scheduling horizon is specified in terms of starting and ending dates. The model converts these to clock hours from a reference point. The user also inputs a time increment (in hours) which determines how often the status of the modeling system will be monitored in simulated time, reflecting how often the model will be able to make decisions. Exclusive of the time required to perform input/output operations, the execution time of the model is roughly inversely proportional to the length of the time increment and directly proportional to the length of the scheduling horizon. One expects that, as the time increment decreases, the model will have more opportunities to make decisions, resulting in a better schedule. Since most

of the cycle times are even, a two-hour time increment has proven to be a good choice in balancing the quality of the resultant schedule with model execution time.

2. The product priority rule can be specified as marketing priority, priority-weighted critical ratio, or priority-weighted product panic ratio. The marketing priority is a numerical weight assigned to show the urgency of completing the requirements of a particular product. Critical ratio is the ratio of time remaining in the scheduling horizon to the time required to complete the product's requirements. If the critical ratio is 1.0, the product must be started immediately or it will be late. Priority-weighted critical ratio results from dividing the critical ratio for each product by the marketing priority for the entire product chain, to give greater weight to highly desired items. The priority-weighted critical ratio for the product chain is the lowest score for the entire chain. Product chains are ranked in descending order by priority-weighted critical ratio scores. "Product panic ratio", devised by Hildebrand (19), is the ratio of gross requirements to gross inventory (the sum of initial inventory and net requirements, divided by the sum of

initial inventory and amount produced), and is intended to assign higher weight to those products which have low initial on-hand quantities and high requirements. Priority-weighted product panic ratio results from multiplying the marketing priority for the product chain by the product panic ratio for each product. The priority-weighted product panic ratio for the chain is the largest score for any product in the chain. Product chains are ranked in ascending order by priority-weighted product-panic ratio.

The latter two priority schemes are computed at the start of the scheduling horizon and recomputed at time intervals specified by the user; this feature gives a dynamic priority rule which reflects changing measures of scheduling urgency as the end of the scheduling horizon approaches. Dynamic critical ratio scheduling may produce a reduction in shop and inventory system performance (19), and this potential effect requires greater study in this application.

3. The user specifies the time required for equipment set-up when changing products in a given rig; this time is assumed constant for all product-rig combinations. The user also specifies the maximum number of equipment

setups which can be in progress simultaneously, reflecting the availability of maintenance personnel. This parameter can be varied for specific products in designated time periods, so the user can trace the performance of a product without being deluged with output.

4. The user specifies the amount of time required for laboratory assay of the product before the batch is released for further processing. This time is assumed constant and independent of the product or type of product.

5. The user may designate the rigs which will be out of service for specified periods. Rigs are out of service periodically for inspections, preventive maintenance, or corrective maintenance. The times required for corrective maintenance vary from several days to nine months, so rig maintenance is a key parameter in developing future schedules or modifying existing ones.

6. The user may specify a list of products which are in-process at the start of the scheduling horizon. The user also may specify a list of batches awaiting laboratory approval at the start of the scheduling horizon. These two options allow the model to consider the

effects of past decisions and to maintain proper tracking of inventory levels.

7. The user may specify a list of deferred products and a list of campaigned products. A product may be deferred over a given time range because required raw materials will not be available or because marketing requirements will not exist until some future date. Products may also be deferred by the user to alter the results of the model. "Campaigning" is the term applied to running a given product-rig combination for a specified period of time, overriding the priority rules used by the simulation model. When a product is campaigned in a given rig combination, the product may not be replaced even though insufficient inventory of inputs exist for production to occur; production then ceases until the required amounts of input products are generated. Campaigning becomes a form of user decision, restricting the model's assignment method.

   The campaign and deferral options are the two primary means of allowing the user to override the model's decisions. The user can generate an initial schedule, review it, decide on revisions, and use the combination of the product campaign and deferral options to generate a revised schedule. This process can be repeated until a satisfactory schedule is generated. In fact, a manually generated schedule can be entered into the model using the campaign option. In this case, the model is used to check the feasibility of the manual schedule and to track inventories, production figures, and costs.

8. The user specifies whether scheduling of products within a given product chain will proceed from finished product toward the lowest-level intermediates ("top-down") or vice versa ("bottom-up"). Manual schedules are generated using a bottom-up orientation, since this is easier. Bottom-up scheduling builds inventories of intermediate products, attempting to schedule the next higher-level product when the current one is completed, so that sufficient inventories of inputs are likely to exist.

   Campaigning products is much easier with this method; however, there are two drawbacks. If marketing requirements for the final product are decreased, the Company has already generated inventories of products for which demand is deferred or no longer exists, resulting in large inventory carrying costs. Secondly, contention for certain key rigs required for "finishing" operations occurs near the end of the scheduling horizon, which usually results in failure to produce the target level of at least one product.

Top-down scheduling has several advantages: it moves material through the finishing operations over the scheduling horizon and is less sensitive to variations in marketing forecasts. One drawback is that this approach may lead to more equipment setups, since intermediate compounds must be produced once the supply of inputs is exhausted. The result is a schedule with more switching and less campaigning, but also with finished product being generated earlier in the scheduling horizon.

9. Several numerical parameters should be mentioned. The first is the annual inventory carrying charge, expressed as a percentage. This carrying charge is designed to include opportunity cost, storage and handling costs, and other factors associated with holding inventory. The second parameter is the "debug level", discussed above, which allows the user to control the amount of detailed output generated by the model. The user can alter the debug level at specified points within the simulation, so that he can resolve apparent

model conflicts and develop insight into the model's operations.

PROCESSING FLOW IN THE HEURISTIC MODEL

This section presents a step-by-step description of the functioning of the heuristic model. A narrative form is used rather than conventional flowcharts in order to easily add commentary about the reasons for the processing flow. The flow is oriented around modular blocks of computer coding, each of which perform a specific set of required model functions.

1. INITIALIZATION. All input data files are read into core storage, and variables are initialized to default values. The Status Log shows the contents of the input data files and the parameters specified by the user.

   Steps 2-10 are repeated throughout the scheduling horizon, once for each value of the "time increment" discussed above.

2. STATUS REVIEW. At the end of a simulated day, inventory carrying costs are computed for that day. If priority recomputation for the product chains is required, a subroutine is called to compute and rank the new values of the priority indices.

3. EQUIPMENT SETUP REVIEW. If an equipment setup is due

to be completed during this time period, the appropriate status indicators are modified, freeing manpower resources for further setups.

4. DEFERRED PRODUCT REVIEW. The list of deferred products is reviewed to determine if any product will be in a deferred status during the time period. If so, the product status indicator is modified accordingly.

5. LABORATORY STATUS REVIEW. The material which has completed assay during the time period is added to the appropriate inventories.

6. EQUIPMENT STATUS REVIEW. The equipment list is examined to determine which rigs are available, currently processing material, or undergoing maintenance. If a rig has completed processing during the time period, the material is added to the laboratory queue, and the rig is made available for processing. All available rigs are checked to see if they are scheduled for maintenance during the next time period; if so, their status is changed to indicate that the rig is undergoing maintenance.

Steps 7 and 8 are repeated for each product chain, in the order of product chain ranking as determined by the priority rules.

7. PRODUCT CHAIN REVIEW. The model examines each product in the chain in the following manner:
    - If the net requirements for this product have been met, no production is scheduled.
    - If the product is to be purchased, no review of inputs or rigs is required; go to Step 8.
    - If the product is already being made in the maximum allowable number of rig combinations, production cannot occur. This is an example of a policy designed to ease strain on waste-treatment facilities and raw material supplies, as well as smoothing production of materials, allowing a more diverse product mix to be scheduled in a particular time period. As indicated in the previous section the maximum number of production possibilities for a given product may be dynamically modified in this section of the program.
    - The inventories of all required inputs are checked to determine if the required amounts are currently available. If the required inventory of any input product is not available, production is not scheduled.

8. RIG REVIEW. Having examined the product's feasibility, the method now examines the feasibility of the allowable rig combinations. Each rig is examined to see if it is available. The rig will not be available if it is currently processing material, undergoing maintenance, or is being campaigned for another product. If the product is being campaigned in a particular rig combination, it is assigned to that equipment, regardless of the product's priority. The various rig combinations are checked in the order of rig choice until an available rig combination is found, or until the list is exhausted.

9. SETUP CHECK. If scheduling the product in the chosen rig combination would require an equipment setup, the limitation on the number of setups which can be done concurrently is checked to ensure that the setup can be scheduled. If not, the model returns to Step 8 to look for another rig combination.

10. SCHEDULING THE PRODUCT. Having met all the constraints, the product is now scheduled. Inventories of all input products are adjusted, and product and rig combination status indicators are set. The amount of material generated by scheduling this product is added to

production totals. The cost absorption, setup costs, and equipment utilization statistics are adjusted accordingly. Information is written to the various output files. The model now returns to Step 7.

11. SUMMARY. At the end of the scheduling horizon, a set of final reports is prepared to show the results of the schedule. All cost parameters, including inventory holding cost, unutilized equipment cost, and equipment setup cost are summarized. The status of each product is presented, including final inventory, total production, and percentage of production target satisfied. Summary reports of the production schedule are prepared in tabular and graphical form.

DATA FILES

Chemical scheduling requires much information for the model to function effectively. This information is organized into input data files described below. Although the number of files is relatively large, each file is small, allowing easy file maintenance.

PRODUCT CHAIN FILE

This file contains the Bill of Material for the finished and intermediate biochemical products made at Tippecanoe. Key parameters for a product include the yield of one batch of the product (which may vary, depending on the rig combination), the amount of this product required to make one batch of the next higher-level product, the cycle time, and the rig combination. At present each product may be made in up to five different rig combinations.

SIMULATION CONTROL FILE

This file contains title information and various control parameters for the simulation, as discussed in MODEL OPTIONS AND PARAMETERS.

FINAL PRODUCT PRIORITY FILE

This file contains the numerical priority assigned to each final product by marketing. A high priority means that the product has high urgency.

PRODUCT NET REQUIREMENTS AND INVENTORIES

This file contains net requirements for each product as well as the current inventory level.

EQUIPMENT FILE

This file contains the equipment designations (e.g., 27.31), capacity, the rig type (glass-lined, etc.), and the rig standard cost per hour, which is used in computing unutilized equipment cost.

DOWN-EQUIPMENT FILE

This file contains the list of equipment which is expected to be out of service during the scheduling horizon, the date each rig will go out of service, and the date when the rig will return to a serviceable condition.

PRODUCT COST FILE

This file contains the standard unit cost of the product, used in computing the inventory holding cost.

ABSORPTION COST FILE

This file contains the absorption value for producing one batch of each product. The value is credited to the producing department to balance the department's labor and overhead costs.

IN-PROCESS PRODUCTS FILE

This file contains the list of products which are being made at the start of the scheduling horizon. Each entry consists of the product name, the dates when the product starts and will finish, the batch output, and the rig combination used.

CAMPAIGNED PRODUCTS FILE

This file is designed for forcing a product into a designated rig combination for a specified period of time.

Each entry contains the product name, the starting and ending dates for the campaign, and the chosen rig combination.

DEFERRED PRODUCTS FILE

This file contains the list of products whose production is to be cancelled for a designated period of time. Each entry contains the product name as well as the starting and ending dates for the deferral period.

PRODUCTS-IN-ASSAY FILE

This file shows each product which is being assayed at the start of the scheduling horizon, the date when the assay will be finished, and the amount of product awaiting approval.

PRODUCT TRACE FILE

This file contains the information necessary for the user to alter the debug level for specified products. Each entry contains the product name, the desired debug level, and the time period for which this debug level is to apply. At the end of this period, the debug level is reset to the value specified in the Simulation Control File.

PRODUCTION LIMITATION MODIFICATION FILE

This file contains the information necessary for the user to change the maximum number of places any product can be made concurrently. Each entry contains the product name, desired maximum number of rig combinations, and the time period.

OUTPUT FILES

The model produces three basic output files which are used to evaluate the schedule.

STATUS AND LOG FILE

This file contains the record of all scheduling activity, including absorption and penalty costing information, inventory and production figures, and detailed debug information requested by the user. This file is the basic narrative which details the starting status of the simulation, the decisions made by the model, and the model results.

DETAILED PRODUCTION SUMMARY

This report gives a list of scheduling activity for each date and time period, including the product scheduled, batch size, and the rig combination. The report is useful in planning production activity at a detailed level.

EIG SCHEDULE OUTPUT FILE

This is not a report as such, but contains formatted data which is used as input to two report generators. The first prints a graphical summary of production activity for each rig by month, and is useful in identifying counter-intuitive decisions made by the model. The second shows summarized production information for each rig by month, and complements the first. The flow of data and the interaction between the Scheduling Model and the Corporate Bill of Material are shown in the flowchart on the following page.

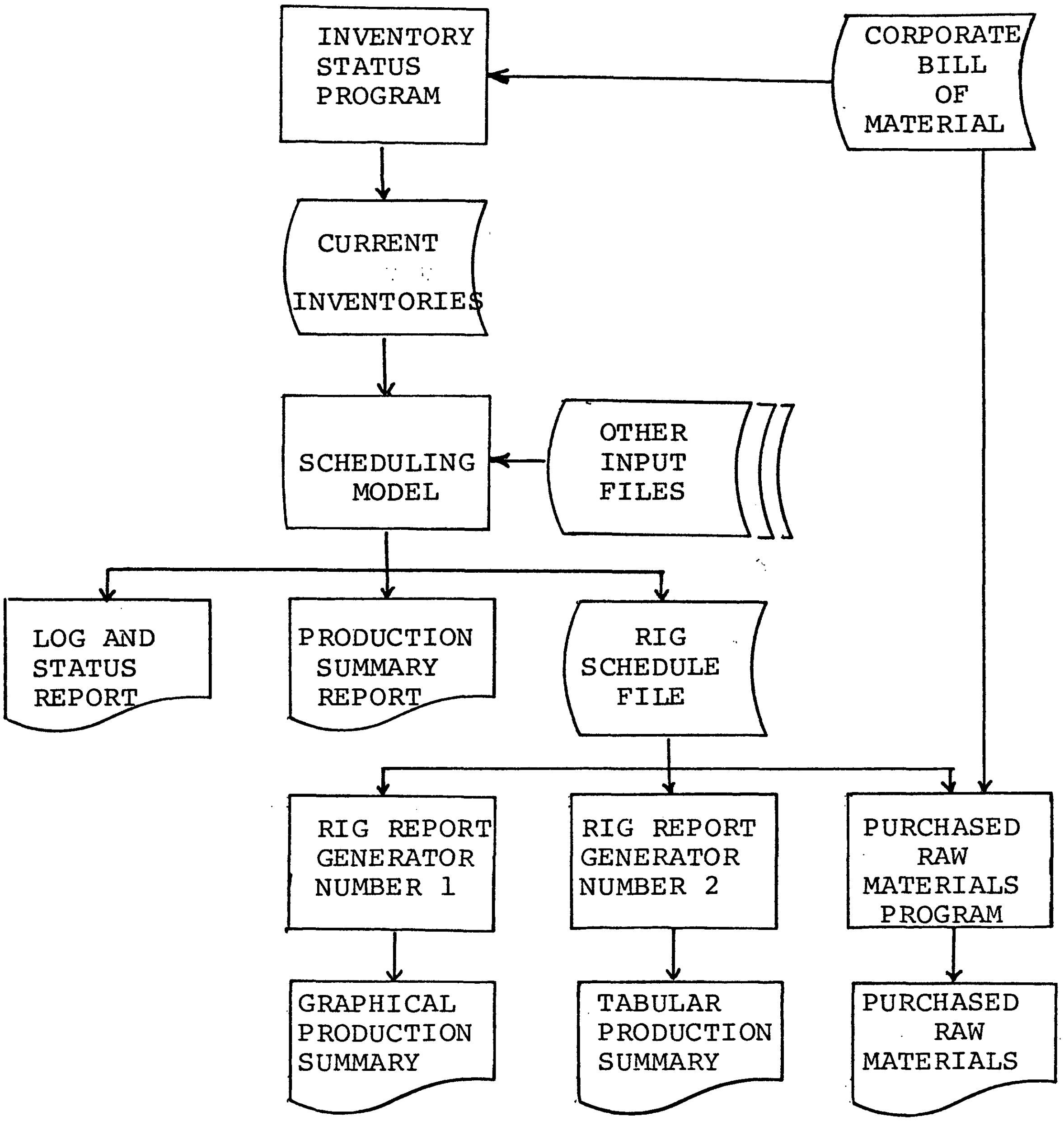

Figure 1

CHEMICAL SCHEDULING SYSTEM FLOWCHART

CASE STUDY

There are a number of possible strategies in using the vertical-loading operations-sequencing simulation model described above. Various combinations of priority and structure rules, together with differing levels of the numerical parameters, give a great deal of flexibility in setting the conditions for scheduling. This chapter presents a case study which shows the potential effects of parameter choices on the scheduling results.

Using requirements for calendar year 1980, schedules were run using two priority rules (Critical Ratio vs. Product-Panic Ratio), two structure rules (Top-to-Bottom vs. Bottom-to-Top), and maximum concurrent setup levels of 2, 3, and 4, respectively. The Marketing Priority alone as a priority rule had been discarded by the Master Scheduler, because this rule leads to many switches between products in the same rig combination. The measure of effectiveness considered is Inventory Holding Cost for the scheduling horizon.

The results of the model run are shown in the table below.

INVENTORY CARRYING COST ($M)

	CRITICAL RATIO		PRODUCT-PANIC RATIO	
	TOP TO BOTTOM	BOTTOM TO TOP	TOP TO BOTTOM	BOTTOM TO TOP
2 SETUPS	2.929	3.325	3.166	3.065
3 SETUPS	2.962	3.379	2.857	3.294
4 SETUPS	2.917	3.494	2.975	3.173

The Analysis of Variance table is shown below.

ANALYSIS OF VARIANCE FOR INVENTORY CARRYING COST

SOURCE	DF	SUMS OF SQUARES	MEAN SQUARES	F
TOTAL	11	0.465711		
PRIORITY RULES	1	0.020917	0.020917	1.215
STRUCTURE RULES	1	0.297360	0.297360	17.279
SETUP LIMITATIONS	2	0.000659	0.000329	0.019
PRIORITY X STRUCTURE	1	0.056170	0.056170	3.264
PRIORITY X SETUP	2	0.005634	0.002817	0.164
STRUCTURE X SETUP	2	0.050553	0.025276	1.469
RESIDUAL	2	0.034419	0.017209	

Using tables of statistically significant values for the F-statistic, the only statistically significant difference in the results for Inventory Carrying Cost results from the Structure rules (20). The averages for Inventory Carrying Cost are:

TOP-TO-BOTTOM: $2.973 MILLION

BOTTOM-TO-TOP: $3.289 MILLION

Scheduling from the top of the product chains toward the bottom would save an average holding cost slightly in excess of $310,000 for the year.

The Priority x Structure interaction, while not statistically significant, shows a value of the F-statistic which is large enough to warrant further investigation. The means are:

CRITICAL RATIO/TOP-TO-BOTTOM: $2.946 MILLION

CRITICAL RATIO/BOTTOM-TO-TOP $3.364 MILLION

PRODUCT-PANIC-RATIO/TOP-TO-BOTTOM: $2.999 MILLION

PRODUCT-PANIC-RATIO/BOTTOM-TO-TOP: $3.177 MILLION

The most advantageous strategy appears to be scheduling from top to bottom of the product chains, using Critical Ratio as the priority rule.

It has been noted elsewhere that the schedules should not be evaluated on the basis of a single criterion. A very significant measure of effectiveness for any scheduling technique is the amount of production which can be scheduled, compared to the production targets. The runs with 3 setups showed significant production target shortfalls for a range of 1-3 products, depending on the priority and structure rules chosen. The runs with 4 setups showed no improvement in this range of shortfalls. In contrast, the runs with 2 setups showed a shortfall range of 7 to 11 products, indicating that a reduction in setup manpower would cause significant degradation in the plant's ability to make production goals. An increase in manpower sufficient to support 4 concurrent setups would pay no dividends against these product requirements.

There are no guarantees that the strategy suggested above is best for all sets of requirements. Examination of various strategies is very fast using the model, and a "best" strategy can be obtained quickly for any given requirements. For the cases outlined above, each model run required 10 to 14 clock minutes on the DEC computer, when the machine is in a relatively "unloaded" condition, In several hours, the user can generate a number of schedules and select the one which best suits the situation.

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