STEPS TOWARDS AUTOMATIC SCHEDULING OF PRODUCTION AT THE BOSTON NAVAL SHIPYARD

by

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Certified by . . . . . .
Faculty Advisor of the Thesis

May 20, 1960

Professor Philip Franklin
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Professor Franklin:

In accordance with the requirements for graduation, I herewith submit a thesis entitled "Steps Towards Automatic Scheduling of Production at the Boston Naval Shipyard."

So many people helped me with this thesis that I am unable to mention each by name. I wish to take this opportunity to thank each and every person who advised, aided, and guided me in the preparation of this paper. I am especially thankful for the many hours of help from Edward J. Connolly, head of the Work Status Section, Production Engineering Division of the Boston Naval Shipyard, who taught me so many things about the shipyard, and to C. Harry Schreiber, my thesis advisor, whose acute sense of judgment helped me stay on the main issue when I tended to get sidetracked with the less important details, and to Mrs. JoAnn Maylor, who so graciously typed this final copy.

Sincerely yours,

CHARLES RALPH BUNCHER

ABSTRACT

STEPS TOWARDS AUTOMATIC SCHEDULING
OF PRODUCTION AT THE BOSTON
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by CHARLES RALPH BUNCHER

Submitted to the School of Industrial Management on May 20, 1960, in partial fulfillment of the requirements for the degree of Bachelor of Science.

The Boston Naval Shipyard has a vast industrial capacity. The problems involved with scheduling the work of four thousand people in a shipyard of this sort are legion. This paper is the result of an investigation of the production processes in theory and fact at the shipyard. Throughout the learning process involved, the goal was to find a method of using an electronic data processing machine to set up the work schedules in place of the human employees currently making the schedules.

The paper tries to first orient the reader with the work of the Boston Naval Shipyard and then more particularly with the scheduling function. After a discussion of the traits desired in a machine solution, a suggested program for scheduling the work is offered. An analysis of this program leads to some final conclusions about the future of this problem.

The conclusions reached are that a final solution must take into account the inherent problems of input information, must be integrated into the production analysis routines, and will probably be a solution by successive approximations. The complete problem is not expected to be adequately solved for at least several years and a working solution will not be available until then.

Thesis Advisor: C. Harry Schreiber

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CHAPTER ONE

A Brief Analysis of the Paper

The problem involved in this thesis is midleading. At first glance one might assume the problem was to find a means of scheduling production automatically on an electronic data processing machine. Professional mathematicians and electrical engineers with years of experience in naval shipyards are still unable to find a working solution to this problem. The problem was to gather enough information from the people involved in the shipyard operation to comprehend just what is implied in a machine calculated schedule.

What contribution could a person with only very limited knowledge of the intimate affairs of a shipyard and equally limited knowledge of electronic computers make towards finding a means of automatic scheduling of work? The contribution is in clearly stating the problem, the necessary conditions of the solution, and the direction for future work. By clarifying the situation, it is hoped that the author has brought the solution to this problem a little closer to being found.

The ultimate problem is simple. The work of the tradesmen at the Boston Naval Shipyard is currently being scheduled by human employees. Because of the sheer volume of the information involved, the men cannot take into account all of the factors required for a superior schedule. Moreover, changes in the schedule to take into account new conditions are exceedingly difficult to make. This type of problem is similar to problems now being solved on electronic data processing machines. The goal is therefore to find a means of solving the scheduling problem on an electronic computer. The advantages of a

machine solution are speed, adaptability, less avoidable mistakes, and an answer that is more in keeping with the constraints of the problem.

The paper first discusses production in the Boston Naval Shipyard and then moves on to the scheduling function itself. A discussion of the expected characteristics of the machine solution is followed by a suggested method of automatic scheduling. The closing chapter analyzes the suggested solution as a means of better understanding the problem and what the ultimate answer will be like.

Two valid conclusions are drawn from the information presented and one hypothesis is left open. The input information is vital to the solution and every effort must be made to make this data as accurate as possible. The program must be integrated into the whole production operation so that control devices and this decision device are compatible. Both of these conclusions imply the importance of a feedback mechanism to check whether the work is progressing as scheduled. Finally it is believed that the most efficient answer to the problem will be a method of successive approximations like the solution suggested.

It is hoped that this paper may serve as a backdrop against which anyone interested in the problem may see more clearly the details involved.

CHAPTER TWO

The Operation of the Boston Naval Shipyard

The United States Navy operates shipyards on both coasts of this continent to maintain its ships in readiness for the defense of the country. The mission of these yards is to service the fleet. In day to day cases, this mission implies doing any work authorized in connection with the construction, conversion, overhaul, alteration, repair, drydocking, and outfitting of vessels. All of those tasks required to keep a fleet ready for action, up to date, efficiently operating, and, at the same time, pleasant for the crewmen must be performed by the naval shipyards.

There are currently shipyards at Portsmouth, Boston, New York, Philadelphia, Norfolk, Charleston, Puget Sound, Mare Island, San Francisco, Long Beach, and Pearl Harbor. In addition to the common operations of each, each shipyard has a special function. This paper is concerned with the operation at the Boston Naval Shipyard although much of the data would be applicable to the other yards. Boston primarily services cruisers and destroyers with only occasional work on other ships like the aircraft carrier, U.S.S. Wasp (CVS-18). Moreover, Boston performs mainly conversion and overhaul work and is not performing any new construction now.

A ship's relationship to a naval shipyard is a periodic function. First the ship is built in either a private or a naval shipyard, although most peacetime construction is done privately. When it is launched, it is as modern and efficient as the technology of the day will permit. After it is launched, the ship is maintained by the naval

shipyards in accordance with the mission of the yards. Thus every two or three years, each ship will be scheduled to spend several months in a shipyard for an overhaul. The overhaul will consist of a general refurbishing in an effort to keep the ship operating at maximum efficiency. Gears may be replaced, pumps may be refitted, minor fixtures may be installed, alterations to electronics equipment may be made, and so forth. The category of overhaul includes each of the operations that either modernizes the existing ship or maintains efficiency.

Sometimes a basic change in the ship itself is called for. The problems of rapid technological change, long economic life, and the need for an up to date navy have been resolved in the conversion. A conversion consists of drastic changes in the actual structure of a ship rather than the very costly process of building an altogether new ship. The first aircraft carriers were converted from battleships in this way. Currently, guided missile conversions are a commonplace; that is, the after deck guns of a ship may be replaced by guided missile launching apparatus. Because of the rapidly changing technology of the modern world and because much more work is involved in a conversion than a mere overhaul, the conversions form a large portion of Boston Naval Shipyard activity.

Finally a ship may have unexpected damage at sea necessitating immediate repairs if the ship is to continue its function in the fleet. Severe storms, many types of human accidents, or ship collisions may result in a distress call to the nearest shipyard whose function then becomes to put this ship back at sea in as nearly normal condition as possible as quickly as possible. The probabilities involved in this type of incident cause a shipyard to expect about one major repair case

each year. It is obvious that a repair case upsets any planning or scheduling involving the period of repair.

The overhaul function will now be considered in more detail. In this process a ship at sea travels to a shipyard, has work performed on it, and then returns to sea again. Any naval vessel is responsible to a type commander, such as Commander of Destroyers, Atlantic Fleet, for its tactical operations. Above the type commander, the Bureau of Ships in Washington, D. C., is responsible for the general planning of ship operations to the Chief of Naval Operations. The Chief of Naval Operations is the highest ranking officer in the navy and his position in many respects is similar to that of a corporation president in the industrial world. With the help of his staff, he plans which ships are to be overhauled in any given year. Moreover, his responsibility for maintaining an up to date navy for the defense of the country and his position as the central coordinator of the navy make him the officer that decides what ship conversions will be performed by each of the naval shipyards.

A couple of words of terminology would be helpful at this point. Availability is the time during which the shipyard will be allowed to work upon a vessel. Thus a destroyer escort may be available from 15 June to 9 August. The arrival date is the date on which the ship is scheduled to be first available to the yard, in the above example, 15 June. All time is figured relative to the arrival date.

Advance planning may start, in a very nebulous state, as much as two years before the arrival date. Thus in preparing the fiscal budget for one year, the overhaul work on a ship may be tentatively postponed until the following year. When the next year's planning

takes place, it may be decided that the ship will be overhauled sometime during the year. As the arrival date gets closer, details are decided upon. The two decisions to be made are which ships will be overhauled in the given year and what yards will be told to perform the overhaul work.

> "Factors considered in formulating the overhaul schedule are: (a) intervals between the previous overhaul availabilities of vessels and the proposed overhauls; (b) the placing of vessels in ... yards capable of performing any required special type of work; (c) the provision of continuity of work in all yards to avoid laying off men intermittently; (d) the probable availability of critical material on important jobs; (e) and any special factors that may arise."[1]

After the yard for the job is chosen, the applicable yard, the type commander, and the ship's commanding officer are left to decide on the finer details. The type commander in consultation with the shipyard decides upon the actual dates of the availability. The factors that are considered include the expected operations of the ship, operations of other ships of the same type, minimum requirements for the ships afloat, and the tentative work load in the yard.

The final problem is to decide upon the actual work that the yard will perform for the ship. The type commander and the ship decide upon the work that they believe should be done. The two major constraints in this decision are the budget of the type commander and the set of standard equipment that is allowed on each ship type. The former restraint means that the type commander must allocate his budget amongst the ships in his command so that any one ship is restricted in the size of her expenditures. The latter restraint implies that certain

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1. Naval Shipyard Duty for Engineering Specialists, Bureau of Naval Personnel, Navpers 10815-A, (Washington, 1956), P. 116.

work desired by the ship, such as putting a windshield on the bridge of a destroyer, may not be performed on a ship; any work of this nature is dropped from the list of work when discovered.

When the yard receives a preliminary copy of the work list, it prepares a preliminary estimate of the time and cost of the items and transmits the results back to the type commander. Amendments to the list are then made under the light of these shipyard estimates. By 120 days before arrival the ship and the type commander submit a "final" preliminary work list to the yard. Planning and scheduling are then based on this "final" preliminary work list with the understanding that many changes will still be made.

At this time the shipyard begins its intensive preparation for the arrival of the ship. Special material or equipment is ordered from subcontractors if expedient or prepared by the yard, plans are drawn up or drawings obtained from another yard, and preliminary schedules of the various shipyard facilities are made. As much of the advance planning and scheduling as possible is completed.

Two weeks prior to the arrival of the vessel in the yard, an arrival conference of designated yard personnel and the ship's officers is held. The purpose of this conference is to discuss the work lists, determining and analyzing the scope, priority, and authorization of each item. It would be quite convenient if the work list could be fixed at this time but many changes are yet to be made. As machinery is shut off or the ship is drydocked, new work is discovered. Thus, when the actual situation is different from the expected situation, as in the case of opening up a boiler to unexpectedly find the tubes so corroded that they must be replaced, changes must be made in

the work list. Other changes result from the mixture of the ideas of the ship's officers and yard personnel.

As part of the background, one must understand that the shipyard workers are grouped by trades into shops. Each shop is assigned certain specific work and manned with specially trained and qualified men adept in that occupation. The shops consist of civil service employees under the control of a civilian. A few examples of shops are the shipfitters shop, the sheetmetal shop, the electronics shop, the paint shop, and the inside machine shop.

The work list to which references have been made consists of various individual jobs. "Subsequent to the arrival conference, the planners and estimators draft the details of the job in the form of a job order."[2] This job order, which is the authority to yard shops to proceed with work, includes the specifications for the work to be performed, and a listing of the shops involved in its accomplishment. The format and actual mechanics of job order issuance will be discussed in the next chapter.

Among other details the job order specifies the dates between which each shop is to complete its portion of the job. If the work progresses as planned, then the shops will work side by side or in succession according to the schedule of dates on the job order. When one realizes that some twenty shops and four thousand men are involved in the operation at Boston, it is obvious that efficient schedules are a necessity. Records are kept as the work advances so that progress reports can be made. Estimates of being ahead or behind schedule may lead to a changed schedule.

The last few days of the availability are set aside for testing

2. Ibid., P. 119.

the work. Tests imply dock trials and sea trials; further work may be required if the work does not test out as expected. After the tests preparations necessary to make the ship ready for sea are finished such as fueling the ship, taking on food, and stocking up on ship's stores. Then the ship returns to the sea.

The history of a conversion is almost the same as the history of an overhaul just outlined. The basic difference is that work involved in a conversion is much more extensive than a simple overhaul; the very structure of a ship is to be changed. Accordingly, the availability is longer and the uncertainties of scheduling even greater. The actual procedure of scheduling and making job orders is the same as for an overhaul.

Emergency repairs are different from normal overhauls in that only the necessary work to make the ship operate normally is performed. The whole procedure is streamlined to enable the work to be accomplished as rapidly as possible. Job orders must still be issued and scheduled as with overhauls and conversions.

CHAPTER THREE

The Current Production Scheduling Process

From the overview presented in chapter two, it is rather obvious that advanced planning is vital to the efficiency of a naval shipyard. Limitations on drydocking facilities, the necessity of returning a ship to sea by the appointed date, a labor force that can be changed only very slowly, limitations on the capacity of any one shop, and the decomposition of each job into dependent tasks are factors that make careful planning an absolute necessity. If the scheduling of the work is not both sufficient and timely, the results may run the gamut from a simple delay to utter chaos.

In this paper the focus is on the scheduling of job orders. (See appendix two for a sample job order and brief description.) An average destroyer overhaul will entail about two hundred and sixty-five orders. Work on cruisers and conversion work involve many times that number of job orders. As an upper limit a major conversion with an availability of eighteen months may run five to six thousand job orders.

When the job order arrives at the scheduling section, it already has a great deal of information on it. It lacks only the actual dates during which the individual line items are to be accomplished before it is ready to go to the shops. This information includes the following: (a) name and number of the ship to be worked on, (b) a breakdown of the job order into individual line items for each shop involved, (c) a job title and a brief description of the work

involved in each of the line items, (d) the total number of manhours for the job and a breakdown of this number into manhours for each line item, (e) the name of the lead shop, that is, the shop that has the overall responsibility for the work on the job order, and (f) a job order priority factor. The other information on the job order does not effect the problem at hand.

The function of the scheduling branch is to add the starting and completion dates of each line item to the job order and to indicate how many working days are involved. Although the physical change in the job order is slight, the addition has involved a major decision. Literally thousands of workers must depend upon the dates assigned. The considerations that are involved in making this decision will be discussed later in this chapter. The problem to be kept in mind is how to best put together the information available to arrive at a schedule that is efficient and timely.

It is important to realize that the actual scheduling of a ship is not done all at once. As was shown in the last chapter, the work list is continually being amended so that a complete work schedule cannot be obtained before the work is finished. The scheduling process extends over a period of about thirteen weeks on a conventional destroyer overhaul and lasts longer on larger ship overhauls and all conversions. About three-fifths of the work is scheduled before the arrival date leaving the remaining two-fifths of the work to be scheduled after the ship is in the yard.

After the scheduling process is completed, the job orders are sent to the shops involved as directives to do the work at the appointed time. The shop planning section plans the details of the job, insures

that material is available, and arranges a time schedule of the workers so that the required completion date is met. The lead shop coordinates the work of the various assisting shops.

What are the considerations involved in the scheduling section's decisions? Experience plays a sizable role in making a schedule. Each scheduler has generally worked from ten to fifteen years in the shops before he moves up to a scheduling position. During this time the men have seen the operation of scheduling as it effects their own shop and by association they have seen its effects on the other shops. They have seen its effects on the other shops. They have learned the idiosyncrasies of the yard as well as the normal yard habits and can apply these lessons in making their schedules. As would be expected, the schedulers come from the productive shops rather than the support shops. The following shops are currently represented in the scheduling branch: shipfitters, sheet metal, inside machine, outside machine, pipe and copper fitters, electric, electronics, and riggers.

A list of principal dates breaks down the ship's availability into smaller intervals such that certain jobs must be performed during certain portions of the availability. The basic dates are the dates of entrance and exit from the drydock and the dates of the dock and sea trials. Other dates may also be specified, such as when a deck will be opened, mast staging removed, and so forth.

Another factor to be considered is the location in the ship of the work specified by the job order. Frequently the only access to a compartment is through the compartment directly overhead, the limited accesses being necessary to preserve "watertight integrity" in case of damage. From a scheduler's viewpoint limited access is a restriction

of freedom in scheduling. If the only entrance to a lower compartment is through an upper compartment, the work in the lower compartment should be completed first. Unless this is the case the workers will have to carry materials and tools through a completed compartment to do their work. If the work in the upper compartment was to lay tile on the deck or install delicate electronic gear, the disadvantage is obvious.

Location is also taken into account when the schedulers attempt to distribute the work being done at one time throughout the ship instead of overcrowding any one area with workers. They are hampered because the compartments involved are not indicated on the job order even though this information was used in making up the line items in earlier planning.

The last factor to be discussed concerns the operation of more than one shop. Can two shops work together on the same job at the same time? The answer is yes in some cases, such as the sheet metal workers and the shipfitters, and no in other cases, such as the painters and electricians. The scheduler must take into account whether two shops should be scheduled to work side by side or whether one shop should wait until the other has completed its work.

Finally at least one simplifying assumption should be mentioned. Throughout the scheduling process, it is assumed that the shops involved always have enough men to perform the work. Although this factor is important, the task of checking through the job orders for all ships being scheduled that day is too complex for a man at his desk to ascertain when a shop does happen to be overscheduled. If a shop is overscheduled, it attempts to use overtime to make up the difference and if this is not sufficient then some of the work is left undone with

the hope that the shop can catch up at a later slack period.

Each scheduler takes the various factors mentioned into account anytime he schedules a job order. That the shops get their work done in an orderly fashion most of the time is sufficient evidence to prove that the current means of scheduling is a workable system. That there are delays, weeks with too much work scheduled for a shop, and other maladies is likewise sufficient evidence that there is much room for improvement. The limiting factor that prevents the schedulers from producing a better schedule with the information available is that they are human. In other words, the schedulers can only sift through the diverse and complex information available to produce a more efficient schedule by sacrificing the trait of timeliness, and likewise, the schedule can be produced quickly only if time is not taken to make it efficient. Since a schedule is no good unless it has both traits, the schedulers have resorted to the best compromise available to them.

CHAPTER FOUR

The Characteristics of a Machine Solution

In considering the current means of scheduling production at the Boston Naval Shipyard, the conclusion was reached that the process was limited by the fact that human beings were doing the work. The human schedulers cannot economically perform the tedious checks necessary to produce a trouble free schedule in a reasonable length of time; this type of repetitive operation is one of the most important uses of modern electronic data processing machines. Machines have certain advantages and certain disadvantages over humans. The purpose of this chapter is to determine the characteristics of a machine solution to scheduling that best makes use of the machine's advantages and minimizes its disadvantages.

A clearer definition must be made than just saying that the machine solution is "better" in some way than the current type of solution. From a purely cost standpoint, one could require the machine solution to be less costly than the current solution on a long run basis. In other words, either the machine solution may cost less to run per week or the savings from a more efficient and timely schedule should offset any extra cost of running the program. Unless there is a significant cost improvement, the automatic schedule has failed to justify itself.

Speed is one factor expected of a machine solution. Assuming reasonable programming efficiency, one weeks worth of job orders could be scheduled in an hour. This saving in time is enormous! The time saving is so good that the whole set of job orders could be programmed

again easily if a new situation made this procedure advisable. One of the limitations of the human schedulers is that the volume of work precludes any extensive rescheduling when conditions change only slightly; the men do reschedule only if there is a major change. With the machine an emergency repair job, delays in acquiring material, work that did not get finished on time, and so forth, could be added to the fixed conditions of the solution and within an hour a corrected schedule, taking into account the latest developments, would be available.

Another advantage of a machine that should be exploited is the ability to take into account the theoretically simple but voluminous details, such as how many men from each shop are scheduled in a particular day. If this check information is available to the computer, it has no reason to assume anything, for it can determine when a shop is overworked or even when a shop is underworked. Simple checks of this sort can eliminate some of the delays that occur in the current means of scheduling.

One critical factor is the amount of input information that the machine requires to produce a schedule. Clearly the less information required, the better the program. The machine must be told what ships are to be serviced, what job orders are to be scheduled, what fixed commitments must be met, and so forth, just like the current schedulers. Since the machine is capable of high speed but low intelligence operations, one would expect that it needs more information for each run than the humans are given in order to produce a schedule. If the work required in preparing the extra information becomes too great, then the machine schedule is no longer feasible.

Finally, it is an advantage if the machine solution to the

scheduling problem is integrated with the other related programs run on the computer. A few words of background will help clarify the situation. The Boston Naval Shipyard installed a Burroughs 205 Electronic Data-Processing System, a medium-scale computing system, a little over a year ago. Since than it has been used mostly for accounting and bookkeeping purposes such as preparing the payroll. About a fifth of the productive time of the machine is taken up with the programs that help guide the operations of the Production Division. Since much of this work is still in the experimental stage, the programs are run independently in spite of the fact that similar information is used for similar purposes. It is expected that as the computer installation matures, the various programs will have compatable inputs and outputs as a step towards efficiency. Since the input and output operations are the most time consuming processes on a computer, this step forward is essential.

Quite a few programs are currently being used to give the management of the Production Division a clearer idea of their division's operations. Three will be mentioned to give a clearer picture of the possibilities in this field. First there is the Forecast Workload vs. Scheduled Workload Graph. The program figures out and plots the following information by weeks: (a) the amount of work in mandays that the yard forecasts it will perform in order to complete the scheduled shipyard work, (b) the amount of the above work that has already been scheduled by the normal scheduling process, and (c) the amount of work that the work force is capable of performing. The program plots this information for twenty-six weeks into the future. One can tell at a glance from this information whether the men have enough

or too much work, et cetera.

Another program, the Manday Status Report, predicts the trend in manning of the ship at any time in the availability. The purpose of this program is to predict a total labor cost for the ship at any time during the availability period in light of whatever changes in plans have occurred. Finally, the Workload Forecast Balance investigates a ship that has not been manned according to the optimum forecast. It spreads the lag or lead in actual manning over the remaining availability, adjusting the optimum predictions until the ship can be expected to be finished on schedule.

The details of these programs are unimportant for present purposes; the important point is to realize that the information involved in these programs could be used in solving the problem of automatic scheduling of production. Moreover, as the other programs are being integrated into compatable information packets, so must the scheduling program be compatable in order to be most valuable in the overall operation of the yard.

CHAPTER FIVE

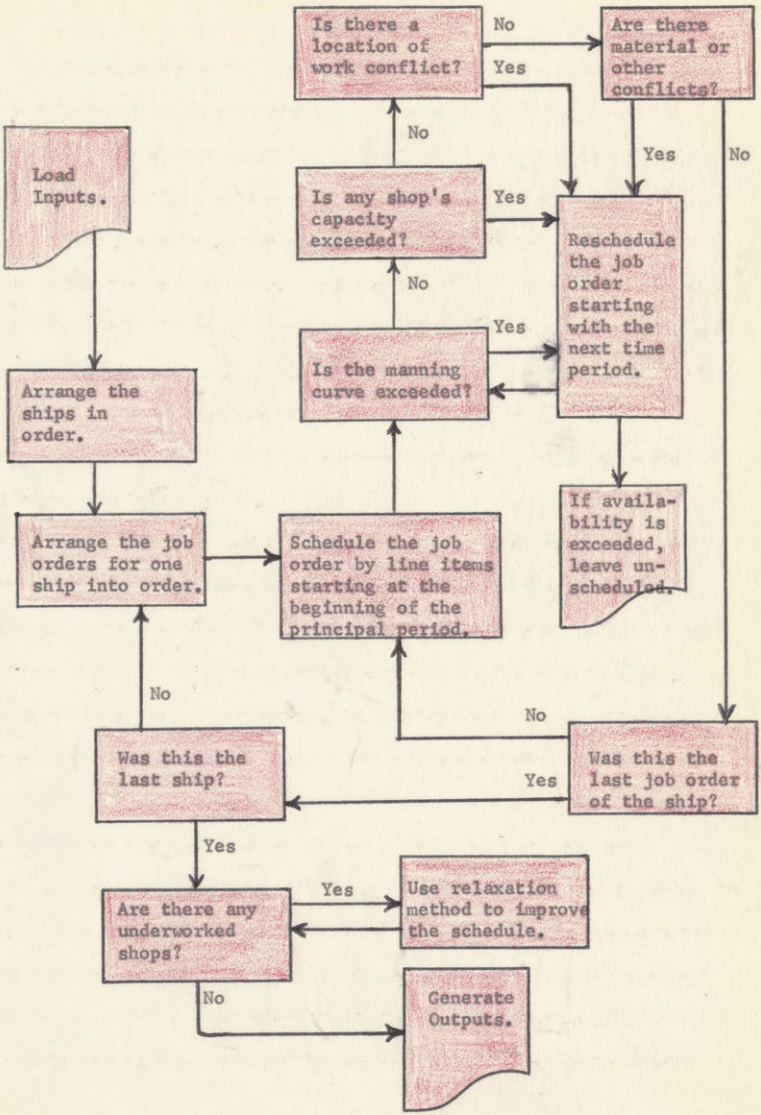
The Suggested Automatic Schedule

This chapter contains a description of one way of attacking the problem of automatic scheduling of production. This method is not offered as the best possible means of machine scheduling; it is a solution that will enable one to see more clearly just what is entailed in the problem. The evaluation of the method will be reserved until the next chapter. One should attempt to understand the implications of this scheduling process and determine the assumptions upon which it is founded. One assumption is that the information fed into the machine is accurate without any wrong numbers, incorrect dates, and so forth. A few of the other assumptions will be mentioned as the process is explained.

A flow diagram of the program appears on the next page. One can trace the various steps of the solution as they are described in the text. Only the major alternatives will be discussed to maintain clarity and to remain in the pattern set by the rest of this paper. The author is aware of most of the minor alternatives and believes that careful programming is the answer to the problem that they pose.

First the various inputs are loaded into the machine. This information consists of the normal job order data that has been mentioned previously and, in addition, the following bits of information: (a) a location factor that tells where on the ship the work is to take place, (b) an indication of the type of ship on which the work is to be done, (c) the principal dates for each ship to be scheduled, (d) a calendar so the machine will not schedule work on weekends or

A BLOCK DIAGRAM OF THE SUGGESTED AUTOMATIC SCHEDULE



holidays, (e) an estimate of the total number of manhours to be worked on each ship, and (f) any job orders already scheduled and their schedules if this information is not to be changed. There are two other pieces of input that will be discussed in the following paragraphs.

For this solution the machine must have the set of manning curves for each ship type to be scheduled. The manning curves merely relate the percentage of the work to be accomplished to the time in which the work is to be accomplished. A small amount of work is done in the beginning of the availability, much work is accomplished in the middle portion, and only the details of finishing and testing are done in the final part of the availability. There is a curve for each shop for each ship type.

The manning curves were derived from historical data that tended to show the relation of quantity of work to time of doing the work. There is a very basic assumption involved. It is assumed that the manning curve is accurate over time. Thus in spite of the fact that two different ships of the same type are getting two different overhauls, it is expected that each shop will perform about the same amount of work and at about the same times during the two availabilities.

In understanding the last set of inputs, one must understand the job of the human schedulers more clearly than heretofore presented. The scheduler has two decisions to make each time he schedules a line item. He must decide how long the work should take and when during the availability the work should be done. Since these two decisions are related, the scheduler is given a little more freedom than being forced to make one choice given the other. The machine is going to lose that extra freedom for simplification. As part of the input information,

each line item will have a designation stating the number of days the work will last. Another program for producing automatic schedules might take into account the possibility of varying the duration of each line item.

As part of the above choice, the scheduler also decides whether two line items can be accomplished concurrently or whether they must procede in succession. This information will also be considered fixed in the input to the machine.

A. The Solution Program

The first calculation that the machine performs is to arrange the ships in an order of importance of completion; the lower a ship is on this list, the more likely it is to have work on it postponed in favor of a more important ship. The order will take into account how close the end of the availability period is and temper this criterion with a priority for important but longer range work. Thus an important conversion with three months to go on its availability may be ranked ahead of a normal destroyer overhaul with only one month to go. At the end of this operation the ships are arranged in the order in which they will be scheduled by the machine.

Next the machine attempts to order the job orders in a process analogous to the ordering of ships. This operation is the most crucial element in the program! The computer must take into account the principal period or periods during which the work must be performed. Drydocking work is set aside to be done during the drydock period, finishing work is left for the final days, pump replacement may be done almost anytime, and so forth. Moreover, related job orders must contain a designation so that later work will follow necessary prerequisite work.

The machine evaluates all of this information and arrives at a date which is the earliest date possible for starting each job order, and therefore has the job orders in a time order.

An interesting consideration in the ordering of work is whether area scheduling or systems scheduling will be used. Area scheduling implies making a unit out of one part of the ship and relating the work to its location in a certain compartment. Scheduling by location works out alright for most of the shops but not for the electricians as one example. These workers would prefer a system schedule, that is a schedule that follows an electric cable through several job orders if they are connected by the same system. Cables do not lend themselves to the artificial boundaries of bulkheads. It seems most expedient to allow area scheduling to prevail when the two methods are in conflict.

B. Successive Approximations

The actual scheduling process involves setting up a schedule and then modifying the first estimate to allow for the various constraints. The computer starts with the first job order of the first ship and schedules it line item by line item from the first day of the availability. After the job order is tentatively scheduled, the computer runs a series of tests to be certain that none of the constraints have been violated. Consider the general case of a job order somewhere in the middle of the pile. Job orders have already been scheduled ahead of this one and the previously scheduled job orders loaded as input also precede this one. Thus some of the shipyard capacity is previously accounted for.

The first check is a comparison of the work scheduled for

a period with the estimate on the manning curve. If the work scheduled for a shop for this period exceeds some factor, such as a hundred and ten percent, of the manning curve prediction, the job order schedule fails this test. That job order or just those line items involved are then put through a rescheduling process. The rescheduler merely does the same date-setting operation as the original scheduler but at the next later time period. After the work is rescheduled, it is resubmitted to the testing procedure. It is noted that this system of scheduling tends to have all of the work scheduled as early as possible, but that the comparison to the manning curve tends to smooth out the work load over the availability period.

If the job order schedule passes the manning curve test, it is tried in the overworked shop test. The computer adds up all of the work scheduled for each shop involved, including the work on the job order just scheduled, and determines if the capacity of the shop is exceeded at any time. If the capacity is exceeded, the job order is submitted to the rescheduling subroutine. If the various shop capacities are not exceeded, the job order moves to the next test.

The computer checks the location of the work to see that there are not too many workers in one area of the ship. If too many workers are supposed to be doing their jobs in one part of the ship, they will tend to get in each other's way and disrupt the planned schedule. Failing this test would send the job order to the rescheduler routine while passing would send the schedule on to be checked for other conflicts.

As a final check, the computer checks other possible conflicts to be certain that the schedule is a good one. The machine

makes sure that any special materials, drawings, tools, and so forth, are available for the job order before the time it is scheduled to be accomplished. When all of the tests have been passed, the schedule is set and another job order has been scheduled. Failing any one of these tests sends the job order back to be rescheduled at a later time. What happens if the job order just will not fit into the constraints?

The simplest and probably most efficient answer to job orders that do not fit the pattern is to reject them. In other words, if the program finds a job order that gets postponed past the last date of the availability, it sets aside that job order to be part of a separate output. These problem cases will then be solved by humans who know all of the possible ways of successfully breaking the rules set up for the computer. As long as the number of rejects is small, the program is working well. A large number of rejects should indicate that the availability period of some ship is no longer reasonable and must be changed.

After the checking procedure, the computer ascertains whether the job order just scheduled was the last one for that ship. If not, it moves on to the next job order and repeats the process. If the job order just scheduled completes the ship, the computer proceeds to the next ship and schedules it by the same process. When the last ship has been scheduled, the computer makes one last attempt to improve the schedule.

C. One Last Adjustment

The machine checks through the shops to find out if any are

underworked in the next few weeks, where underworked can be defined by some figure like eighty percent of capacity. If this is the case, then the computer attempts to reschedule the job orders involving this shop to an earlier period until the shop is not as underworked. This process would be comparable to the mathematical process of relaxation in estimating a parameter over a lattice. The checking process would show what shops were overstaffed and at the same time provide them with enough current work to prepare them for any extra work that might occur in the future. Otherwise extra workers would be laid off.

Now the computer is ready to divulge its results. One must decide how much of the information available is desirable and in what form. Obviously the output should contain all of the job orders and their schedules and separately those few job orders that have not been scheduled. It is also obvious that the information for a Forecast Workload vs. Scheduled Workload Graph is available and desirable to have. Others of the normal control devices can be produced directly from the information available to the machine when it has finished its schedule. Thus when the computer has finished its scheduling function, it can produce from the same information enough descriptive reports to enable management to decide on vital matters.

D. Role of the Scheduling Program

There is still a question that must be answered. What is the role of the scheduling program in the overall production system? If a program of this sort were worked out in detail and

used weekly, it would become the fundamental program of the Production Division. The system would probably work as follows. Each week the computer would schedule the work of the yard for the next six months taking into account whatever input information was deemed appropriate. The shops would be sent the job orders for the fourth week in the future and whatever new job orders were written for the next three weeks. Each shop would have already received the bulk of the job orders for the next three weeks since they were delivered in past weeks. The job orders that were already scheduled would be entered into the machine as fixed input so as not to be changed.

All work for the fifth and following weeks would have been scheduled but not delivered. Thus if the machine changes the schedule the following week, no notification needs to be sent the shops; they never received the original schedule. Any time a new schedule had to be produced, the machine would use whatever fixed input was felt to be appropriate under the conditions and compute any changes. A changed job order schedule could then be sent to each shop. The shop would acknowledge receipt by returning the originally scheduled job order. Those job orders involving special materials, and so on, would become fixed many weeks in the future and thereafter they would be fixed inputs to the program.

Between runs of this program, there should definitely be a feedback process whose purpose is to control the work being done by the shops. The program just states that work should be completed by a certain date and there remains the problem of checking to see that the commitment is met. The process of checking to see that the schedule is met is not only a basic check on the shops but also

the best check to see if the automatic schedule is as good as expected.

Since the automatic scheduling program has become the basic source of control information, provision should also be made for updating the information used. Any changes in the schedules of facilities, information on whether the line items have been completed, notation of whether basic materials have arrived at the yard, and so forth, must be entered into the series of constraints against which the computer is going to schedule. The problems of feedback and updating the information are very vital to the automatic schedule but their solution is not the point of this discussion. Suffice it to say that these problems can be overcome.

Finally one can see that the schedule resulting from this program is strictly a function of the inputs to the machine. If there are serious changes in plans or too many missed commitments, the new information can be submitted to the computer and it will generate a new schedule. The new schedule will only apply to those job orders considered variable since scheduled job orders used as input information will remain constant.

The ramifications of the changes in shipyard activity due to automatic scheduling are too numerous to be discussed individually. This chapter will close in the acknowledgment that many details have not been mentioned. It is believed that none of these unmentioned details are sufficiently serious as to disturb the general picture.

CHAPTER SIX

An Analysis of the Suggested Solution and Its Relation to the Problem

This chapter contains an analysis of the solution to automatic scheduling suggested in the previous chapter. In the light of the information gained from the solution, an attempt will be made to point out the future of this field and even where the ultimate solution to the problem will be found.

First a few of the attractive features of the solution will be discussed. The method will produce a machine schedule with all of the inherent advantages of an automatic schedule over the current method of handling the problem. Speed, ability to handle small details, and so forth, are all traits of this computer solution but not the human solution. A new schedule can be produced and processed in only a matter of hours with this method any time there are changes in availabilities, sufficient missed commitments, or an unexpected repair problem.

It was also seen that this program produces as by-products many types of management controls. Integration of the scheduling process and the controlling process will produce a more efficient shipyard. There will be a considerable saving in machine time because control and forecast programs will not have to be run separately. Moreover, the control devices will be more accurate because estimates can be replaced with actual scheduling information.

Finally as long as the inputs to the program are reasonable and accurate, the solution will be reasonable and accurate.

If the initial conditions are changed, the solution will be changed to take into account the new information. Thus any time the yard personnel decide that an input factor has changed, the program will automatically take into account the changes without having to be rewritten. This program has a long potential lifetime then, dying only when one of the fundamental assumptions on which it is based changes.

The same topic of input information can be used to start the discussion of the deficiencies of the solution. The schedule is only as good as the information put into the computer. Are the manning curves valid? Do they change over time? Are the decisions of how long the work should take accurate, or should the machine be given this other degree of freedom? Although particularly true in the suggested solution, any machine schedule fails if the input data is not sound.

Most important this program is of no use unless there is a feedback process telling whether the line items are being completed on time by the shops. The job orders and other input information must be updated each week. Even though this updating problem is separated from the scheduling problem in theory, in fact the two problems are so closely related as to require solutions that fit together.

Another detriment, common in some degree to all machine solutions, is that information not currently used will have to be assembled and put in proper form for the machine to use. Also common to any program of the complexity and diversity of an automatic schedule of production is the requirement of a more capable

machine than the Burroughs 205 for reasonable efficiency. The solution is simply to get a larger and faster machine or more likely to rent time on one that is being used in the area.

Summing up, there are certain benefits and detriments common to all machine solutions to the scheduling problem. These factors should only enter into the choice of one program over another as far as the factors are different. The other factors that are peculiar to a single solution will be the final decision points in deciding between alternative solutions. The problems involved in finding and using an efficient and workable solution are still several years from being answered. There are, however, several valuable lessons to be learned from the suggested solution and this critique of it.

It is apparent that any ultimate solution to this problem must take into account the quality of the input information. If the inputs contain estimates, the outputs will suffer from the discrepancy between the estimate and the truth. Therefore in solving the scheduling problem, one might just as well set up a feedback system checking whether the work is being performed as scheduled to assure that the input data is reasonable.

One extension of the input problem is also important. Management needs information from which it can make decisions. The reports used as a basis for these decisions and the information involved in the automatic schedule are very similar. If the various processes are integrated so that the information is compatible to all, the data processing machine can be used most advantageously.

Finally it is believed that the basic method of successive approximations to the answer is quite valid in this problem. The most efficient solution is to take a starting schedule and then improve on it be reference to the shipyard constraints. Also stopping a little short of forcing everything to fit will provide valuable management controls and save a great deal of effort on the part of the computer.

The benefits to be derived from a machine solution to the scheduling of production are so great that the people involved should make every effort to help find the answer. Currently, there are various individuals working on the problem from different viewpoints in scattered parts of the country. These individuals should be brought together periodically to trade ideas and conclusions. The resulting flow of information from these meetings would probably shorten considerably the time necessary to find a workable solution to the problem. Also the best automatic schedule will probably be a combination of a couple of separate ideas and will never be found in the current pattern of individual searches for the solution.

It is hoped that the discussion in this paper has helped clarify the problems involved in automatic scheduling of production at the Boston Naval Shipyard in particular and naval shipyards in general. Only the next few years of work will prove whether the principals set forth herein will be valid in the ultimate solution. If these paragraphs have helped in any way bring the answer a few steps closer, the author will be satisfied.

APPENDIX ONE

Summary of the Shops at the Boston Naval Shipyard

Number and Name		Function
06	Central Tool	Installation, maintenance, and repairing of all plant equipment in the industrial shops.
11	Shipfitter	Fabrication, assembly, and erection of the structural parts of a ship.
17	Sheet Metal	Fabricating, assembling, erecting, and repairing of all sheet metal work of No. 10 U.S. gage or lighter gage metals.
23	Forge	Responsible for all types of forging and heat treating.
26	Welding	Perform all welding and burning operations; a service shop.
31	Inside Machine	Internal combustion engine repairs and tests and fabrication of spare parts; dynamometer tests.
38	Outside Machine	Installation, repair, test, conducting of docktrials, and assisting on sea trials of machinery and ordnance equipment on vessels.
41	Boiler	Manufacture, test, and repair of all types of pressure vessels and their appurtenances.
51	Electric	Maintenance and major repairs of shipyard electrical equipment, temporary lighting, battery servicing, and all ship electrical work.
56	Pipe	Responsible for the pipe fitting, plumbing, copper-smithing, insulating, lead tinning, electroplating, zinc metal and thiokol rubber spraying involved in the construction and maintenance of ship and shipyard work.
64	Woodworking	Pattern-making, building wooden furniture, installation of fiber glass insulation and wooden deck treads.
67	Electronics	Installation, maintenance, and repair of electronic equipment including radio, radar, sonar, loran, and teletype equipment.
71	Paint	Responsible for all shipboard painting in the shipyard.

Number and Name		Function
72	Riggers	Responsible for the cranes and rigging equipment and auxiliary labor and salvage work; a service shop.
94	Pattern	Prepare patterns for castings and making all models.
99	Temporary Service	Miscellaneous service activities in support of the work of the other shops on ships.

Reference: Naval Shipyard Duty for Engineering Specialists, pp. 108-113.

APPENDIX TWO

The Job Order

The following page is a facsimile of a sample job order reduced slightly from its normal eight and one half by eleven inch size. These forms are normally hectographed and distributed to the shops and to any individuals who are involved in the production processes.

A line item is the part of the whole job to be accomplished by one shop at one time. Each line item is given a separate instruction number; each starts on a new line and hence the name.

The second and any additional pages to the job order are similar in form to the line item part of the top sheet but have only a one line heading.

JOB ORDER
IND-BSNNS-1015 (1-60)

SHEET 1 OF 2

JO CODE	REVISION	DATE	PREPARED BY	EXT	SUPV. PAE	TYPE DESK
16215/5102	0	2-19-60	Craft	364		

SHIP OR PROJECT	SHIP NO.	P/E	FINAL	ARTF FOR
USS Rooks	DD 804	No	✓	

LABOR	MANHOURS	PRIORITY	ITEM NO.	AUTHORITY
601	168	8.1	A-3-S	Cdl. Adv. Act

OVERHEAD	LEAD SHOP	CLASS
482	41	C

MATERIAL	CODE ROUTING
50	232

TOTAL 1133

JOB TITLE: No. 1 Superheater, Repairs to

SHOP	11	17	23	26	31	38	41	51	56	64	67	71	72	94	06 99			
MAT'L							50											
HOURS				24			96		24						24			
REVISED HOURS																		

INST. NO.	STD	SHOP	HOURS	WORK DAYS	START DATE	COMP. DATE	REF	REPORTS — WORK INSTRUCTIONS
001		99	16	2	2-26	2-29		Provide air, lights, and water in No. 1 Fire Room and maintain during repairs to No. 1 superheater.
002		41	24	2	3-1	3-2		Inspect Hand Hole seats and build up with weld as required in second pass of No. 1 superheater.
003		26	24	2	3-1	3-2		Provide Welding Service to build up hand hole seats as per direction of Shop 41.
004		41	56	4	3-3	3-8		Set up Elliot refacing machine on No. 1 superheater and machine hand hole seats to a true surface.

WORK UNDER CGGN OF SUPT.	WORK COMPLETED	DATE