SHIP PRODUCTION COMMITTEE
FACILITIES AND ENVIRONMENTAL EFFECTS
SURFACE PREPARATION AND COATINGS
DESIGN/PRODUCTION INTEGRATION
HUMAN RESOURCE INNOVATION
MARINE INDUSTRY STANDARDS
WELDING
INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING

September 1981
NSRP 0008

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Proceedings of the REAPS Technical Symposium

Paper No. 21: Planning and Scheduling Ship Construction Subject to Limited Resources

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
SEP 1981	**N/A**	**-**

4. TITLE AND SUBTITLE
The National Shipbuilding Research Program Proceedings of the REAPS Technical Symposium Paper No. 21: Planning and Scheduling Ship Construction Subject to Limited Resources

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Surface Warfare Center CD Code 2230 - Design Integration Tools Building 192 Room 128 9500 MacArthur Blvd Bethesda, MD 20817-5700

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**22**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

DISCLAIMER

Proceedings
IREAPS Technical Symposium

September 15-17, 1981

Baltimore, Maryland

INSTITUTE FOR RESEARCH AND ENGINEERING FOR AUTOMATION AND PRODUCTIVITY IN SHIPBUILDING

IREAPS

PLANNING AND SCHEDULING SHIP CONSTRUCTION SUBJECT TO LIMITED RESOURCES

Laurent C. Deschamps
President
Spar Associates Inc
Annapolis, Maryland

PREFACE

The over-riding concern in shipbuilding today is how to increase productivity, However, attention instead should be focused upon improving management policy. Qua1ity of goods and services produced and the improvement of production operations from a control1ed learning experience should be management's primary goals, By concentrating on these, increased productivity wi11 be a by-product.

The learning process, however, requires a basis from which management, can eva1uate past performance and develop a program for avoiding failures and improving upon the successes This basis does not evolve by happenstance, It must be the result of deliberate, careful and reasonably detailed planning and a means for capturing actual performance against the plan,

This discussion addresses the vital need to consider and accommodate the impact of 1imited resources (manpower, floor space, crane capacity, etc.) to the planning Problem, Often ignored by planning, resources, if not available in sufficient. quantities, or not applied properly, will most. definitely lead to higher costs and longer production schedules.

I.0 Introduction

In a well-managed company, the determination of resource requirements is essential both to insure that sufficient resources are available, and that excess resources do not burden overhead costs. Resource planning is a cross-check between the resource assignment and scheduling processes.

The analysis of resource availability can determine if planned schedules are indeed achievable, The basic sources of data needed to develop resource requirements are the resource estimates and planned schedules of work. Resource analysis accuracy depends upon the level of detail at which the resource estimates and schedules have been developed,

Information typically available at the early stages of a contract are the major milestone *dates* (start, launch, delivery, etc.) and the bid estimates, usually at the major account work breakdown *level* of the project, Overall department or trade breakdown detail may also be available at this time. With this information, and with the aid of historical curves, preliminary resource requirements (primarily manpower) can be derived and will be as accurate as the degree to which the historical curve actually conforms to *the* new contract situation. Unfortunately, such is not normally the case. Many shipyards currently develop initial production schedules and resource requirements at the *very minimum* levels of detail.

Modern computerized techniques have proved that a smooth loading curve is not always possible as may be attempted manually, Consider, for example, the case where there are critical time periods where deviation from schedule *is* not possible *in* order to meet contracted delivery dates. If manual smooth loading were adopted under such circumstances, there would result an immediate impact upon the delivery and the plan would begin as a losing situation without anyone realizing the eventual problem until too late.

A condition like that *above,* if repeated on a number of contracts, too often leads to a general lack of confidence in a plan even before a project begins (negative attitude on the part of Production?).

2.0 the Work Package Approach

For a company that has adopted the work package concept, the ideal level of information would be the entire set of work packages, complete with resource estimates and schedules. There is, at this level, no need to use historical curves per se because the overlaying of resource requirements for each work package will generate its own profile, as will be discussed in Section 4.0.

In the manual. process Of resovrec loading, the bar Chart format (see Figure 3, 0.2) is genarally chosen, but. interrelationships are difficult.. to maintain in an orderly way Therefore, *it.* is almost impossible to comprehend the various alternatives that can be used in attaining the ultimate goal of scheduling within the limits of available resources.

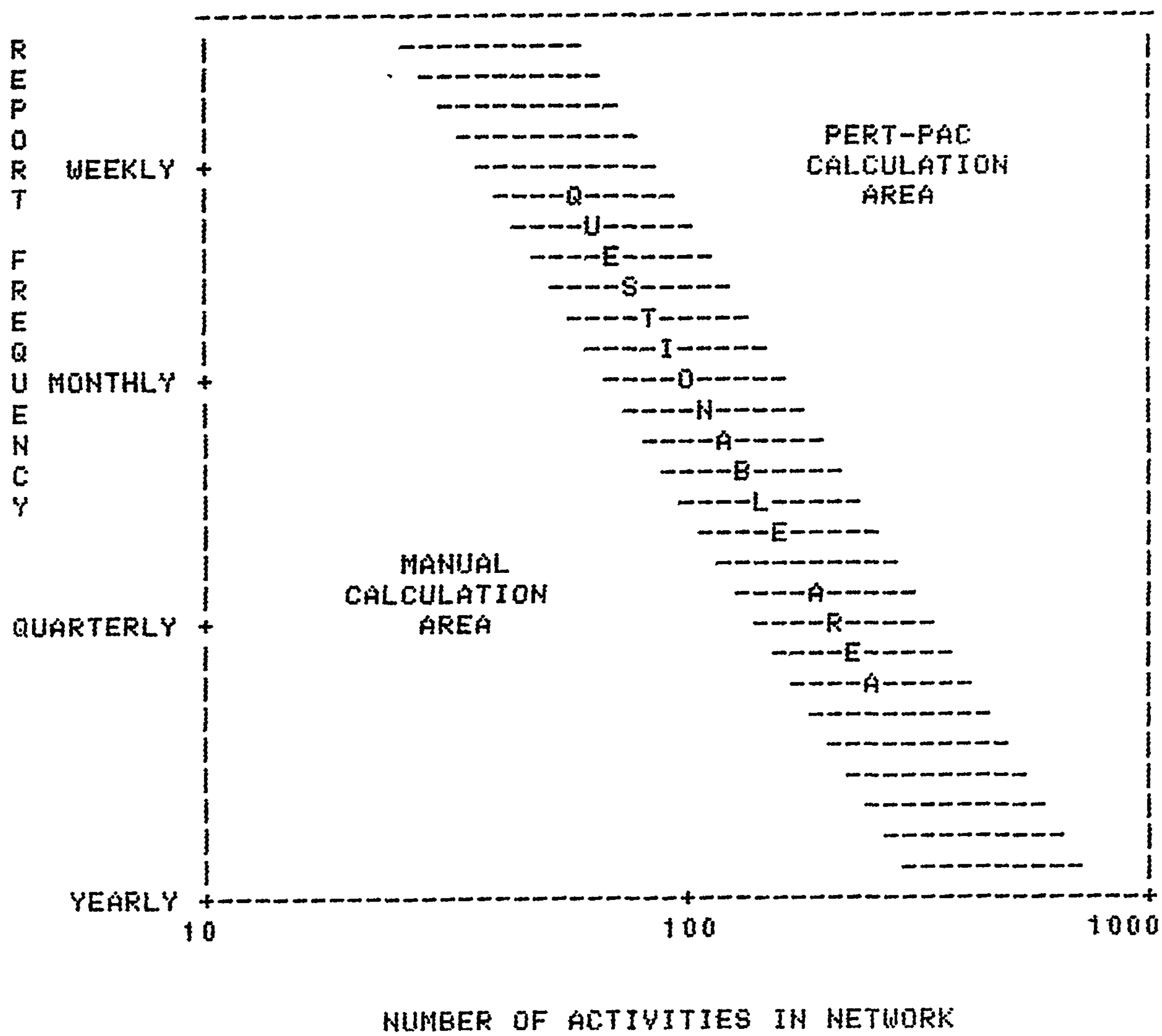
Once a project has been planned and scheduled, the planning effort should not stop. Management. likely will always need to evaluate cost and schedule performance on a continuous basis and make necessary decisions to re-plan and re-direct available resource in the best ways possible.

If an. average project involves some 5 ,000 activity and management demands accurate and timely repots but is reluctant to expand overhead staff', it is unlikely that a solid plan with realistic resource loading and practical production schedules can be developed,

The computer, however, can be exploited quickly and cost effectively. Software is available to expedite the detail scheduling process accurately and in an orderly way using such methods as the critical path network technique, And, if resource estimates can be applied to the same level of work breakdown (activities), very accurate and meaningful resource requirements can be easily determined to forma rational basis for the ultimate project scheduling.

The choice between using a computer Or manual method is mainly *a* question Of cost and convenience, A definitive *answer* is difficult for small projects, but larger ones, or once requiring an interplay between multiple projects, can derive significant benefits its from a computered approach, Factors which influence the decision to computerize include the number of activities, the number of schedule performance reports expected, the content to *wh i ch* resources involved are to be analyzed, and the desired output format, Figure 2. 0.1 illustrates the relative breakeven *points for given* numbers of' activities and the reporting frequency,

FIGURE 2.0.1: Chart Of Computerized Versus Manual Methods Selection



3.0 Network Scheduling

Network scheduling (critical path method) is a planning technique that allows schedules to be developed from appropriate start/stop dependencies between activities, See Figure 3,0.1 for a sample network iilustration.

The advantage of using the critical path method for scheduling is that it provides a means to logically develop all work within a project and to establish the proper sequences of activities, Networks generate real work priorities needed later to maintain schedules. As work is actually completed, priorities can change, and management must continuously strive to expedite the more critical work.

For non-critical activities, the method determines slack time available, within which time activities may be started and completed without any further restraint by the network configuration.

Figure 3.0.2 illustrates a sample barchart result of network scheduling, Note that the critical path method has established early start dates for all activities; those with slack time available (shown with dashed lines) are free to start. any time within this slack time frame, provided they do not finish any time later than the date at the ends of their slack periods. Figure 3.0.3 presents the manpower loading if all activities started at their earliest start dates, regardless of the slack time available,

Ideally, any project should be expedited on the earliest possible start date for all work involved; this better insures that any delays will have minimum effect upon the ultimate completion of the project. However, what may well make *this* ideal impractical is whether or not these non-critical activities have sufficient resources to all start at their earliest start dates,

Even if resources are available, applying them all at the earliest possible time may not be cost effective, either in the short or long run. Practically speaking, however, the ability to perform work at a constant level of manpower normally means lower costs. Erratic levels of manpower usually translates into excessive overtimes, unstable hiring requirements, low worker morale and all the attendant problems - and expenses. Hiring-and-firing policies lead to high employee turnover which, in turn, leads to poor product quality and higher costs.

Figure 3.0,4 presents the manpower loading if all activities started at their latest start dates, any slippage whatever obviously leaves no room for recovery of the total planned project completion schedule.

Figure 3.0.5 presents the range of possible rates of manpower expenditures permitted *within* bounds of the critical path scheduling, The object, thus, is to develop a rate consistent to meet final delivery schedules and to *minimize* overall costs,

If resources are limited, the least critical activities should be delayed until after the more critical activities have been completed and resources are available.

Clearly, additional efforts must be expended in the planning process to have schedules meet not only critical path, but also limited resource requirements.

FIGURE 3.0.1: SAMPLE CRIT1CAL PATH METHOD NETWORK

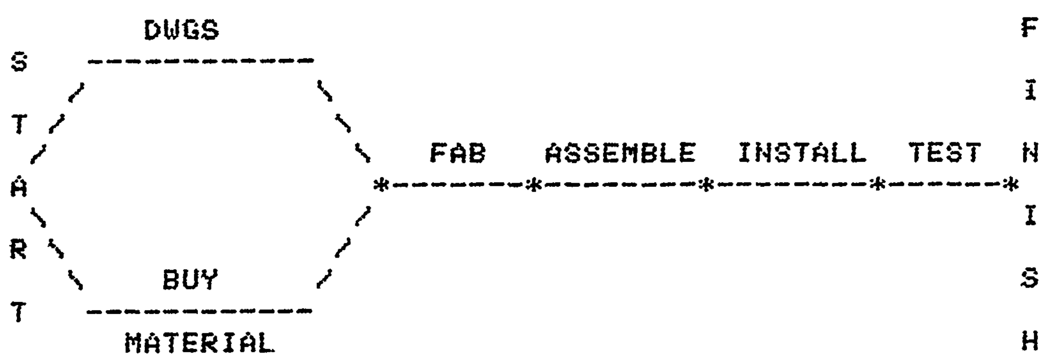


FIGURE 3,0,2

WORK PACKAGE SCHEDULES
BEFORE
LIMITING MANPOWER; IN OUTFIT

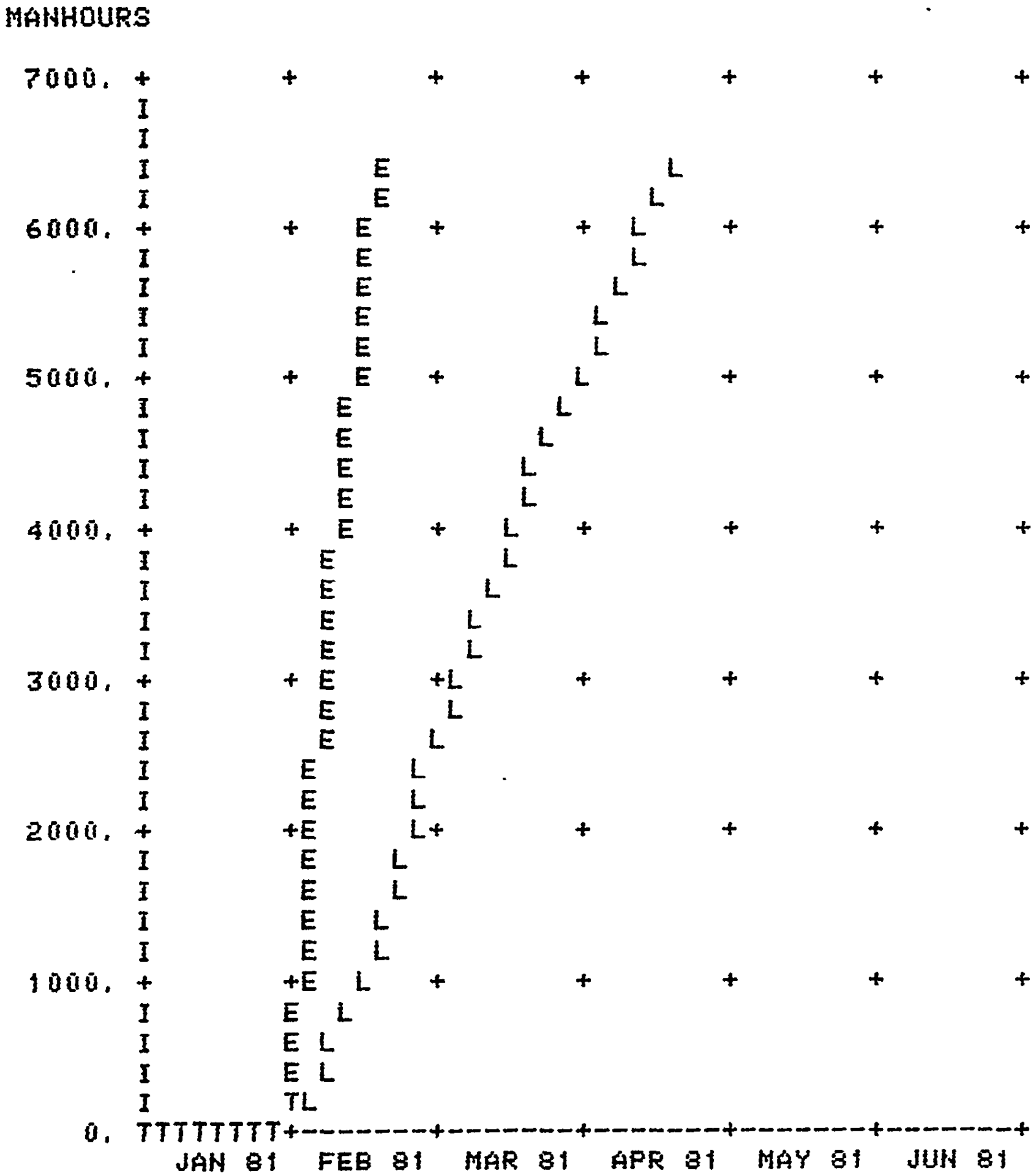
```
  JAN 81  FEB 81  MAR 81  APR 81  WC     PKG                 HRS
+-------+-------+-------+-------+ ------------------------------
+    XXXXX-----------------     +  2  102110. SHOP ASSEMBLY  500.

+    XXXXX---------------       +  2  102109. SHOP ASSEMBLY  500.

+    XXXXX------------- +       +  2  102108. SHOP ASSEMBLY  500.

+    XXXXX-----------   +       +  2  102107. SHOP ASSEMBLY  500.

+    XXXXX---------     +       +  2  102106. SHOP ASSEMBLY  500.

+    XXXXX--------      +       +  2  102105. SHOP ASSEMBLY  500.

+    XXXXX----- +       +       +  2  102104. SHOP ASSEMBLY  500.

+    XXXXX----  +       +       +  2  102103. SHOP ASSEMBLY  500.

+    XXXXX--    +       +       +  2  102102. SHOP ASSEMBLY  500.

+      XXXXXXX---------------   +  3  103110. UNIT OUTFIT    650.

+      XXXXXXX--------------    +  3  103109. UNIT OUTFIT    650.

+      XXXXXXX-------------     +  3  103108. UNIT OUTFIT    650.

+      XXXXXXX-----------       +  3  103107. UNIT OUTFIT    650.

+      XXXXXXX--------- +       +  3  103106. UNIT OUTFIT    650.

+      XXXXXXX-------   +       +  3  103105. UNIT OUTFIT    650.

+      XXXXXXX-----     +       +  3  103104. UNIT OUTFIT    650.

+      XXXXXXX---       +       +  3  103103. UNIT OUTFIT    650.

+      XXXXXXX- +       +       +  3  103102. UNIT OUTFIT    650.

+      XXXXXXX  +       +       +  3  103101. UNIT OUTFIT    650.

+-------+-------+-------+-------+
  JAN 81  FEB 81  MAR 81  APR 81
```

```
TOTAL MEN PLANNED
   80. +       +       +       +       +       +       +
       I
       I               FIGURE  3.0.3
       I
       I
   70. +       +       +       +       +       +       +
       I
       I        MANPOWER LOADING WITHOUT LIMITS
       I         (Schedules In Early Start)
       I
   60. +       +       +       +       +       +       +
       I
       I
       I      TTTTTTT
       I      T     T
   50. +      T+    T  +       +       +       +       +
       I      T     T
       I      T     T
       I      T     T
       I      T     T
   40. +      T+    T  +       +       +       +       +
       I      T     T
       I      T     T
       I      T     T
       I      T     T
   30. +      T+    T  +       +       +       +       +
       I      T     T
       I      T     T
       I      T     T
       I      T     T
   20. +      T+    T  +       +       +       +       +
       I      T     T
       I      T     T
       I      T     T
       I      T     T
   10. +      T+    T  +       +       +       +       +
       I      T     T
       I      T     T
       I      T     T
       I      T     T
    0. TTTTTTTT+----TTTTTTTTTTTTTTTT---+-------+-------+
         JAN 81  FEB 81  MAR 81  APR 81  MAY 81  JUN 81
```

```
TOTAL MEN PLANNED
      40. +       +       +       +       +       +       +
          I
          I               FIGURE  3.0.4
          I
          I
      35. +       +       +       +       +       +       +
          I
          I      MANPOWER LOADING WITHOUT LIMITS
          I         (Schedules In Late Start)
          I
      30. +       +       +       +       +       +       +
          I
          I
          I
          I
      25. +       +       +       +       +       +       +
          I
          I                      TT
          I            T    T T TTT
          I            T    T T TTT
      20. +       +    T  + T T TTT       +       +       +
          I            T    T T TTT
          I            T    T T TTT
          I            T    T T TTTTT
          I          TTTTTTTTTTTTT  T
      15. +       +  T  TTTT      + T     +       +       +
          I          T  TTTT        T
          I          T  TTTT        T
          I          T  TTTT        TT
          I        TTT  TTTT         T
      10. +       +T      +       +  T    +       +       +
          I        T                 T
          I        T                 T
          I        T                 T
          I        T                 TTT
       5. +      TTT      +       +   TT  +       +       +
          I      T                    TT
          I      T                    TT
          I      T                    TT
          I      T                    TT
       0. TTTTTTTT+-------+-------+---TT--+-------+-------+
            JAN 81  FEB 81  MAR 81  APR 81  MAY 81  JUN 81
```

FIGURE 3.0.5

Range Of Possible Manpower Rates Of Expenditure



4.0 The Resource Allocation Problem

A method to develop resource requirements is illustrated in Figure 4.0.1. By tallying the resources over the time periods that. the activities are in process, the total reseurce requirements at all points in time can be estimated by assuming that resources will be expended at a tonstant rate over the time period of the activity. This constant expenditure assumption is valid for most practical purposes if activities ace reasonably small and of shot duration. Also, net effects from summing numerous activities tend to even out any 1ocal distortions that may arise whenever this assumption fails to match actual expenditures exactly,

Non-constant resource expenditures are also possible, hut. suffer the drawbacks of being too complicated for most planning applications, And, the do not contribute significantly to the overall accuracy of the scheduling if the activities are developed properly.

Once resources have been estimated for activities, t-he next. problem is to establish overall limits to their availabilities, These limits may be applied to different types OF resources (manpower, floot- space, cranes, etc.and made time-variable to better model expected conditions within the shipyard,

4,i Limiting Project Resources

The resource leveling effort attempts to maintain ail activity start dates as the early start dates developed by the critical path method of scheduling, This helps insure that any actual delays in schedules will have minimum impact upon the over al1 project completion schedule. In the resource levelling procedure, critical activities should be loaded first so that they consume resources first. The procedure then should continuously check whether resources are available to begin a new activity; if not, the activity must be delayed and its slack time reduced accordingly.

Under no circumstances should an activity be delayed beyond its computed slack time.

Figure 4, 1.1 illustrates the manpower requirements subject to 1imited resources. Figure 4, 1,2 provides a revised bar chart of activity schedules reflecting these adjustments,

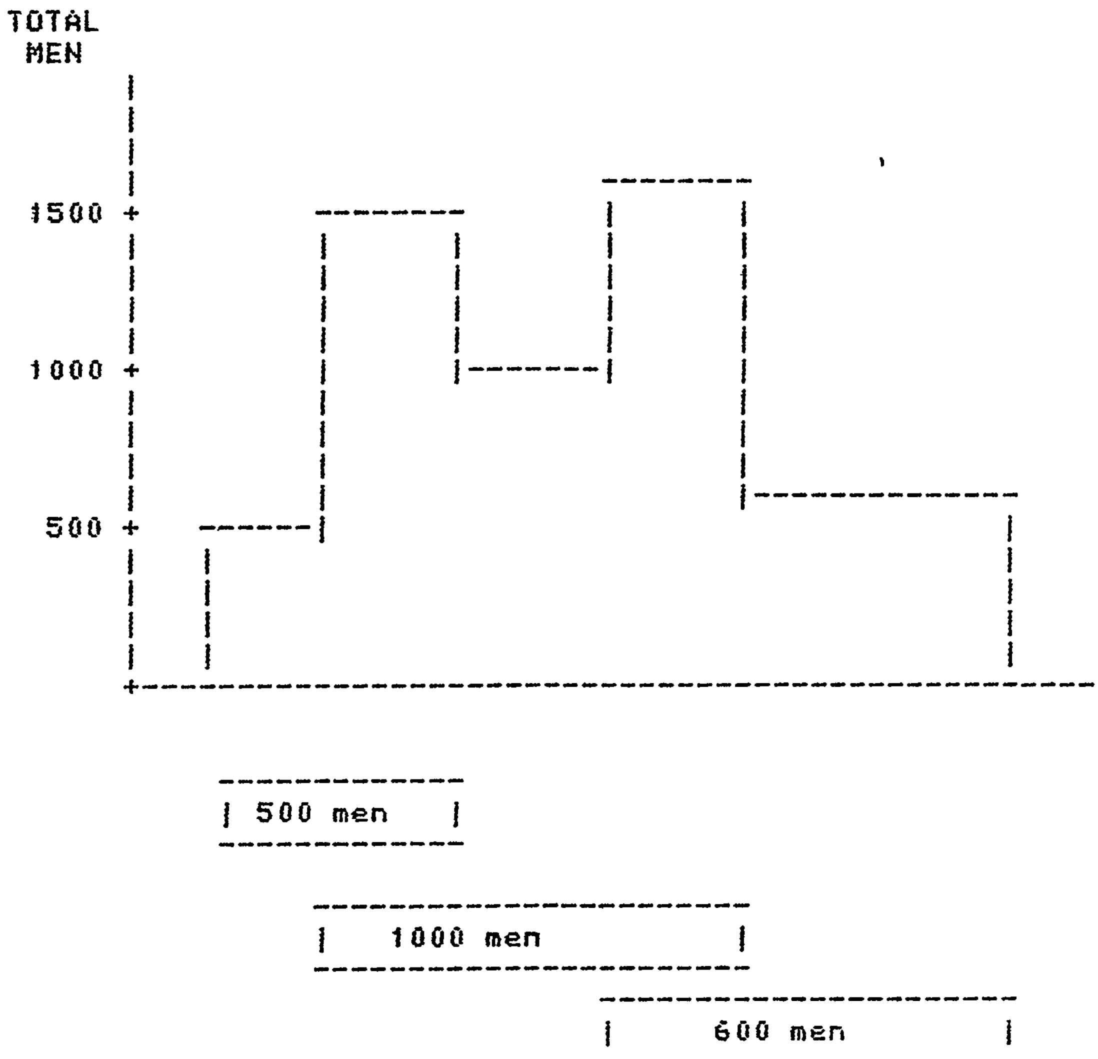


Figure 4.0.1: PERT-PAC Procedure For Developing Resource Requirements

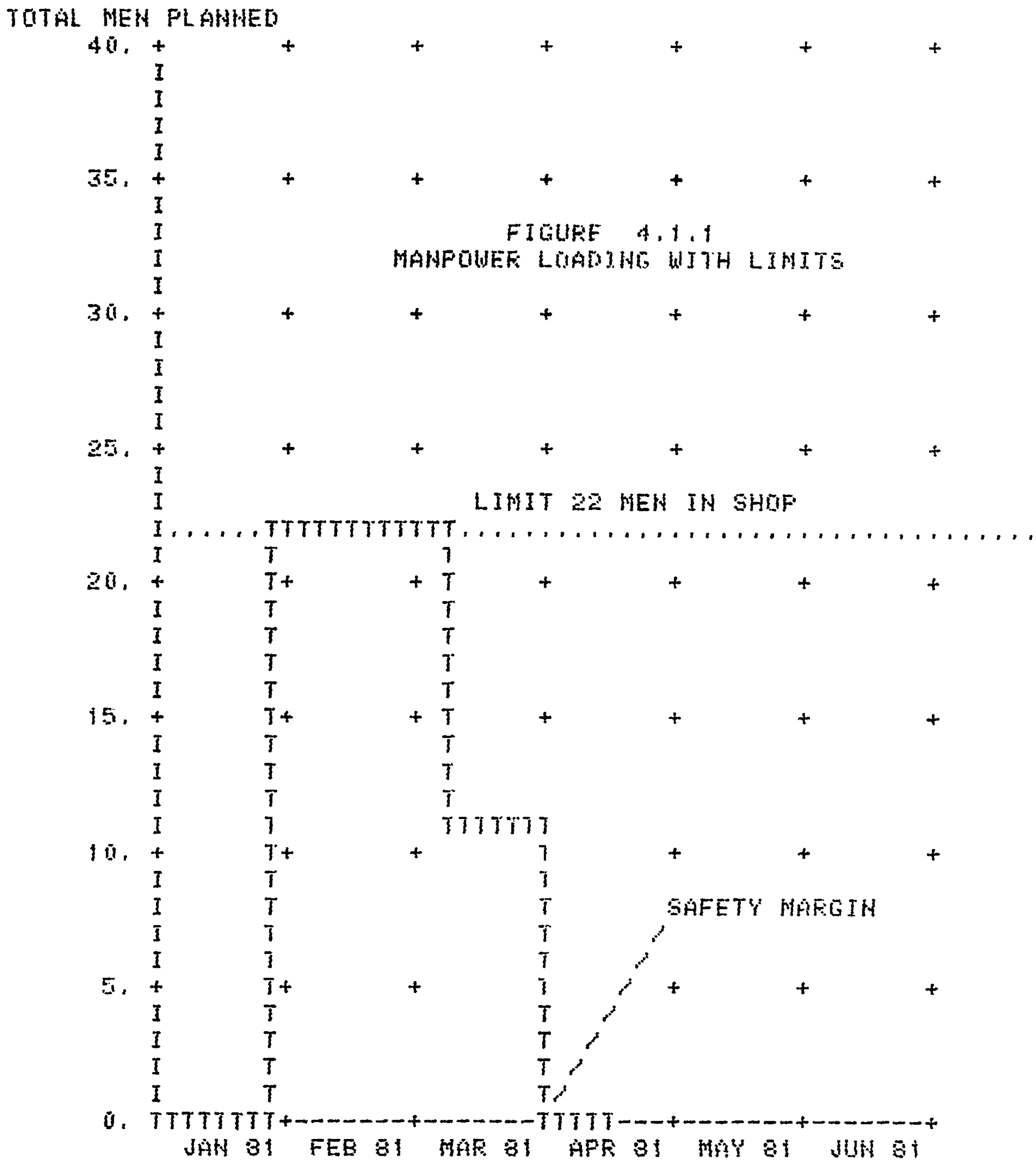


FIGURE 4.1.1
MANPOWER LOADING WITH LIMITS

FIGURE 4.1.2

WORK PACKAGE SCHEDULES
AFTER
LIMITING MANPOWER IN OUTFIT

```
  JAN 81  FEB 81  MAR 81  APR 81  WC     PKG                  HRS
+-------+-------+-------+-------+ -----------------------------
+    XXXXX-----------------     +  2  102110. SHOP ASSEMBLY  500.

+    XXXXX---------------       +  2  102109. SHOP ASSEMBLY  500.

+    XXXXX------------- +       +  2  102108. SHOP ASSEMBLY  500.

+    XXXXX-----------   +       +  2  102107. SHOP ASSEMBLY  500.

+    XXXXX---------     +       +  2  102106. SHOP ASSEMBLY  500.

+    XXXXX--------      +       +  2  102105. SHOP ASSEMBLY  500.

+    XXXXX----- +       +       +  2  102104. SHOP ASSEMBLY  500.

+    XXXXX----  +       +       +  2  102103. SHOP ASSEMBLY  500.

+    XXXXX--    +       +       +  2  102102. SHOP ASSEMBLY  500.

+      XXXXXXX-----     +       +  3  103104. UNIT OUTFIT    650.

+      XXXXXXX---       +       +  3  103103. UNIT OUTFIT    650.

+      XXXXXXX- +       +       +  3  103102. UNIT OUTFIT    650.

+      XXXXXXX  +       +       +  3  103101. UNIT OUTFIT    650.

+       +    XXXXXX--------     +  3  103108. UNIT OUTFIT    650.

+       +    XXXXXX------       +  3  103107. UNIT OUTFIT    650.

+       +    XXXXXX---- +       +  3  103106. UNIT OUTFIT    650.

+       +    XXXXXX--   +       +  3  103105. UNIT OUTFIT    650.

+       +       + XXXXXXX----   +  3  103110. UNIT OUTFIT    650.

+       +       + XXXXXXX---    +  3  103109. UNIT OUTFIT    650.

+-------+-------+-------+-------+
  JAN 81  FEB 81  MAR 81  APR 81
```

The limiting resource problem, however", is not without its 0wn limitations, There is a point beyond which resources are so scarce that the project cannot be expedited within the time-frame planned. In terms of the *critical* path meth-od, this means that a point is reached where there is no more slack time available for delaying activities in order to avoid those time periods of full resource utilization. The only recourse, under these conditions,. is to accept the resource excesses by scheduling over-time, additional sub-contracting, and/or new hires.. etc ...or allow the entire project to slip. Figure 4.1.3 illustrates the problem where no more slack can be bled out. of the network schedules,

Any given work package may exhibit multiple resource limit restrictions, The planning process must accommodate at *least* for the worst case; i.e,, the resource with the greatest excess over it5 limit,

5,0 The Updating Problem

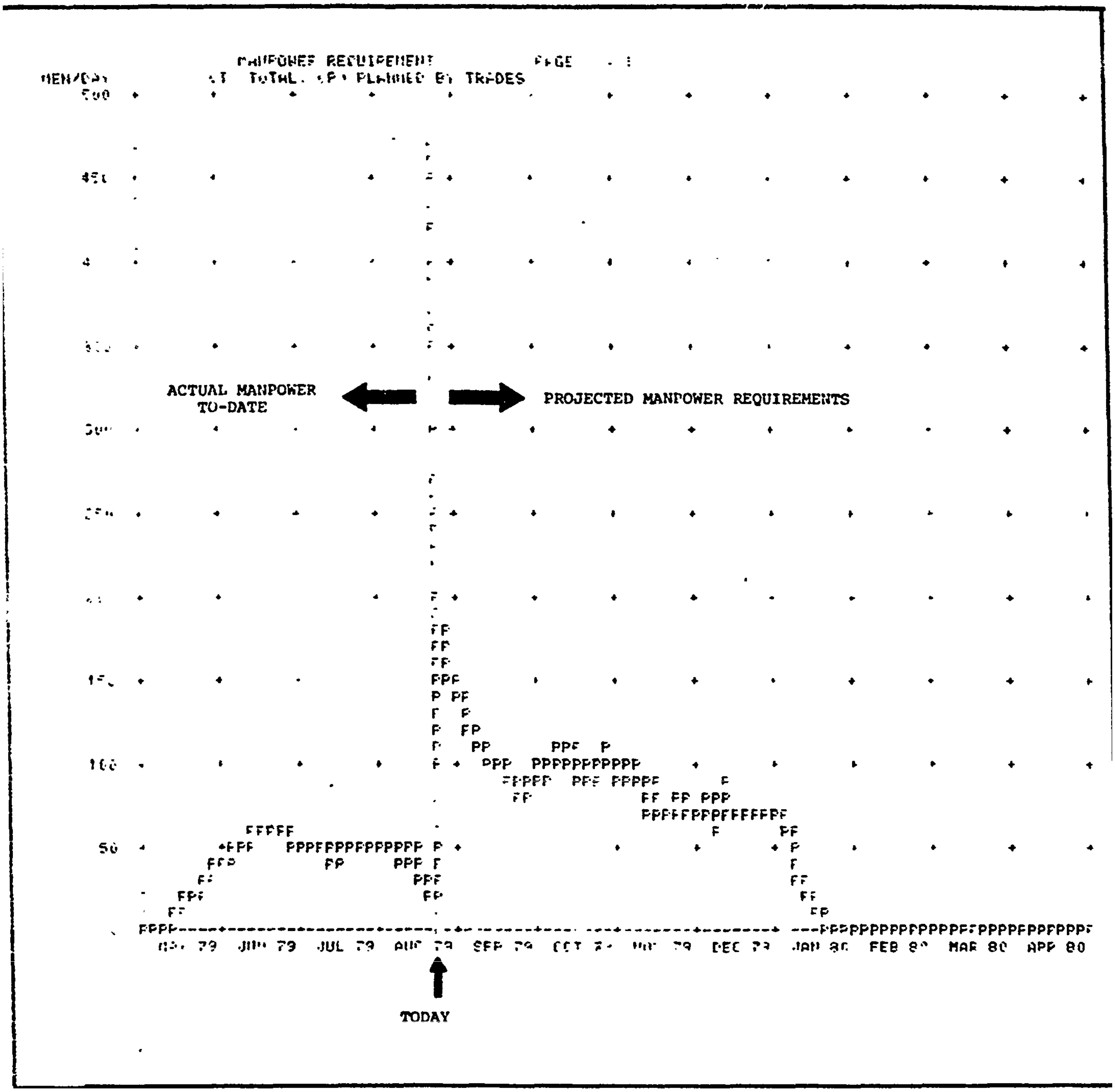
While good planning in the beginning of a project is a good step toward insuring the successful completion of the project, circumstances do arise that cannot be anticipated beforehand and can alter the course of the project costs and/or schedule, It is unlikely that the actual duration of an activity will equal the estimated time shown in the orig-inal analysis. The initial plan can help get the job organ-ized and started right, but a: activities take more or less time than originally estimated, control of the work is lost unless the plan is updated to monitor progress, evaluate impact of deviations, and to adjust planning in order to complete the work by established contract requirements,

An "out-of-control" project can be recovered by means of strategies developed by a plan control team and a meaningful performance feedback system. However, the longer the delay to respond to problems, the less the chances for a successful recovery. Management needs a capability to constantly view status and determine just how bad the problems are and what areas should be given the highest pri-ority to minimize costs and delays. Figure 6,O,l illustrat-es a classical need for re-planning. The "bow wave" phenom-enum is not unusual when plans fall apart: schedules not being maintained and the progressive growth of remaining work piling up as time advances.

Recovery strategies must not only minimize problems that inevitably arise but also should try to improve upon costs and schedules from planned levels, These efforts, however, should not ignore the effects of limited resources upon solving the problems.

```
TOTAL MEN PLANNED
     40. +       +       +       +       +       +       +
         I
         I
         I
         I
     35. +       +       +       +       +       +       +
         I
         I                      FIGURE  4.1.3
         I        MANPOWER LOADING WITH INSUFFICIENT SLACK
         I
     30. +       +       +       +       +       +       +
         I
         I
         I
         I
     25. +       +       +       +       +       +       +
         I
         I                           Insufficient Slack
         I                      TTT /    Available
         I                      TTT/
     20. +       +       +      TTT      +       +       +
         I                      TTT
         I                      TTT
         I                      TTT
         I          TTT TTTTTTTTTTTT    LIMIT 15 MEN
     15. +.......+  T T TTT      + T.....+.......+.......+
         I          T T TTT        T
         I          T T TTT        T
         I          T T TTT        T
         I      TTTTT TTTTT        TT
     10. +      T+       +       +  T    +       +       +
         I      T                   T
         I      T                   T
         I      T                   T
         I      T                   T
      5. +      T+       +       +  TTT  +       +       +
         I      T                    TT
         I      T                    TT
         I      T                    TT
         I      T                    TT
      0. TTTTTTTT+-------+-------+---TT--+-------+-------+
           JAN 81  FEB 81  MAR 81  APR 81  MAY 81  JUN 81
```

FIGURE 5, 0.1: Classic Example OF Need To RE-Plan



6.0 Conclusions

The effort to plan and schedule large-scale ship production operations cannot be done effectively by manual means, especially for those yards who keep planning staffs to a minimum. The scope of variables that should be considered arc too many and the work required to assemble all necessary information needed to develop realistic production schedules and determine economical resource requirements too overwhelming,

Solutions to this problem can only lie with computer software systems, provided they adequately address the practical aspects of planning: a system that is reasonably straightforward and un-complicated, yet provides a reasonably accurate modeling of the work to be performed. The system must also be capable of producing a complete set of production plans without undue delay; shipbuilding typically operates on too short a fuse to permit a lengthy planning period prior to the on-set of production.

SPAR Associates, Inc. has developed various computer software systems that have been designed to meet these needs and more) they employ techniques that enhance the planning and production control processes even further than systems available in other industries long engaged in automated planning methods The shipbuilding problem is one that offers special challenges> particularly with regard to developing schedules that meet contract obligations within the constraints of the shipyard's limited available resources:, Additional copies of this report can be obtained from the National Shipbuilding Research and Documentation Center:

http://www.nsnet.com/docctr/

Documentation Center
The University of Michigan
Transportation Research Institute
Marine Systems Division
2901 Baxter Road
Ann Arbor, MI 48109-2150

Phone: 734-763-2465
Fax: 734-763-4862
E-mail: Doc.Center@umich.edu