THE APPLICATION OF THE CRITICAL PATH METHOD
TO AIRCRAFT MAINTENANCE

by

HAROLD ANGUS CHARLES SUMMERS
B.A., University of British Columbia, 1962

A THESIS SUBMITTED AS PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF BUSINESS ADMINISTRATION

in the Faculty
of
COMMERCE AND BUSINESS ADMINISTRATION

We accept this thesis as conforming to the
required standard

THE UNIVERSITY OF BRITISH COLUMBIA
March, 1965
In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the Head of my Department or by his representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Commerce and Business Administration

The University of British Columbia,
Vancouver 8, Canada

Date March 13, 1965
ABSTRACT

The use of expensive and highly specialized equipment in any industry is only advisable if the cost of the equipment can be justified by a sufficiently large output. The greater the output, the smaller will be the cost of the equipment to be borne by each unit. Thus, once such equipment has been purchased, management endeavours to maintain output at a maximum in order to reduce unit costs or to increase profits.

It is for this reason that airline managements continually endeavour to increase the utilization of jet aircraft. By increasing the number of revenue flying hours only one hour each week on one jet aircraft, an airline will realize an additional net contribution to overhead (or profits) of approximately $60,000 per year.

One method of increasing utilization is to decrease the downtime of the aircraft for maintenance purposes. This requires a reduction of the total elapsed time of the maintenance check. The critical path technique has found wide application in solving the general problem of reducing the time required to complete a project which consists of many inter-related jobs. For example, the technique has been used to reduce the time required for constructing a building, for completing the periodic overhaul of a chemical plant, and for completing the Polaris Missile Development Program. It was therefore felt that the critical path
technique might be of use in solving this problem of increasing the utilization of jet aircraft.

This thesis, based on the results of a study carried out at Canadian Pacific Air Lines during the months of May through August, 1963, describes the various ways in which the technique can be of use in solving this problem.

It was found that the technique did have a wide applicability. In the initial period of application, it would be of great value as a tool for analyzing the problems of the check. It can be used both to point out the jobs or chains of jobs which prohibit the reduction of the check time and also to direct the revision of the scheduling of these jobs in such a way that the elapsed time is reduced. This reduction of elapsed time will have the effect of increasing the number of jobs which must be completed at the earliest possible time if the check completion time is to be a minimum. As a result there will be a greater need to use the technique both for scheduling and monitoring all the jobs of the check.
Acknowledgements

The writer wishes to express his sincere thanks to Mr. I.A. Gray, Director of Maintenance and Engineering, Canadian Pacific Air Lines, for his encouragement and guidance throughout this study. Thanks are also due to the maintenance staff of Canadian Pacific Air Lines for their full cooperation.

The writer is deeply indebted to Professor J.P. van Gigch under whose direction the study was carried out.

Thanks are also due to Professor T.D. Heaver for his guidance and direction throughout the preparation of this thesis.
# Table of Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>THE PROBLEM</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Airline Profits</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Reasons for Low Profits</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>The Importance of Maximizing Utilization</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>The Need for Increased Utilization</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>at Canadian Pacific Air Lines</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Method of Procedure and</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Sources of Data</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Plan of the Thesis</td>
<td>17</td>
</tr>
<tr>
<td>II</td>
<td>CONDITIONS AT CANADIAN PACIFIC AIR LINES</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Departmental Organization</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Character of the Maintenance Work</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>The Work of the Maintenance Planner</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>The Schedugraph Board</td>
<td>23</td>
</tr>
<tr>
<td>III</td>
<td>METHODS OF SOLVING THE PROBLEM</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>The Schedugraph Board</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>The K.L.M. Approach</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Plannet</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Critical Path Scheduling</td>
<td>30</td>
</tr>
<tr>
<td>IV</td>
<td>THE CRITICAL PATH TECHNIQUE</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>The Technique</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>The Charting of Relationships</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Calculations</td>
<td>37</td>
</tr>
<tr>
<td>Chapter</td>
<td>THE METHODS OF APPLICATION OF THE CRITICAL PATH TECHNIQUE TO AIRCRAFT MAINTENANCE</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The Technique in the Analysis of Completed Checks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The Technique in Analysis Before and During the Check</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other Applications</td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>THE BENEFITS OF CRITICAL PATH ANALYSIS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TO AIRCRAFT MAINTENANCE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reductions in Elapsed Time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reductions in Man-hours</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reductions in Costs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Less Tangible Benefits</td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>EVALUATIONS AND CONCLUSIONS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The Post-Mortem Analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The Use as a Framework for all Scheduling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analysis of Check Segments</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PERT and Man-Scheduling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BIBLIOGRAPHY</td>
<td></td>
</tr>
</tbody>
</table>
### List of Tables

<table>
<thead>
<tr>
<th>I</th>
<th>Net Income as a Percentage of Total Operating Revenues for United States Domestic Trunk Airlines</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>Net Profit of U.S. Domestic Trunk Airlines</td>
<td>4</td>
</tr>
<tr>
<td>III</td>
<td>Net Profit of Canadian Pacific Air Lines</td>
<td>5</td>
</tr>
<tr>
<td>IV</td>
<td>Sample Calculations</td>
<td>40</td>
</tr>
<tr>
<td>V</td>
<td>Comparative Interest and Depreciation Costs, the DC-8 and the DC-3.</td>
<td>54</td>
</tr>
<tr>
<td>VI</td>
<td>Breakdown of all Work on Check #25, Aircraft #603, According to Criticalness</td>
<td>66</td>
</tr>
</tbody>
</table>
List of Figures

1. Sample Critical Path Network 41
2. Engine Removal 42
3. Chart of All Jobs Performed by Group II During Equalized Check #25, on Aircraft #603. 70
4. Chart of All Jobs Common to All Checks 71
Airline Profits

The air transportation industry from its beginning, has been characterized by a comparatively low level of profitability. Commercial air transportation in the United States, which had its foundation in the Air Mail Act of 1925, was in the early years made profitable by the subsidy of the government through airmail contracts. Reflecting continuing financial difficulties in this industry, the United States Civil Aeronautics Act of 1938 directed that a carrier's mail rate would be sufficient, together with all its other revenues, to enable the carrier "to maintain and continue the development of air transportation to the extent and of the character and quality required for the commerce of the United States, the Postal Service, and the national defence."

The postwar years have shown some, though no great progress toward financial stability for the airline industry. The first three years of this period were years of financial loss for the United States domestic trunk lines.\(^1\) For the next eight years the earnings of the industry in general were better, although those of many companies were highly erratic. Then, in 1957, the financial impact of the introduction of jet equipment began to be felt and industry profits became markedly lower. (See Table I.)

Table I

Net Income as a Percentage of Total Operating Revenues
For United States Domestic Trunk Airlines. (Years ending
Dec. 31.)

<table>
<thead>
<tr>
<th>Year</th>
<th>% Income</th>
<th>Year</th>
<th>% Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>.06</td>
<td>1954</td>
<td>5.27</td>
</tr>
<tr>
<td>1959</td>
<td>3.43</td>
<td>1953</td>
<td>5.51</td>
</tr>
<tr>
<td>1958</td>
<td>2.96</td>
<td>1952</td>
<td>6.97</td>
</tr>
<tr>
<td>1957</td>
<td>1.90</td>
<td>1951</td>
<td>6.61</td>
</tr>
<tr>
<td>1956</td>
<td>4.57</td>
<td>1950</td>
<td>5.86</td>
</tr>
<tr>
<td>1955</td>
<td>5.56</td>
<td>1949</td>
<td>2.91</td>
</tr>
</tbody>
</table>

It was not until 1962 that the industry showed a definite recovery from the shock of the introduction of the jet. This recovery has continued with increasing profits to the present time. (See Table II). The profit history of Canadian Pacific Air Lines parallels that of the U.S. domestic trunk lines as is illustrated in Table III.

A search for the reasons for this low profit level in postwar years reveals two underlying and industry-wide problems which are excess capacity and rapid technological change. Excess capacity in a competitive industry prevents profits from being at a maximum because the equipment is not being fully utilized. There are three main reasons for excess capacity in the airline industry. First, the industry has been over-optimistic in its forecasting of the demands for its services.2

Second, the airlines are often managed on the basis of social and political expediency rather on sound economic principles. For example, A. Vandyk points out that many new nations which want to use their carriers to show their flag abroad, not only regularly operate their own aircraft at less than break-even load factors and at unprofitable levels, but by their presence force the airlines of the older nations to do so also.3

Table II

Net Profit of U.S. Domestic Trunk Airlines.

<table>
<thead>
<tr>
<th>Year</th>
<th>Profit ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1963</td>
<td>14,471,000</td>
</tr>
<tr>
<td>1962</td>
<td>10,378,000</td>
</tr>
<tr>
<td>1961</td>
<td>(34,566,000)</td>
</tr>
</tbody>
</table>

Brackets indicate a loss.

Source: Increases in Airline Operating Revenues and Profits, Aviation Week and Space Technology, June 1, 1964, p. 34; and May 6, 1963, p. 45.
### Table III

Net Profit of Canadian Pacific Air Lines.

<table>
<thead>
<tr>
<th>Year</th>
<th>Profit ($)</th>
<th>Year</th>
<th>Profit ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td>4,300,000</td>
<td>1954</td>
<td>969,000 *</td>
</tr>
<tr>
<td>1963</td>
<td>347,000</td>
<td>1953</td>
<td>366,000</td>
</tr>
<tr>
<td>1962</td>
<td>(1,200,000)</td>
<td>1952</td>
<td>364,000</td>
</tr>
<tr>
<td>1961</td>
<td>(7,600,000)</td>
<td>1951</td>
<td>1,084,000</td>
</tr>
<tr>
<td>1960</td>
<td>(4,700,000)</td>
<td>1950</td>
<td>205,000</td>
</tr>
<tr>
<td>1959</td>
<td>(3,900,000)</td>
<td>1949</td>
<td>115,000</td>
</tr>
<tr>
<td>1958</td>
<td>(1,900,000)</td>
<td>1948</td>
<td>(194,000)</td>
</tr>
<tr>
<td>1957</td>
<td>(113,000)</td>
<td>1947</td>
<td>(584,000)</td>
</tr>
<tr>
<td>1956</td>
<td>525,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1955</td>
<td>275,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Brackets indicate a net loss.

* Includes $593,000 profit from sale of aircraft.

The third reason for this excess capacity is rapid technological change. Since 1945 there have been three major aircraft changes for most of the world's airlines. First came the changeover from the prewar and immediate postwar aircraft to the four engine, long range aircraft such as the Constellation and the DC-6. Then in the mid fifties came the turbo-props and at the end of the decade, the jets. These changes were necessary not because the existing equipment was physically depreciated and causing excessively high maintenance costs, but rather, they were a direct result of the nature of the public demand for air travel and the obsolescence of the replaced aircraft. Thus, in order to reduce operating costs and to attract passengers who demanded seats in the fastest and most modern aircraft, the airlines were forced to order and to place in service the new and larger aircraft as soon as possible, preferably before the competition did so. This caused industry overcapacity as the larger planes frequently replaced the smaller on routes where the new load factors would be below the break-even point. In addition, the planes that had been replaced were either sold (usually at a price lower than their depreciated book value), put into storage, or placed on other routes. In this last case, low load factors were again the result as the aircraft were often larger than the traffic warranted.

4. For some airlines, the introduction of the DC-6 or Super-Constellations in the early 1950's must be counted as a fourth major aircraft change.
Rapid technological change also had a more direct effect on airline profit. New aircraft are expensive. Because of the rapidity of the technological change, the initial cost of the aircraft generally had to be depreciated over a period of no greater than seven years and sometimes as few as three or four years. In addition to the cost of the plane itself, the airline had to bear the high costs of new specialized equipment and exclusive staff training. Since these costs could only be amortized over a very short period of time, the high per unit costs resulted in large financial drains.

The Importance of Maximizing the Utilization

As a result of these problems the airlines have been forced to economize in every possible way. One method of minimizing the loss due to the retirement of mechanically good, yet obsolete equipment is to increase its utilization in the years preceding its obsolescence. The rationale here is based firstly on the realization that the amortization rate for the aircraft is a function of the number of years from its date of purchase to the date of obsolescence rather than a function of the number of hours of useful service it renders. This means that the cost of depreciation will be a constant daily figure regardless of the number of hours flown. But amortization is only one of the many fixed costs involved in the operation of an airline. Since the

ratio of fixed to variable costs for an airline is high, the earnings from increased utilization should be substantial.

The effect of an increase in the daily utilization (say from ten to eleven hours per day) may be described in either of two ways. If the ten hours of operation are at break-even load factors (no profit earned) and an additional hour of operation is added at the same load factor, a profit will result from the increased utilization and will be equal to the revenue from the additional hour of operation minus the direct operating costs for that hour. This profit is greater than $400,000 per annum for one jet aircraft alone. On the other hand, if the additional hour of operation is included in the break-even analysis the break-even load factor will be lower. The reason for this is that the fixed costs previously spread over ten hours of operation can now be spread over eleven hours. Since the rate charged each passenger is usually fixed either by a government body such as the Air Transport Board, or an international organization such as the International Air Transport Association, and since the costs associated with each hour of operation are reduced, the number of revenue passengers that are necessary to provide break-even revenues is reduced.

6. This figure is arrived at by assuming a 365 day year and a contribution to fixed costs as $1,100 per hour (365 days/year \* $1,100/day = $401,500/year). In actuality the $1,100 figure is very low since Canadian Pacific Air Lines estimates fixed costs to be $1,150 per hour when a utilization of twelve hours per day was used in the calculation.
This latter line of reasoning has been followed by Continental airlines. During the early years of the jet transition which were generally unprofitable ones, this airline consistently increased its jet utilization. It did so by scheduling additional flights with load factors lower than its average and in 1961 had an average load factor of 50.3%, the lowest of the United States domestic trunk lines. However, its break-even load factors were also lowered (partly because of a very strict cost control) to a point where this airline was earning a profit of 10% of gross sales, a profit greater than any of its competing domestic trunk carriers.\(^7\).

How can an airline increase its utilization? One simple answer is to send an aircraft that is to be sitting idle for some hours on a revenue producing flight. It is unfortunate that the solution to the problem is not that easy. It rarely occurs that a serviceable aircraft is sitting idle. When this does occur it is almost always a result of the peaking problem and it is idle simply because there is no demand for it. The real solution seems to be organizational in nature. In most airlines there are two departments involved; scheduling and maintenance.

It is the aim of the scheduling department to so organize the flight plans of all aircraft that the overall air-

craft utilization is maximum. This would mean no waste or idle minutes in the life of the aircraft. However, this is not the only aim of the department. It must also attempt to minimize such costs as crew expenses and the cost of meeting peak demands for service at certain airports at the busy hours of the day. In addition, other factors such as the need to leave certain slack time in the aircraft schedule so that a minor delay will not affect subsequent flights of the aircraft, or connecting flights of other aircraft, must also be considered. All of these aims are pursued in the light of the overall airline objective of long run profit maximization. Since the majority of the decisions made in relating one of the minor aims to the others are subjectively arrived at, it is very difficult for airlines to improve their utilization by improving their scheduling. It is, however, questionable whether the scheduling departments of the airlines in general are taking full advantage of such factors as the high percentage of fixed costs and the recent developments in statistical and computerized methods of correlation and optimization in order to increase their utilization.

When the maintenance department attempts to increase aircraft utilization its problem is simply, "how can the maintenance work be so organized as to minimize the number of hours that the aircraft is out of service for mechanical reasons?" If the maintenance department can complete all its work in say ten fewer hours each month, the scheduling department can attempt
to use the extra hours for additional revenue flights. It is this maintenance problem which prompted the study upon which this thesis is based.

The discussion of the above paragraphs does not apply merely to airlines in general; it applied specifically to Canadian Pacific Air Lines. Table III, above pointed out the profit difficulties of the company and the effects of the excess capacity and rapid technological change are evidenced in this profit record. This airline also felt a need for increasing its utilization by reducing the elapsed time on its maintenance checks. This need was evidenced in four different ways.

First, comparisons with maintenance data from other airlines showed that certain of the airlines recorded a shorter elapsed time on similar maintenance checks. In addition, other airlines were making rapid reductions in their own elapsed times.

The second evidence was found through a study of the aircraft mechanics' time cards. These indicate both the job worked on and the duration of each job. The number of men on "standby" (men to whom no work has been assigned) was excessive especially during the last few shifts of each check. Coupled with this was the fact that many unreasonably long durations were found listed against certain jobs. These durations were often five to ten times greater than the "standard" or "expected" durations. Although it was found to be not uncommon for a
mechanic to charge against one particular job the time he spent working on another, the frequency of inaccurate time listings was found to vary somewhat inversely with the work load. This indicated that the mechanics would often spend far more time than was needed working on a particular job just to give the impression of being busy. This, of course, is in agreement with Parkinson's Law. The conclusions reached were that the work load for each mechanic was not adequately balanced throughout the check, and that much of the work could be completed in a shorter elapsed time.

Third, a brief analysis of the type of jobs which were performed during the last half of the check and particularly of those which prohibited an early completion of the check showed that in most cases the jobs could have been scheduled to begin much earlier and thereby an earlier completion might have been possible.

Fourth, management desired both more efficiency in the maintenance checks and a reduction of elapsed time. For various reasons, one of which was a poor profit record in the years preceding 1963, management felt that even with an increased work load possible in the near future, the maintenance department required not more but slightly fewer mechanics. In addition, the desire for increased aircraft utilization resulted in a tenative scheduling of the jet aircraft requiring a reduction in the elapsed time of the "equalized" check from seventy-two to approximately fifty hours. Thus, there was not only evidence of
an area for possible improvement in work procedures but also the likelihood of major problems if these improvements were not forthcoming.

The problem, therefore, was twofold. First, how to reduce the elapsed time of the maintenance checks, and second, although of lesser importance and urgency, how to improve the work procedures? Although these are two different problems, they are not completely independent. For example, change in elapsed time will often be made possible only by a change in work procedures, and a change in work procedures almost always results in different elapsed times. Since improved work procedures are only of secondary importance both to Canadian Pacific Air Lines and to this present paper, they will be discussed, in the following chapters, only in terms of their relationships to the elapsed time of the checks. Discussion of improvements in work procedures solely for the sake of increased efficiency will be omitted.

The purpose of this paper is to outline one type of solution to the problem of reducing the elapsed time of the maintenance checks. This solution involves the application of a scheduling technique to the many individual jobs to be performed in such a way that the project be completed in the minimum of elapsed time. Such a scheduling technique is the "critical path method", or the "critical path technique".
The Method of Procedure and Sources of Data

The first step in any methods analysis is to become familiar with the real problem. That a problem existed was evident from transportation literature, discussion with Canadian Pacific Air Lines personnel and an analysis of Canadian Pacific Air Lines maintenance data. Following this first step, a solution to the problem is sought. Since there was a lesser, though still important problem of improving work procedures associated with the main problem, a solution which would meet both needs was preferable. Here literature in both the transportation and industrial administration fields was searched.

The critical path method was conceived of as a possible solution. Two main difficulties arose. In most instances the technique had been applied to projects of much longer duration, usually many months. The aircraft maintenance


projects had durations of from one and one-half to two and one-half days. In addition, in the aircraft maintenance projects approximately one-half of the jobs to be performed could not be known until the first eight or more hours of the check had elapsed.

For these reasons it was felt that the feasibility of applying the technique could only properly be determined after a period of experimentation on a trial and error basis. This was conducted by the writer under the direction of Professor J.P. van Gigch and with the cooperation of the maintenance staff of Canadian Pacific Air Lines. The project was carried out at the company's maintenance base at Vancouver Airport, B.C., during the months of May through August, 1963.

During these months attempts were made to apply the technique in four different ways. The first was to the analysis of checks which had already been completed. The objective was to point out what mistakes were made and to lay plans for avoiding them in the future. Secondly, an attempt was made to make full use of the technique before and during each check. Thirdly, from evidence gained in the early analysis it became obvious that it was not the check as a whole but certain portions thereof which were lengthening the elapsed times of a majority of the checks. Therefore, attempts were made to segment the checks in such a way that these problem areas could be analyzed on their own. Finally an attempt was made to apply both the PERT\textsuperscript{12} and the Man-Scheduling\textsuperscript{13} computer programs to the equalized checks.
Since this experimentation led the analyst and management to conclude that there was considered value in the use of the critical path technique, the final step was to formalize the use of the technique and then to explain its use both to those who would be mainly responsible for its implementation and also to all those indirectly affected by its implementation.

Plan of the Thesis

The following chapter describes the maintenance department at Canadian Pacific Air Lines and explains such background information as is necessary for an understanding of both the problem of excessive elapsed time and also of the possible solution to it. In Chapter III, various of these solutions are presented along with their major advantages and disadvantages.

The remaining four chapters deal with the critical path method as a solution to the problem. In Chapter IV the technique and the method of charting a project are described in detail. Then, in Chapter V, the various methods of applying this technique to aircraft maintenance are presented followed by a discussion of the benefits to be derived from them in Chapter VI. The final chapter contains a critical evaluation of the usefulness of the technique and the conclusions.

12. As will be pointed out in Chapter V, the PERT (Program Evaluation and Review Technique) program has the advantage of providing some measure of the probability of completing a given project at a certain hour or date. See International Business Machines, PERT, op. cit.

13. This program is designed to schedule all jobs in such a way that the work load for each workman is balanced while the critical path is not lengthened. See Chapter VII and International Business Machines, Man-Scheduling Program for the IBM, 1620, 1620 General Program Library, 10.3.013.
Chapter II - Conditions at Canadian Pacific Air Lines

Departmental Organization

Before proceeding to a detailed discussion of the application of the critical path technique, the organization and activities of the maintenance department at Canadian Pacific Air Lines prior to this study must be considered.\(^1\) The department is headed by the Director of Maintenance and Engineering. As far as the maintenance of jet aircraft is concerned, his supervision extends over four divisions: viz: engineering, maintenance, quality control, and maintenance planning. The responsibility of the engineering division is to outline in detail the work that must be done on each job. Since the vast majority of the jobs are of a routine nature, such as the replacement of components and the repairing of faulty parts, this division concerns itself with the regular maintenance checks only when major problems arise or when some aircraft modification is required.

The maintenance division is responsible for the actual completion of the work assigned to each check while the quality control division must see that all work performed complies with the safety regulations.

\(^1\) The conditions have changed little since that time.
The maintenance planning division is responsible for the assignment of the work load to each maintenance check. This is done, of course, within the limits imposed on it by the other three divisions.

There are four types of maintenance checks for the DC-8 aircraft. The "M 1" and "M 2" checks are performed after each flight, unless a more major check is to be performed, and have a total elapsed time of from sixty to ninety minutes. The "annual check", or major overhaul, is performed once each year and requires from five to ten days. The "equalized check" is performed every 300 to 500 flying hours and requires two to three days for completion. Since Canadian Pacific Air Lines has only five jet aircraft, it performs only one equalized check per week, and only five major overhauls per year. Because of the lack of frequency of the annual checks and because they are purposely scheduled to fall in that period of the year when the demand for Canadian Pacific Air Lines' jet flights is not at a peak, the value of decreased down-time for these checks was considered to be of secondary importance. In addition, an attempt to reduce the downtime on the M 1 and M2 checks was not made because of their short duration. Therefore the emphasis in the remaining chapters will be on the reduction of the total elapsed time of the equalized checks.
Most of the maintenance work is either of a routine or an urgent nature. The routine work is assigned regularly to the same type of check each time it becomes necessary, and the urgent work must be performed whenever it arises. However, for many of the jobs, the maintenance planning division has the freedom to assign the work to one of a number of checks. In this way it attempts to balance the work load.

This work load on the equalized check is composed of jobs from seven job categories. The first is the basic category consisting of jobs which must be performed every equalized check (See Figure 4). Next are the periodicity items. These jobs must be performed in a regular manner every second, third, fourth, -- nth check. Many of the component parts of the aircraft (units) demand independent maintenance. For each of these units a history is kept on file indicating the location (the aircraft number and position in that aircraft) of the component and the number of flying hours until its removal for maintenance or replacement. It is the removal and maintenance jobs on these component parts that comprise the third category. The fourth category contains the extra work which the maintenance planning division deems advisable. This is often rescheduled work which arises when the work load on the preceding check was extra heavy, or fleet campaign work which arises when it is felt that all aircraft should be examined to ensure that the malfunction found in one aircraft does not exist or occur in the others also. In the fifth category are the aircraft modifications requested
by the engineering division.

The jobs in the above five categories account for about fifty percent of those to be performed on an average equalized check. The remaining jobs are referred to as "snags" and are the unscheduled maintenance. They are of two types; flight snags and inspection snags. The flight snags which are the sixth category arise because of malfunction of the aircraft and are reported by the flight crew to the maintenance planning division a few hours before the check begins. The inspection snags, comprising the seventh category, are reported during the check itself either by the inspectors or the mechanics. The vast majority of the snags are inspection snags.

The Work of the Maintenance Planner

In planning the work content of an equalized check, the planner, who is a member of the maintenance planning division, first lists all jobs which under normal circumstances would be performed during the check. This includes the jobs in the first six categories above. He then attempts to balance the work load so that the production of each mechanic and the total work done on the aircraft are both maximized. He must at the same time attempt to ensure that the aircraft will be serviceable at its scheduled departure time.
His next task is therefore to seek out those jobs which are of a non-urgent nature for the purpose of adding them to, or subtracting them from the check as the work load dictates. Jobs in the aircraft modifications and planned extra work categories are frequently non-urgent as are some of the snags. In addition, when the number of hours between removals of components is several thousand (this is frequently the case) there is often an opportunity to schedule the removal ahead or back one check.

There are many factors which make the planners' task much more complicated than the solving of a straight-forward assembly-line balancing problem. There are ten groups of workmen involved: viz: engines and fuel; air conditioning, oxygen, etc.; hydraulics, undercarriage and flight controls; radio; electrical; upholstery; woodwork and paint; sheet metal; cleaning; and inspection. These workmen are trained in the work of their own group and a workman cannot readily be transferred from one group to another. In addition, the number of men working with each group is not stable. General manpower problems such as transfers, resignations, etc. produce conditions such as were found in the air conditioning and oxygen group in the spring of 1963. At this time instead of having eight men per shift, there were eight men in shift #4, seven in shift #6, and only six men in shift #5. In certain groups, especially radio, the technicions are available only when there are no pressing needs
for them elsewhere on the maintenance base. Sickness also upsets the manpower balance. However, the seriousness of these problems is partially reduced by the fact that in cases of urgent need, additional manpower can be obtained from or supplied to the shops and servicing divisions.

Further complications arise when certain of the aircraft's systems are considered. There are three major sources of power in the jet aircraft: viz: electrical, pneumatic and hydraulic. Many jobs involving workmen from almost all the trade groupings can only be performed when one particular power source is available. However, there are an even greater number of jobs which can be performed only when one or more of the power sources is turned off.

When one considers the various areas of the aircraft, the problem of congestion comes to the fore. Certain areas, especially the cockpit and the engines, may require the work of many men and a number of different trade groupings throughout the course of the check. However, there are often physical restrictions as to the number of men that can work in the area at any one time. In the cockpit, for example, the maximum is three men working at one time and even then they will be in one another's way if they are not working in separate corners of this confined area.

The planners' major problems, however, are not those described above. They arise out of two unknown quantities; the number and nature of the snags which will be reported in the initial hours of the check, and the number of manhours required
to complete the work on many of the complicated and non-routine repair jobs.

The planner's main means of overcoming these problems and keeping the work load balanced are his breadth of knowledge and experience in aircraft maintenance, as well as his ability to adjust, within limits, both the work load and the manpower as the need arises.

The actual completion of the work in the check is the responsibility of the maintenance division. On each shift the man assuming this responsibility is the chief mechanic. He makes the actual assignment of his men to definite jobs and supervises all work done on the aircraft. Working along with him, though in an advisory capacity, is a maintenance planner from the planning division. It is his responsibility to keep a record of all jobs completed, those still in progress, and those still to be started. With the help of a schedugraph board he attempts to coordinate the activities of the ten trade groupings, involving about fifty men and some five hundred jobs, and advises the chief mechanic as to when each of the jobs should be performed.

The schedugraph board is a mechanical aid to job organization.² It has an area of twenty square feet being five feet wide and four feet in depth. Vertically, it is divided into eighty rows, each of which contains the work to be performed by one man. It is divided horizontally by a time scale. Here, the first column represents the work to be done during the
first hour of the check, and the subsequent columns, the work to be done in the following hours.

The work load on a given check is organized by first preparing a card for each job containing an estimate of the time required for the completion of the job. This estimate is indicated by placing a mark on the base of the card so that its distance from the left-hand side of the card, measured in inches, corresponds to the elapsed time of the job. Next each card is placed on the schedugraph board in the row which corresponds to the workman to be assigned to the job with its left-hand edge corresponding to the hour of the check at which time the work on the job is expected to begin. In this manner both the planner and the chief mechanic can see at a glance all the work that is to be done by one man, by one group, or at any given time. As the check progresses the board is continually updated reflecting such changes as new durations for certain jobs, changes in the available manpower and changes in job sequence and scheduling.

2. The schedugraph system has since been replaced by the "Plannet" approach. See chapter III, and E.R. Bossange Jr., op. cit.
Chapter III - Methods of Solving the Problem

The Schedugraph Board

The problem as stated in the preceding chapters was to reduce the total elapsed time of the equalized checks. There are many ways of approaching this problem. The use of the schedugraph board is one. The main advantage of this system is that it brings order out of confusion (the completion of five hundred, and at times one thousand different jobs, many of which are individually inter-related with many others, all to be completed in the barest minimum of time by one hundred fifty men working on three different shifts can easily result in confusion). The schedugraph board enables the chief mechanic and his advisor, the maintenance planner, to balance the work load continually throughout the check in the light of the latest developments.

The major disadvantage of this system lies in its failure to draw attention to the important job inter-relationships. It is true that for one man working on a chain of related jobs each of which follows the other in an efficient order, the inter-relationships are adequately pointed out by a glance at the appropriate row. Similarly, the relationships between a number of jobs all to be performed at the same time are revealed by an analysis of the columns of the board. But these are frequently only of secondary importance. Of primary
concern are the causal relationships stating that job B cannot begin until job A is completed. The reason for this is that it is a chain of jobs which determines the maximum elapsed check time. If such chain relationships did not exist, the elapsed time of the check could be made to equal the elapsed time of the longest job simply by increasing the manpower and performing all jobs simultaneously. Because of the complexity of the aircraft and its systems, it is common for job B to be performed by a workman from a different group than the one who performed job A. Thus with a schedugraph board, the planner must scan all the rows in order to find job B. The problem becomes far more complicated when one faces such common occurrences as ten or twenty jobs all dependent upon the completion of job A.

The K.L.M. Approach

Another approach is being utilized by K.L.M. - Royal Dutch Airlines, in the major overhauls of their jet fleet. It involves planning a series of deadline completion points throughout the check. First of all, the check completion point is set by the scheduling department. Next, deadlines are set for each system in the aircraft such as rigging, pneumatics, and hydraulics. These deadlines as set so as to give adequate time for function-

1. J.M. Roos and G. Herring of the Production, Planning and Control, Technical Division at K.L.M. described this approach to the writer in an informal discussion at the 10th Meeting of the International Air Transport Association's Production Planning and Control group in Dublin, Ireland, April, 1964.
ing\textsuperscript{2} each system before the aircraft departure time. In a similar fashion, key deadlines are set closer to the beginning of the checks. Then each of the jobs throughout the whole check are given a deadline in relation to these key points.

Such a method overcomes many of the shortcomings of the schedugraph system. Here the many deadline points do draw attention to the important job inter-relationship and to the importance of job chains. However, such a scheduling method is not designed to reduce the elapsed time to a minimum but to guarantee completion of the check within a given, though greater than minimum time. This is because the job deadlines are set so as to give the maximum amount of time for the completion of the majority of the jobs. The system is therefore best suited to an airline whose services are sufficiently peaked that no great pressure is placed on the maintenance department for a more rapid check completion. Such was the case at K.L.M. during 1963.

Another serious disadvantage of this method arises from the location of the "slack time" during the check. This slack time is the difference between the minimum job time, or check completion time, and the maximum. It is unwise to schedule a check to be completed on the basis of the estimated job completion times since many time-consuming complications may arise.

2. Functioning is the term used to describe the testing of the various systems to determine any malfunctioning.
Thus some slack time is added to reduce the possibility of a delayed flight departure due to these complications. Since neither the seriousness of the complication, nor its time of occurrence during the check are predictable, the greater the slack time and the closer it falls toward the end of the check, the smaller will be the probability of a delayed departure.

The K.L.M. approach to the problem has the disadvantage that its deadlines are set on the basis of a minimum time to check completion, leaving little or no slack in the system once the first deadline is reached. The majority of the slack time falls in the early hours, or days, of the check and is therefore, in a sense, wasted.

Plannet

Pan American World Airways have developed another approach to this problem called Plannet (Planning Network). Its use at Pan American resulted in the reduction of elapsed time on the four hundred hour DC 8 "Equalized Services" check from thirty-four to twenty-two hours.

There are two major reasons for its success. First, responsibility for the early completion of the check was given to the first line supervision. This is composed of the foremen

3. The material presented in this section was gained from discussion with Mr. C.G. Rose, Supervisor of Maintenance Planning, Canadian Pacific Air Lines, and from Plannet, a paper by E.R. Bossange Jr., op. cit.

4. ibid. p. 2.
in charge of the ten trade groups. They report to the chief mechanic. Since they are the closest level of supervision to the workmen they have a wealth of knowledge and sphere of influence over their men which no other supervisors have. In the plannet approach, it is these foremen who draw up the overall schedule of work completion and set their own time standards for the work that is to be done. There is therefore more incentive to equal or beat the estimated times.

Second, full advantage is taken of the fact that certain of the jobs performed in a check are in the "basic" category and are thus performed on every equalized check. About 25% of all jobs fall into this category. In plannet, the majority of these jobs are performed in a highly organized manner approximating an assembly-line technique, and thus far greater efficiency is achieved.

One major disadvantage of this technique is that work that has not been pre-planned often upsets the assembly-line system. In addition, although much of the routine work and the over-all check plan are scheduled with critical path principles in mind, non-routine work is scheduled without the help of a formal critical path framework.

Another method of shortening the elapsed time is simply to schedule the aircraft departure time earlier. Since, within certain limits, the amount of time required to perform a job is proportional to the amount of time available, scheduling
a shorter check may of itself solve the elapsed time problem. This is particularly true where there is evidence that the jobs are being made to last in order to give the appearance of work as was the case at Canadian Pacific Air Lines.

A final method of reducing the elapsed time is of course the critical path method itself.

Only a few of the methods of solving the problem have been described above. It should be noted that these methods are not mutually exclusive. One method may be followed as the major scheduling procedure to which adaptations from many others may be added. For example, in 1964 Canadian Pacific Air Lines was using the schedugraph system coupled with many adaptations from plannet. In addition, it was making use of many of the principles of the critical path method and scheduling much shorter checks. The result was a reduction of elapsed time from seventy-two hours on a three hundred fifty hour check in 1963 to a time of forty hours for a five hundred hour check, containing considerably more jobs, in 1964.
Chapter IV - The Critical Path Technique

The Technique

The Critical Path Technique is a method of scheduling activities developed by the United States Navy during the Polaris Missile Development Programme for the purpose of reducing the elapsed time required to complete a project.

In this technique the traditional "Gantt" or "bar chart" is replaced by a network of activities which represents a project. (See Figure 1) Each arrow in the network represents one activity (job) to be completed before the end of the project. Each "node" in the network represents the commencement of and, or completion of one or more activities. It therefore represents a point in time.

The activities are charted in the network according to the order in which they must be performed for successful completion of the project. Consider for example, the activities performed in the changing of an engine on a propeller driven aircraft. (See Figure 2) Node "A" represents the time at which work on the project, the engine change, may begin. Three jobs, the removing of the propeller, the preparing of the new engine, and the disconnecting of the engine to be removed may all commence at this time and, hence, are given the common "tail node" A. The tail node indicates the commencement of the
job. In addition, each job is given a "head node" (head of the arrow), indicating the completion of the job. For the above jobs these head nodes are G, E, and B respectively. The job of desludging the propeller dome cannot be started until job A-G, propeller removal, is completed. To indicate this relationship the desludging job is given the tail node G. Similarly, the job of removing the engine is dependent upon the completion of the job A-B, disconnecting of the engine, and is therefore given the tail node B. However, this job cannot be started until the propeller has been removed. This would suggest that it should be given the tail node G, also. It is not possible to have one arrow (one job) emanating from two nodes. Therefore, a dummy job, G-B, is drawn indicating that all jobs terminating at node G must be completed before any work starting at node B can commence. In general, a dummy is inserted to avoid ambiguity in charting the dependent relationships, and also to make it possible for each job to have an unique pair of node numbers. Since a dummy does not represent an actual job, but merely a relationship, its duration will be zero. In this manner, each job is given an unique combination of tail and head nodes.

The network must be charted in such a manner that for each job there will be indicated at least one job which must precede it and at least one which must follow it. Stating this another way, each node in the network must be a head node and a
tail node. One exception to this rule occurs for the node indicating the commencement of the project and for the job(s) emanating from this node. It is a tail node but not a head node and each job emanating from it is preceded by no job. The only other exception to this rule occurs at the node indicating the completion of the project where the node is never a tail node and each job terminating at it is followed by no job. This identification serves to relate each job to all other jobs and to the project as a whole. In this sense a dummy is considered to be a job.

The Charting of Relationships

In charting, two main questions arise. First, how should interdependent relationships between jobs be charted and second, how should limited resources available for performing jobs be treated?

In order for a job to be given a position on the chart or network, some dependent relationships between that job and other jobs in the project must be recognized. That is, a job must be given a tail node and a head node. However, merely identifying the relationships required to facilitate the charting of the job is insufficient. The critical path that will be calculated from the chart will be misleading if all the inter-job relationships for each job in the project are not identified and charted.
The first type of dependency exists when a given job \( X \) cannot be started until certain jobs are completed. If there is only one preceding activity required (job \( Y \)) the charting will be \( \overrightarrow{Y} \rightarrow \overrightarrow{X} \). Where there are multiple dependencies the use of dummies may be required. For example, if job \( X \) cannot be started until \( A, B \) and \( Y \) are all completed the charting might be:

\[
\begin{align*}
  & \overrightarrow{D} \rightarrow \overrightarrow{A} \\
  & \overrightarrow{B} \rightarrow \overrightarrow{X} \\
  & \overrightarrow{Y} \rightarrow \overrightarrow{O}
\end{align*}
\]

It is obvious that if job \( D \) precedes job \( A \) in the network diagram, stating that job \( A \) must be completed before job \( X \) can commence implies that job \( D \) must also be completed. In a similar manner more than one job may be dependent for its commencement upon the completion of job \( X \). If such is the case, charting may be as follows:

\[
\begin{align*}
  & \overrightarrow{E} \\
  & \overrightarrow{F} \\
  & \overrightarrow{X} \\
  & \overrightarrow{O}
\end{align*}
\]

Another type of dependency exists where one job (or a chain of jobs) must be completed while another job is in progress. Since each job in the network must have an unique nodal identification (the node numbers are omitted in these examples) a job which must be completed while job \( X \) is in progress will be charted as follows:

\[
\begin{align*}
  & \overrightarrow{J} \\
  & \overrightarrow{X} \\
  & \overrightarrow{O}
\end{align*}
\]

Another dependency exists when one job cannot be worked on while a particular job is in progress. That is,
jobs K and H cannot both be performed at the same time. If a logical reason can be found why H should precede, or follow, K the dependency is simply that of our first type. However, for certain jobs there is no better reason for performing H before K than there is for K before H. In such cases a purely arbitrary decision will have to be made and the chart drawn accordingly. However, once the critical path and the total floats for all jobs have been calculated, the scheduling of jobs H and K must be re-examined and rescheduled (if this is required) to provide first the shortest critical path and second, the greatest total float.

It may be that a given job X can commence when job L is only partially completed. For charting purposes, job L should be divided into two jobs \((L_1, L_2,\) in such a way that job X will commence as soon as \(L_1\) is completed.

The second problem area in charting arises from physical limitations. Examples are a restricted number of workers in a given trade, a limitation in the equipment available or a limitation as to the number of men who can work on a given area, e.g. the cockpit.

The problem mentioned above of how to chart two jobs which cannot be worked on simultaneously is exactly this problem, and, therefore, the solutions are the same. For example, if there are four jobs which could be preformed
simultaneously but, because the area is so small that only three men can work there at one time, only three jobs can be performed, an arbitrary decision might be made to delay one of the four. This decision will be re-examined by the analyst when the critical path and total floats are known.

Experience shows that on an equalized check (other checks are similar) there are a great many more jobs which can be performed at one time than there are men available. Thus, to follow the above solution would result in a great many arbitrary decisions as to which job follows which and the development of many critical paths which are really not critical since the jobs do not necessarily follow one another. To determine the true critical path from such a network would be most difficult.

The second method of solution is to assume, for purposes of charting, that manpower is unlimited (that all these jobs may be performed simultaneously). Under these conditions the true critical path will be obvious from the network. However, the work load in each trade must then be examined to determine whether, with the manpower available, all the work for that trade can be completed within the time limits imposed by the critical path.

The general conclusion is that where relatively few arbitrary decisions are required, the first solution is the best. However, if there are many jobs requiring such treatment,
the second solution is preferable.

The following rules should be kept in mind as charting proceeds.

1. Each job must have an unique pair of node numbers.
2. The node numbering need not necessarily be in increasing order. That is, it is possible to chart a job as running from tail node 8 to head node 4.1.
3. The charting for each job should indicate:
   a. What jobs must precede this one,
   b. What jobs must follow this one,
   c. What jobs can be performed concurrently,
   d. What jobs cannot be performed simultaneously with this job, but must not necessarily precede it or follow it.

Calculations

The objective of this critical path technique is to point out the minimum elapsed time for a project and to indicate which jobs must be performed on schedule if the project as a whole is not to be delayed. Consider the engine change project again, (Figure 2). The numbers printed between the nodes and above the arrows indicate the most probable time required to complete the indicated activity. For example, job A-G,

1. This rule may vary with the computer program used.
removing of the propeller, is expected to require one hour to complete. It can be seen that if all jobs were to be completed as soon as the time estimates indicate, the project would not be completed in less than eleven hours. This time limit is equal to the longest path, in terms of hours, between the first and last nodes in the network. This path, indicated in Figure 2 by the double line is the "critical path". If the project is to be completed in the shortest possible time, each activity in the "critical path" must be completed as soon as the schedule will permit. However, any of the other jobs in the network may be delayed for a limited amount of time. Thus, there is an urgency associated with the completion of critical jobs which is not associated with any of the others.

Each activity in the network is characterized by a particular value of each of the following:

a. E.S. - Earliest start, the earliest time (measured from the commencement of the project) that an activity can start.
b. E.F. - Earliest finish - the earliest time that an activity can finish; EF = ES + duration.
c. L.S. - Latest start, the latest time at which an activity can start without jeopardizing the completion of the whole project in the minimum elapsed time.
d. L.F. - Latest finish, the latest time at which an activity can finish without jeopardizing the completion of LF = LS + duration.
e. T.F. - Total float, the time available between latest
finish and earliest finish. TF = LF - EF. When the total float is zero, the maximum time available equals the time required for completion of the job and the job is considered "critical".

f. F.F. - Free float, the maximum time an activity can be delayed without delaying the earliest start of the following activity.

In calculating these values for job H-I, putting the propeller back on, the analyst would proceed as follows. The earliest time at which the job can start is dependent upon the completion of all the preceding jobs. Since the longest path from node A to node H is the path A-B-C-D-E-F-H, the earliest start is limited by the time required to complete the jobs on this path, 6 hours. The earliest finish for the job equals the earliest start plus the duration, or 7 hours. If the project is to be completed in the shortest possible time, 11 hours, the latest finish for the job H-I is equal to 11 hours minus 3 hours (the duration of the longest path from node I to node K the end of the project), 8 hours. The latest start equals the latest finish minus the duration, or 7 hours. The total float equals the latest finish minus the earliest finish (8-7), one hour. In a similar manner, calculations for all jobs can be made. (See Table IV).
<table>
<thead>
<tr>
<th>Tail Node</th>
<th>Head Node</th>
<th>Duration</th>
<th>Description</th>
<th>Earliest Start</th>
<th>Earliest Finish</th>
<th>Latest Start</th>
<th>Latest Finish</th>
<th>Total Float</th>
<th>Free Float</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>G</td>
<td>1</td>
<td>Prop. Off</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>G</td>
<td>B</td>
<td>0</td>
<td>Dummy</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>G</td>
<td>H</td>
<td>3</td>
<td>Prop. Dome Desludge</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>7</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>A</td>
<td>E</td>
<td>3</td>
<td>Prepare New Engine</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>F</td>
<td>1</td>
<td>Engine In</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>0*</td>
<td>0*</td>
</tr>
<tr>
<td>F</td>
<td>H</td>
<td>0</td>
<td>Dummy</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>I</td>
<td>1</td>
<td>Prop. On</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>8</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>F</td>
<td>I</td>
<td>2</td>
<td>Connect</td>
<td>6</td>
<td>8</td>
<td>6</td>
<td>8</td>
<td>0*</td>
<td>0*</td>
</tr>
<tr>
<td>I</td>
<td>J</td>
<td>1</td>
<td>Final Inspection</td>
<td>8</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>0*</td>
<td>0*</td>
</tr>
<tr>
<td>J</td>
<td>K</td>
<td>2</td>
<td>Run-Up &amp; Function</td>
<td>9</td>
<td>11</td>
<td>9</td>
<td>11</td>
<td>0*</td>
<td>0*</td>
</tr>
<tr>
<td>A</td>
<td>B</td>
<td>2</td>
<td>Disconnect</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0*</td>
<td>0*</td>
</tr>
<tr>
<td>B</td>
<td>C</td>
<td>1</td>
<td>Remove Engine</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>0*</td>
<td>0*</td>
</tr>
<tr>
<td>C</td>
<td>D</td>
<td>1</td>
<td>Clean Firewall</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>0*</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>E</td>
<td>1</td>
<td>Inspect Firewall</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>0*</td>
<td></td>
</tr>
</tbody>
</table>

* Indicates Critical jobs
SAMPLE CRITICAL PATH NETWORK

HEAD NODE FOR ACTIVITY "A"
TAIL NODE FOR ACTIVITY "B"

ACTIVITY "A"

ACTIVITY "B"

FIGURE 1
FIGURE 2

ENGINE REMOVAL

FIGURE 2

1. REMOVE ENGINE
2. DISCONNECT
3. PREPARE NEW ENGINE
   - PROPELLOR DOME DESLUDGE
   - INSTALL ENGINE
   - FINAL INSPECTION
   - RUN-UP AND FUNCTION CHECKS
   - CRITICAL ACTIVITY
   - DUMMY ACTIVITY

A → B → C → D → E → F → I → J → K

REMOVE ENGINE
CLEAN FIREWALL
INSPECT FIREWALL
INSTALL ENGINE
CONNECT
FINAL INSPECTION
RUN-UP AND FUNCTION CHECKS
Chapter V - The Methods of Application of the Critical Path Technique to Aircraft Maintenance

The Technique in the Analysis of Completed Checks

The critical path technique was explained in the preceding chapter. The question that now arises is, "How can this technique be applied to aircraft maintenance?"

Let us first consider the use of the technique in the analysis of a completed equalized check of a DC-8. The equalized check is considered because it is a time consuming project performed weekly by the maintenance crews. The DC-8 is chosen because of the maintenance planning problems resulting from the great complexity of this aircraft. A completed check is chosen for the first application because all of the jobs performed in a completed check are known. If a check is yet to be completed, many jobs, such as those arising from the initial inspection of the aircraft are not known and therefore cannot be plotted in the network.

In applying the technique in this application, the first task is to plot the network of the jobs that were performed on the check according to the sequence that the analyst feels to be most efficient, not necessarily in the sequence in which the jobs were performed. Following this, the critical
path will be determined. Because of the great number of jobs involved in each check, use is made of an electronic computer in determining this path. In general, if the network consists of one hundred or more activities, it is more economical to employ a computer.

There are many computer programs available. Ray Sauer's LESS program, Least Cost Estimating and Scheduling, is the one that was chosen for use at Canadian Pacific Air Lines. The input data consists of a separate card for each activity in the project containing:

a. Tail node
b. Head node
c. Duration
d. Description

The output, cards and/or a printout, consists of all the input information plus a calculation for each job of the earliest start, earliest finish, latest start, latest finish, total float and free float; that is, a table similar to Table IV.

The next step is the analysis of this output. This is performed with two major objectives in mind. First, and most important, every attempt will be made to reduce the elapsed

2. As the name, Least Cost Estimating and Scheduling suggests, the program will also accept input data on the cost of each activity and calculate from it the total project cost. However, in the present example, the benefits to be derived from the additional knowledge gained are not great when compared to the additional cost of preparing the input data.
time of the project by reducing the length, in hours, of the critical path. Second, the total float of critical and "near-critical" jobs will be increased. This latter objective is, however, of only secondary importance and must, under no circumstances, be pursued if it will prohibit the attainment of the former. The reason for this latter objective is that the total float is based on estimated, not actual job durations. It can be seen that if a snag causes a job with one hour total float to be delayed two hours, the whole project will be delayed one hour. There is an inverse relationship between the length of the total float and the probability of a delay.

The analysis begins with an examination of the critical path. Those activities lying on this path which can be rescheduled to another portion of the check where they will neither be critical nor cause other activities to become overly "near-critical" will be rescheduled. Revised time estimates will be given for all critical jobs which can be performed in a shorter time than the original estimates indicate. This will be possible where an increase in manpower assigned to a given job, an increase in equipment, or a change in work procedures, etc., will cause a reduction in the required time. Following this, whole groups of activities containing some critical or near-critical jobs will be

3. It should be noted that in general, the durations assigned to a particular job when the chart is first plotted will be the best estimate of the time required assuming that the allocation of resources will be the most efficient and that the manpower assumed to be assigned to the job will be that which would perform the job most economically, even if this means a longer duration than might otherwise be possible.
examined for possible time reductions. When this revision is completed, calculations will be made to determine the new critical path which will, in all probability, be comprised of more critical jobs (on parallel critical paths) yet have a smaller elapsed time. This process of analysis, revision, and production of revised critical paths will continue until the analyst is satisfied that he has reduced the elapsed time to a workable minimum.

In this manner the analyst determines what the schedule should have been, or the "ideal" schedule. Since his records tell him what did actually happen in the check, the analyst is in a position to compare the actual with the ideal with a view to improving the performance on future checks.

The Technique in Analysis Before and During the Check

The critical path technique can also be used to provide the maintenance planner with valuable information before and during the check. As was pointed out above, the major difficulty with this approach is that approximately fifty per cent of the jobs that will be performed on any given equalized check cannot be preplanned because they are not known until the check is in progress. A possible solution to this problem is to make periodic calculations of the critical path throughout the check. For example, a recalculation of the critical path could be made every four or five hours on the basis of the latest available information on work load and job durations. The critical path for each successive calculation would be expected to change reflecting both
the additional jobs included in the network and the revision of
certain time estimates. Thus, as more recent calculations of
the critical path are made available, the planner can reschedule
the jobs that are still to be performed in such a way that the
total elapsed time for the check is reduced.

One great value of a periodic calculation of the
critical path during the project is that revised estimates of
total float are made available. In general, as the check pro-
gresses the total float for all jobs still to be completed
approaches zero. The reasons for this are that the job itself,
or some preceding jobs in the network, were not started at
the earliest possible start, some jobs took longer to complete
than was estimated, or, additional jobs were added to the net-
work. This periodic calculation provides the planner with in-
formation designed to ensure that the non-critical jobs are not
ignored to the point that they become critical. For example, if
there are four hours float for a chain of jobs but the start of
one job is delayed six hours, a most serious problem has arisen.

When computers are employed in the calculation of the
critical path, extensive use may be made of the input data
category, "description". All the input information for this
category is reproduced on the output cards. Thus, the output
cards may be sorted according to the description of the input.
For example, there may be ten or more different trade groups all
working on the same check; painters, cleaners, electricians,

4. Because of the interdependencies of the jobs in the network,
a delay in one job will in most cases cause a reduction in
the total float of the jobs following it.
inspectors, etc. If the analyst is interested in examining in more detail the work performed by any particular group, he may indicate in the description of the job which group is employed and then sort the output data according to groups. In this way, a foreman provided with such a listing may see at a glance all jobs under his jurisdiction, both critical and non-critical. It may be that the planner is having difficulty in co-ordinating the work in one particular area (e.g. the cockpit or the flaps). If the description of each job includes the area in which the job is to be performed, all jobs in the area may be sorted from the output deck for ease of analysis. The description might also contain the manpower requirement for each job, thus facilitating the planner's job of balancing the work load.

Further sorting may facilitate analysis even more. For example, the jobs performed by a particular trade may be sorted in order of total float to indicate, by position on the list, the relative criticalness of various jobs. A different sort according to earliest start time may also be helpful. Sorting the output deck three times, first by trade, and for each trade separately by total float and next, earliest start time, might also be desirable. The resulting list will show for each trade, jobs in order of increasing earliest start time, and for all jobs with identical earliest start in the same trade, jobs in order of increasing total float. Thus, at any time during the check the planner will know for each trade which jobs could be started and the urgency associated with each.
Other Applications

The use of the technique is not limited to operations utilizing a computer. In many instances a manual calculation is preferable. For example, it is often desirable to study intensely one small area that has been presenting certain problems. In such cases there may not be enough jobs involved to warrant the use of a computer. This "manual" technique is of value in the "post mortem" analysis, the analysis of what was wrong during the check. It may be that one particular system or area in the aircraft (say hydraulics) has been responsible, in part, for a number of delays. A manual critical path analysis of the activities of the system in each of the checks where the delays occurred may indicate the reasons for them, and future delays may be avoided.

Experience shows that certain areas are the major problem areas repeatedly. When this is the case a detailed manual critical path analysis of the problem area is required, but a critical path analysis of the whole check would mean wasting the analyst's time. In addition, the manual technique is useful before and during a check. For example, the most recent computer report of a check that is not yet completed may indicate a probable delay resulting from problems in a certain system. A detailed manual analysis of the problem may point out ways of avoiding this delay. In a similar way, a detailed study of work scheduling may be performed before work on a modification to the aircraft or its system is begun.
The technique, either manual or with the aid of a computer, will be of value in the study of a wide variety of projects in the field of maintenance planning. Its application to the equalized check has been described above. It will also be of great value in the analysis of overhauls and annual checks where the total elapsed time for the check is five or more days compared with only two days for the equalized check. On these longer checks the total work load is much greater. This makes scheduling more complex. The additional time required for the longer checks, and the resulting complexity in the scheduling of the many jobs caused by the greater volume of work both serve to increase the usefulness of the critical path technique.\(^5\)

For checks of this duration the analyst may prefer to make use of the PERT program (Program Evaluation and Review Technique) rather than the LESS program to determine the critical path.\(^6\) The value of PERT lies in the fact that it requires three separate estimates of the duration of each activity as input data. These are:

1. \(0\). Optimistic time; the shortest possible time in which a job might be completed.
2. \(M\). Most probable time.
3. \(P\). Pessimistic time; the longest possible time to complete the job.

5. It is because the annual check is performed so seldom at Canadian Pacific Air Lines, (only five times per year) that emphasis is laid on the application to the equalized checks.

6. See International Business Machines, PERT, \textit{op. cit.}
Time 0 and P would be chosen in such a way that the probability of the actual time being either less than 0, or greater than P would be one in one hundred.

The PERT output is a measure of the probability of completing the project in the time available, or conversely, the probability of a delay in the delivery of the aircraft. This probability measurement is not to be mistaken for an accurate measurement with mathematical precision. It is true that it is determined on the basis of mathematically sound formulae, but the parameters 0 and P which are part of these formulae are subjectively rather than objectively determined. However, even with this limitation the probability measurement is of considerable value. Consider the example of a check which because of a scheduled flight must be completed in 40 hours. Suppose that the critical path analysis indicates a check completion of 38 hours. If the probability measurement as calculated by the PERT method for the 38 hours completion were .8, the planners would show little concern. However, if the probability were .1, the planners would take immediate steps to reschedule some work, or to reduce the durations of some of the critical jobs.

Another possible area of application is in the analysis of new or unique projects. For example, the technique would be most helpful in planning the maintenance work for a new type of aircraft.

In addition, the tool is valuable for the analysis of certain sections or segments of the projects mentioned above. For example, such segmentations may be made in terms of trade groupings (e.g. electricians), aircraft areas (e.g. cockpit), aircraft systems (e.g. pneumatics) or shifts.
The benefits to be derived from an application of the critical path technique to aircraft maintenance are numerous. The tangible benefits are: reductions in the elapsed time of a project, reductions in the number of man hours required for completion of a project and reductions in the cost of a project.

Reductions in Elapsed Time

The main objective of the critical path method, as was pointed out in the preceding chapters, is to reduce the elapsed time of a given project. The various ways in which the technique can be used to attain this objective were also pointed out. In the paragraphs that follow the importance of reducing this time to a minimum will be presented.

It is a well known fact that capital invested in equipment earns a return for its owners only when the equipment is operating productively. Non-productive hours are non-revenue hours. In addition, the greater the cost of the equipment the more important it becomes to make full use of the output capacity (maximize the utilization) of the equipment. These generalizations can be illustrated by considering two different aircraft. Table V shows that if the cost of one piece of equipment is 100 times greater than that of another, and if all other factors are
<table>
<thead>
<tr>
<th></th>
<th>DC-8</th>
<th>DC-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cost</td>
<td>$7,000,000</td>
<td>$70,000</td>
</tr>
<tr>
<td>Annual Depreciation (10%)</td>
<td>700,000</td>
<td>7,000</td>
</tr>
<tr>
<td>Annual Interest Expense (6% of total Cost)</td>
<td>420,000</td>
<td>4,200</td>
</tr>
<tr>
<td>Total Annual Expense</td>
<td>1,120,000</td>
<td>11,200</td>
</tr>
<tr>
<td>Revenue Flying Hours Per Year</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Total Interest and Depreciation Expense per Revenue Flying Hour</td>
<td>280.00</td>
<td>2.80</td>
</tr>
</tbody>
</table>

Source: Since each of these figures vary considerably from airline to airline those chosen are rough approximates of 1963 data and are rounded for ease of presentation.
equal, the additional earnings resulting from increased utilization of the equipment will be 100 times as great also. Thus, the maintenance department will exert great efforts to reduce the check time of the DC-8 but will not be too concerned if the check time for the DC-3 is not at a minimum.

Consider again the example of a DC-8. If we assume an average revenue per seat mile of $6.3\$, an average number of passengers of 65 (a 50% load factor) and an average speed of 500 miles per hour, the return per aircraft per revenue flying hour is approximately $2,050 per hour. \((6.3\$/seat mile \times 65 \text{ seat} \times 500 \text{ miles/hour} = 2,047.50/\text{hour.})\)

If we also assume the out-of-pocket cost of flying the DC-8 one extra hour to be $900, it is obvious that the net contribution to overhead (and profits) is $1,150, \((2,050 - 900 = 1,150).\) (The assumed figures are very close approximations to actual operating experience.) Thus, if an application of the critical path analysis to the equalized check can result in a reduction of elapsed time of five hours per check, and if 50 equalized checks are performed each year, the resultant contribution to overhead would be $287,500 \((1,150 \times 5 \text{ hours/check} \times 50 \text{ checks/year} = 287,500 \text{ per year}).\)

The underlying assumption here is that the five additional hours of flying time made available will be used by the scheduling department for average revenue producing flights. If all of these additional hours cannot be used, or if the revenues
received from these additional flying hours are less than average, the net contribution will be reduced. It will be remembered from the example of Continental Airlines given in chapter I that the break-even load factor must not of necessity be attained on the additional flight. So long as the revenue of each additional flight is greater than the out-of-pocket costs for that flight, the airline will be increasing its profits. On the otherhand, it may be that by making the aircraft regularly available say five hours earlier, an extra flight of ten hours may be scheduled where no flight at all had been possible before. If this is the case, the yearly contribution to overhead will be twice $287,500 or $575,000.

Reductions in Manhours

In general, use of the critical path analysis will lead to increased efficiency. There will be marked effects on the man hours required for critical and non-critical jobs as well as a reduction in standby time.

All critical and near-critical jobs will be performed in the shortest possible elapsed time. The duration of certain jobs will be shortened and the man hour requirements for these jobs will be affected in one of four ways, as described hereunder.

1. Some jobs will be performed more quickly because of the increased efficiency of the mechanic who realizes that the job on which he is working is critical.
2. Some jobs will have a shortened duration because the application of the technique led to a more efficient work procedure.

3. Some jobs will experience a decrease in duration only by suffering an increase in the number of man hours required. For example, one mechanic may be able to complete a given job in three hours. However, if two men are assigned to the job, completion may be possible in two hours, the total manhour requirement being four manhours.

4. Some jobs will experience a decrease in duration only by suffering an increase in costs. For example, more equipment may be required to reduce the duration of certain jobs.

It can be seen that for critical and near-critical jobs whose durations are shortened, those which fall into groupings 1, 2, or 4, experience a reduction in manpower requirements.

In addition, non-critical jobs will also experience a reduction in manpower requirements. There are two reasons for this. First, the critical path technique will lead to an analysis of non-critical as well as critical jobs which will result in more efficient work procedures. Second, when there is a probability of a delay and the critical jobs are not easily distinguishable from the non-critical, there is a possibility of attempting to complete the non-critical jobs in the shortest possible time also. This may result in an inefficient use of manpower (See the example of group #3 above). If the critical path technique is employed the non-critical jobs will be clearly indicated and this manpower waste will be avoided.
The third effect that the technique will have on manpower requirements concerns standby time and overtime. Standby time is present in aircraft maintenance because of the planner's inability to provide a perfectly balanced work load for all trade groups and all workers in each group. The critical path technique could make available to the planner systematized data on the work load of each group and each worker. An example of this information is a computer output listing all jobs to be performed by a given group according to the criticalness of each job, or, according to the earliest start time of each job. Because the technique necessitates a detailed scheduling of all jobs, the planner is in a better position to forecast work loads at any given time. Acting on this knowledge, he may reschedule certain non-critical jobs to balance the work load.\(^1\) If rescheduling does not solve the problem, a complete deferment of certain jobs to a future maintenance check may be possible. It can be seen that such advance warning will also result in a reduction of overtime expenses.

Thus the overall effect on manhours of the technique is an increase in efficiency. This may result in either a completion of more work in a constant number of manhours or of the same amount of work in fewer manhours, thus freeing manpower.

\(^1\) It should be noted that in a check lasting 60 hours, approximately 80% of the jobs would have a total float in excess of 10 hours and, in more general terms, the vast majority of jobs, for most projects, are non-critical. There is therefore much opportunity for rescheduling at this point. See Table VI.
However, it may be advisable to permit the total manpower costs to increase if the additional costs are more than compensated for by the increased revenue from greater aircraft utilization. These increased manpower costs may arise for two reasons. First, they may result from an inefficient use of manpower or other resources, caused by the reduction of the duration of certain jobs. Second, if it is limited manpower and not job sequence that is prohibiting a contraction of the elapsed time for the check, high costs might result if the additional manpower required to overcome this limitation cannot be given employment elsewhere in the maintenance operations once the check has been completed. If such is the case, there will be an increase in standby time chargeable to the check.

Reductions in Costs

The critical path technique will effect income and expenditures in four ways.

1. Where reductions in elapsed time for a check are possible, and where the additional flying hours made available can be turned into revenue flying hours, great contributions to overhead will be obtainable.

2. In order to reduce the elapsed time on a check to a minimum, it may be advisable to increase the cost of performing certain critical jobs in order that their durations may be reduced.

2. An example of this situation would be where the total project duration based on the length of the critical path is 30 hours but the total estimated work load for a given trade of only four men is 160 hours. The critical factor here is not job sequence, 30 hours, but the work load per man, 40 hours.
This increase would result from additional expenditures on materials, equipment, manpower, etc.

3. As a result of the analysis, certain improved job procedures will be found resulting in lower cost for the jobs affected.

4. There is a cost of carrying out the critical path analysis which is primarily the cost of the analyst's time.

The following generalizations regarding the above may be made.

1. The possible additional revenues resulting from the additional flying hours are of a far greater magnitude than the above mentioned costs.

2. The increased costs incurred in reducing the duration of critical jobs are of the same order as, and largely offset by the savings from improved procedures.

3. The less tangible benefits, may be of sufficient magnitude to offset the cost of the analyst's time.

Less Tangible Benefits

The less tangible benefits differ from those mentioned above in that they do not lend themselves to objective, but rather subjective evaluation. In general, the technique facilitates better planning, scheduling and control and better allocation of manpower. In the paragraphs that follow some of the less tangible benefits will be mentioned along with a description of how each is obtained by the application of the critical path method.

1. The technique permits and encourages management to exercise more control over the project analyzed. The systematized
information that is made available to the planners before and during the check increases their ability to co-ordinate and organize the various activities to be performed in the check. Because this plan is much more detailed, deviations from it are more easily spotted. In addition the analysis involves both a study of what was done as well as what should be done, and therefore, management is forced to examine and to evaluate past performance.

There are two ways in which this increased control will benefit management. First, the data that is at present being collected (for example, the time a man spends on a particular job) will become more accurate and hence, more useful. This is because management will be systematically reviewing the data collected, examining it for unexpected and irregular details and demanding explanations for the irregularities in an attempt to reduce elapsed times.

Second, management will be more alert to deviations from the expected standards, especially where an excessive elapsed time is encountered. Regardless of the manner in which the technique is used, either before and during the project or in post-mortem analysis, the planner as a result of his analysis will produce expected standards of work performance. In an attempt to determine the reasons for deviations from these standards, management will, in actuality, be evaluating the mechanics, the work procedures and, indirectly, its own management abilities. From this evaluation, strengths and weaknesses will be pointed out, and corrective action, where
required, will be taken.

2. In addition, the technique forces a systematic analysis of a project and provides a tool by which such an analysis may be carried out. Without a goad similar to this technique, the analysis of a check if performed at all, tends to lack an overall plan or system, resulting in the study of specific checks or segments thereof each analyzed independently and at irregular intervals. The outcome of the more systematic analysis is more objective and leads to more reliable information and conclusions. In addition, this systematic framework encourages the analyst to make greater use of the information he collects. For example, regularly collected and comparable data may have some statistical value for indicating trends, frequently recurring problems, etc.

3. This leads to the third benefit, that of pointing out the problem areas. If a systematic analysis is not followed, management may not be aware that a certain problem exists, nor will it be able to objectively evaluate how critical the problem is. However, the critical path technique can be used to point out the critical jobs, those areas most frequently responsible for delays, those trades that require more or less manpower, the loss of time due to lack of equipment or materials, etc. From that information acquired in gaining the basic data for the analysis, each of these problem areas can be evaluated, and the seriousness and loss to the company from each ascertained. Once this is known, definite action towards the
solution of the major problems can be taken.

4. The fourth benefit, a reduction in the number and seriousness of delays, has both tangible and intangible aspects. Use of the critical path technique throughout the check will in many cases point out the likelihood of a delay earlier than would otherwise be possible. For the calculation of the critical path, time estimates must be made, and as the check progresses and successive critical paths are calculated, estimates must also be updated for all jobs which appear to be critical. This provides the planner with complete information, based on the best estimates available, on the likelihood of delays. In addition, the technique will provide him with more of the information helpful in either avoiding, or reducing the seriousness of the expected delays. The tangible and less tangible benefits are a saving of all the cost of the delay that was avoided such as passenger inconvenience, loss of goodwill, and cost of rescheduling aircraft.
Chapter VII - Evaluations and Conclusions

In the first chapter of this thesis mention was made of four different attempts to apply the critical path method to aircraft maintenance. In chapters V and VI, the detailed form of these applications was given, followed by the benefits which could be expected if such applications were made. However, due to certain circumstances, some of which were peculiar to Canadian Pacific Air Lines, some of these applications were not advisable. The purpose of this chapter is to examine these applications and to evaluate the usefulness of each.

The first attempt to make use of the technique was an analysis of checks that had already been completed. There is little question as to the value of such analysis and the benefits listed in chapter six will not be repeated here. How frequently should such an analysis be performed? Because it serves as a useful and powerful tool for closer control, yet requires no more than ten hours for a trained man to complete and analyze, it should be performed at a regular or irregular intervals at least once every two months. Then again, because of its value as a source of data and a guide to problem areas, it may be advisable to perform it much more frequently.

At the beginning of the study, it seemed wise to use the technique as the basis of all the scheduling both before and during the check. This would have required extensive use of a
computer. For many reasons this particular application proved to be inadvisable. First of all, a computer was not available at the maintenance base. Because of this, even if the data could be collected and prepared for the computer in a minimum of time, say one-half hour, the planner would receive a run-off containing information that was at least three hours old. When the majority of the checks are only forty to fifty hours long, decisions must not be delayed for three hours.

However, a computer could be provided on the maintenance base reducing this time lag to one-half hour, which is an acceptable time. This would be possible only if the department underwent extensive changes in work organization, and was willing to bear the cost of the additional data processing involved. This was deemed inadvisable at the time the study was carried out because Canadian Pacific Air Lines was at that time introducing the plannet approach to the problem of reducing the elapsed time.

Neither the cost, nor the presence of plannet would have prevented the introduction of the critical path technique, however, had preliminary experimentation and analysis not led to two discoveries. One was that eighty-nine percent of the jobs performed on the average check had a total float of eight hours or more (see Table VI and Figure 3). This meant that there was little reason for analyzing these jobs in the light of critical path principles. Rather, for these jobs, a method of assembly-
Table VI
Breakdown of all Work on Check #25, Aircraft #603, According to Criticalness

<table>
<thead>
<tr>
<th>Criticality of Float</th>
<th>No. of Jobs</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical jobs (no float)</td>
<td>33</td>
<td>4</td>
</tr>
<tr>
<td>Jobs with less than 4 hours float</td>
<td>34</td>
<td>4</td>
</tr>
<tr>
<td>Jobs with 4 to 8 hours float</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td>Jobs with 8 to 16 hours float</td>
<td>159</td>
<td>19</td>
</tr>
<tr>
<td>Jobs with 16 to 24 hours float</td>
<td>346</td>
<td>44</td>
</tr>
<tr>
<td>Jobs with float over 24 hours</td>
<td>231</td>
<td>26</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>825 Jobs</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>
line balancing would be more efficient. This conclusion is further substantiated by the fact that for certain checks, the critical path is so short that it is lack of manpower alone which prohibits an earlier check completion.

The second discovery was that it was frequently the work of the same one or two groups which was the critical work and was causing the delays. This meant that it was a detailed critical path analysis of the work of these problem groups that was required, not an analysis of the whole check. Since the work in these groups was not great, this analysis could be performed manually.

The general conclusion is, therefore, that when the conditions are similar to those that existed at Canadian Pacific Air Lines, a continual use of a computerized critical path analysis of each check as it progresses is not only unwarranted but may be very wasteful. However, these critical path and other techniques will be used to reduce the elapsed time and as this happens, a larger percentage of the jobs will become critical or near critical as will more groups. The result will be an increasing need for the computerized "in-check" analysis as the elapsed time of the check decreases. Thus it is to be expected that the computer will see increased use in this analysis in future years.

The technique will find its most frequent application in the analysis of various segments of the check. Whenever the need arises for a reduced elapsed time, be it of a job, a chain of jobs, or the check as a whole, the technique should be used. It will be used before, during, and after a check as the basic framework for the analysis of trouble spots.

Most frequently the work will involve charting the important elements of the network on paper. On certain instances the charting of the relationships will be a mental process only. In other cases, where particular segments of the check are continually presenting the planner with problems, a critical path board may be made use of. This will have the appearance of a chart but will have the advantage that the jobs, their inter-relationships, and their durations may be continually updated by moving the job cards on the board. Because of the complexity of the job inter-relationships, such a board is only of value in the analysis of a fairly small number of jobs such as those in one group, one area of the plane, etc.

As was stated in chapter I, the fourth attempt was to apply the PERT and the Man-Scheduling programs. The limited usefulness of PERT was described in chapter six. The Man-Scheduling program is designed to schedule each job in such a manner

that the work load for each workman is balanced, yet each job is completed before its total float expires. It was found to be impossible to apply this program because the storage capacities of the computers available were too small, and the computer time required proved to be too costly.

The study performed at Canadian Pacific Air Lines showed that the critical path technique had, at the time of the study, a wide applicability in aircraft maintenance particularly as an analytical tool. This applicability is not of a temporal nature but should be made use of increasingly until the point is reached when all the organization and scheduling of the check will be based upon and monitored by the critical path technique.
Chart of all jobs performed by Group II during equalized check 25 on A/C 603

Figure 3

Note: Heavy line indicates jobs performed by trades other than Group II.


12. General Electric, Computer Department, Phoenix, Arizona
13. Grubbs, F.E., Attempts to Validate Certain Pert Statistics,
   the Editor, pp. 912-914.
15. International Business Machines, Man-Scheduling Programme for
   the IBM, 1620, 1620 General Programme Library, 10.3.013.
16. International Business Machines, MISS LESS, 1620 General
   Programme Library, 10-J-011-C, 10.3.012.T.
17. Jet Utilization - Cost Control Increase Continental's Profits,
18. Kelly, J.E. Jr., and M.R. Walker, "Critical Path Planning and
   Scheduling," Proceedings Eastern Joint Computer Conference
19. Kelly, J.E. Jr., "Critical Path Planning and Scheduling:
   Application of a Technique for Research and Development
   Program Evaluation, Operations Research, Vol. 7, 1959,
   pp. 646-669.
   Processes With Critical Path Methods, United Air Lines.


25. RAMPS; Resources Allocation and Multi-Project Scheduling, Steel, August 6, 1962.
