Report No. FAA-AV-71-5

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AN APPLICATION OF DYNAMIC PROGRAMMING TO CAPITAL INVESTMENT DECISION ANALYSIS

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Washington, D.C. 20591

transpo 72

U.S. International Transportation Exposition
Dulles International Airport
Washington, D.C.
May 27-June 4, 1972

SEPTEMBER 1971

FINAL REPORT

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Prepared for

DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

Office of Aviation Policy and Plans

Washington, D.C. 20591

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Distribution: ZRD-344

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-AV-71-5		

4. Title and Subtitle	5. Report Date
An Application of Dynamic Programming to Capital Investment Decision Analysis	September 1971
	6. Performing Organization Code: AV-100
7. Author(s): George J. Couluris	8. Performing Organization Report No.
9. Performing Organization Name and Address: Office of Aviation Policy and Plans, Federal Aviation Administration, Department of Transportation, Washington, D.C. 20591	10. Work Unit No.
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address: Office of Aviation Policy and Plans, Federal Aviation Administration, Department of Transportation, Washington, D.C. 20591	13. Type of Report and Period Covered: Final
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report describes a method of evaluating capital investment decisions that utilizes the dynamic programming concept. Dynamic programming is an operations research technique that is effective in solving multistage decision problems. The dynamic programming process reduces many elaborate problems into a form that may be readily solved (provided the original problem is not excessively complicated).

The particular problems discussed in this report concern the identification of an optimum capital investment decision. Typically, the problem involves the selection of a capital investment decision from a group of competing or alternative investment decisions.

The method proposed in this report determines the discounted (present worth) value of the costs associated with each capital investment decision. The capital investment decision, or project, corresponding to the minimum discounted total cost is optimum. This solution is shown to be equivalent to the solution obtained by benefit-cost ratio analysis.

17. Key Words	18. Distribution Statement
Dynamic Programming, Benefit/Cost of ILS	Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151, for sale to the public.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	109	$3.00 PC .95 MF

Form DOT F 1700.7 (8-69)

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EXECUTIVE SUMMARY

This report describes a method of evaluating capital investment decisions that utilizes the "dynamic programming" concept. Dynamic programming is an operations research technique that is effective in solving certain types of problems. The dynamic programming process reduces many elaborate problems into a form that may be readily solved (provided the original problem is not excessively complicated).

The particular problems discussed in this report concern the identification of an optimum capital investment decision. Typically, the problem involves the selection of a capital investment decision from a group of competing or alternative investment decisions.

The method proposed in this report determines the discounted (present worth) value of the costs associated with each capital investment decision. The capital investment decision, or project, corresponding to the minimum discounted total cost is optimum. This solution is shown to be equivalent to the solution obtained by a benefit-cost ratio analysis.

I. INTRODUCTION

Dynamic programming is a method of formulating complex multi-stage problems as a sequence of easily solved one-stage problems and as such, is applicable to capital investment decision analysis.

This report first examines the underlying assumptions and implications of the capital investment analysis theory. This is followed by a discussion of the application of dynamic programming. A sample application is then presented which includes a description of a computer program that has been developed in accordance with the analysis process proposed in the report. A method of applying sensitivity analysis is also demonstrated.

The dynamic programming application discussed in this report is based on a concept described by Velona (1).

II. CAPITAL INVESTMENT ANALYSIS THEORY

The dynamic programming capital investment process gives a solution in terms of discounted (present worth) dollars. The following discussion introduces the discounting concept and subsequently develops a capital investment analysis methodology based on the process of discounting dollar expenditures or costs to their present worth value. (The reader may refer to Grant and Ireson (2) for an excellent detailed discussion.)

A. REVIEW OF THE DISCOUNTED COST CONCEPT

Discounting is a technique used to determine the present value of a dollar that is spent or received at some future or past date. It is a method of evaluating dollar transactions occurring at different times in terms of a common measurement scale, the present value of the dollar. This transformation into a common measurement base permits a meaningful comparison between alternative fiscal or monetary transactions occurring at different times. The term transaction refers to either a monetary expenditure or receipt.

Let: P = The present worth of an expenditure or receipt incurred the end of time period n

S = An expenditure or receipt incurred at the end of time period n

i = The interest rate or discount rate

n = Number of time periods (usually years)

$\frac{1}{(1+i)^n}$ = Present Worth Factor PWF(i,n)

Then: $P = S \times PWF(i,n)$

The selection of a discount rate is crucial to the evaluation of competing monetary transaction alternatives because the present worth values of time dependent transactions are often critically sensitive to the magnitude of the discount rate. See references (2) and (3) for further discussion of this topic.

B. CAPITAL INVESTMENT ANALYSIS BASED ON THE UNIFORM SERIES CAPITAL RECOVERY CONCEPT

For our purposes, capital investment is defined to be the initial cost of establishing a facility or the cost of initiating a project. It included all costs incurred during the planning, developing, and construction of a facility or project. The capital investment cost does not include any operating, maintenance, or penalty costs incurred while using a facility. To expedite mathematical analysis, the capital investment cost is assumed to be incurred at the beginning of the first time period during which the new facility is used (if necessary, the capital investment assignment may be calculated by discounting the appropriate capital costs to the above-mentioned time instant). Then, the discounted value of the capital investment cost allows a meaningful comparison between this capital investment occurring at any other time.

For purposes to be clarified later, it is often desirable to transform an initial capital investment into an equivalent uniform series of time period (e.g., annual) costs. Normally, the number of time periods over which the capital investment is transformed is equal to the usable life of the facility.

Let: R = The capital recovery cost of an initial capital investment at the beginning of time period n

P = Initial capital investment at the beginning of time period n

i = Interest rate or discount rate

k = Capital recovery life of the investment

$\frac{(1+i)^k-1}{i}$ = Capital recovery factor CRF(i,k)

Then: $R = P \times CRF(i,k)$

The initial investment, P, incurred at the beginning of time period n is transformed into a uniform series of k end-of-year capital recovery cost is assigned to the end of time period n and the last is assigned to the end of time period n+k-1.

C. TOTAL COST ANALYSIS

In addition to capital investment costs, there are two other types of costs normally relevant to capital investment decision analysis. These are referred to as "operating costs" and "penalty costs." Operating costs are composed of direct operating expenditures, and maintenance costs, but do not include costs associated with the establishment of a facility and do not include operating and capital investment costs. For example, consider the case of a single runway. The relevant penalty cost associated with this facility consists of all the delay, diversion, and accident costs that are incurred by aircraft attempting to use the runway.

Operating and penalty costs are incurred after a facility is established and used. Therefore, a decision to make a capital investment implies a willingness to accept the recurring operating and penalty costs that follow. To expedite mathematical analysis, these costs are assigned to the end of each time preiod. These end-of-period costs represent all the operating and penalty expenditures that are incurred during that time period. (Note: depending on the accuracy requirements of the problem, it may be necessary to compound the expenditures incurred during the time period to the end of that time period.) Finally, the discounted value of all the operating and penalty costs incurred is obtained by summing the individual present worth costs.

The overall cost experienced during the usable life of a facility may now be defined as the sum of all present worth costs incurred during a time period. It represents the present worth costs that will be experienced once a given capital investment is undertaken. These cumulative discounted total costs are then used as the basis for comparison among competing capital investment decisions. However, there are some important considerations involved in such a comparison that have not yet been discussed. These concern the relevant time periods under analysis and the relevant costs required.

D. STUDY PERIOD CONCEPT

In dealing with projecting costs into the future, there is some limit to the time span over which forecasts may be reasonably and reliably made. Currently, most forecasting techniques estimate statistics for a future period of twenty years or less. Estimates beyond this time frame are usually unreliable. However, many capital investment decisions involve facilities whose capital recovery life exceed this period of reliability. For example, a capital investment decision to build a facility ten years from now

usually involves a capital recovery life extending beyond the 20-year period of reliable forecasts. Furthermore, there is a need to define a method of meaningfully comparing the decisions to establish one facility, or another facility, at any time during the next five, ten or fifteen years.

The "study period" concept is a method that effectively handles these complications. The study period is merely a fixed time span over which all costs attributable to each capital investment decision is evaluated. The capital investment, operating and penalty costs assignable to each capital investment alternative during each and all time periods contained in the study period are examined.

The uniform series capital recovery cost technique is used to assign the capital investment cost to the appropriate time periods. By the study period analysis method, only the capital recovery costs assigned to the time periods contained in the study period are considered. Since the operating and penalty costs incurred only during the study period are examined, this method is a means of relating the capital costs to the specific period of use being analyzed. This means that any capital recovery costs assigned beyond the end of the study period are not relevant to the solution process proposed.

That capital investment decision which accumulates the minimum discounted total costs over the study period is optimum. In terms of equivalent present worth dollars, this alternative is the least expensive.

For example, consider the one runway airport. It is desired to examine the economic feasiblility of establishing a second runway sometime in the near future. Reliable aircraft activity forecasts are available only for the next ten years. Therefore, penalty costs due to aircraft delays, diversions, and accidents maybe reasonably estimated only for the next ten years. This ten year period is the study period. We are now concerned with two alternatives: to build a second runway sometime during the study period or not to build a second runway at all. Let us assume that a time period is one year. In the formulation of this problem, the decision to build a second runway is equivalent to establishing this facility at the beginning of one of the time periods during the study period.

Let: $M =$ Study period (ten years)

$i =$ Discount rate

Consider the decision not to build a second runway; i.e., maintain the existing situation (one runway) throughout the study period. This runway already exists and we may assume that it will continue to operate, without replacement, during the study period. Therefore, there is no capital investment cost associated with this alternative, however, there are operating and penalty costs involved. The cumulative discounted total cost associated with the decision not to establish a second runway is calculated as follows:

Let: OC_j = Operating cost assigned to the end of time period j due to using only one runway

PC_j = Penalty cost assigned to the end of time period j due to using only one runway

TC_1 = Cumulative discounted total cost attributable to a one-runway operation during the study period

Then: $$TC_1 = \sum_{j=1}^{M} \left[\frac{OC_j + PC_j}{(1+i)^j} \right]$$

One competing capital investment decision is to establish the second runway at the beginning of some time period n. Assume the usable life of the second runway, without replacement, is equal to some fixed number of years, k, such that k is greater than the study period duration m. Assume the capital investment cost of expanding from the one-runway operation to the two-runway operation is P_{n-1}, and this cost is assigned to the beginning of time period n. During the time periods 1 through n-1, only one runway is used and the operating and penalty costs for this situation are applicable. During the time periods n through m (the end of the study period) two runways are used. Therefore, operating and penalty costs for the two runways are applicable to those time periods. Usually, the increase in capital investment and operating costs incurred by this expansion would be expected to result in a decrease in penalty costs. The cumulative discounted total cost over the study period associated with decision to use one runway during time periods 1 through n-1 and two runways during time periods n through m is calculated as follows:

Let: P_{n-1} = Capital investment cost of establishing second runway at the beginning of time period n (end of time period n-1)

OC_j = Operating cost assigned to the end of time period j

PC_j = Penalty cost assigned to the end of time period j

k = Capital recovery life of the second runway

i = Discount rate

CRF(i,k) = Capital recovery factor

R_j = Capital recovery cost of P_{n-1}

TC_2 = Cumulative discounted total cost, accumulated over the study period

Then: $R_j = P_{n-1} \times CRF(i,k)$

$$TC_2 = \sum_{j=1}^{M} \left[\frac{R_j + OC_j + PC_j}{(1+i)^j} \right]$$

There are no capital recovery costs assigned to the time periods preceding the time period of establishment; i.e., $R_j = 0$, $j<n$. All capital recovery costs assigned to the time periods beyond the end of the study period (i.e., R_j, $j>m$) are not included in the analysis.

The procedure is to calculate the cumulative discounted total cost for all values of n, n = 1, -----, m, and that capital investment decision which gives the minimum cumulative discounted total cost is the decision alternative that will incur the lowest overall expenditures by all parties concerned (i.e., airport owner, aircraft operators, and passengers, etc.). As is later shown, this solution is equivalent to the solution obtained from a benefit-cost ratio analysis.

III. DYNAMIC PROGRAMMING

Dynamic programming is an operations research technique that is applicable to problems involving decision sequences. Given a problem involving a finite number of alternative decision sequences, a dynamic programming approach may be used to efficiently determine the "optimum" sequence. The optimum solution is the feasible sequence of decisions that optimizes some predefined objective function, e.g., minimize costs, maximize profit, etc. The overall problem must be capable of being decomposed into a series of stages. At each stage there are a finite number of "states" corresponding to the decision alternatives. A stage and state comprises a sub-problem. Each sub-problem is solved such that the solution to that sub-problem implies an entry state to the next stage. A solution is obtained for all possible states at each state. Upon solving the final stage, the overall optimal solution may be deduced from the resultant series of sub-problem solutions by tracing back through the implied states. This final solution consists of the series of decisions that defines what is to be done at each state, i.e. the state of each stage, such that the objective function is optimized.

A naive approach to optimizing a multi-alternative, multistage process would require examining all feasible alternatives and exhaustively comparing the results. However, in the dynamic programming formulation, the solution to a subproblem at one stage implies the state at the next stage and so it is necessary to go through the sequence of stages only once because the optimal sequence of decisions can be deduced from the last stage solution. Clearly the power of dynamic programming is its ability to significantly reduce the number of comparisons necessary to solve the problem.

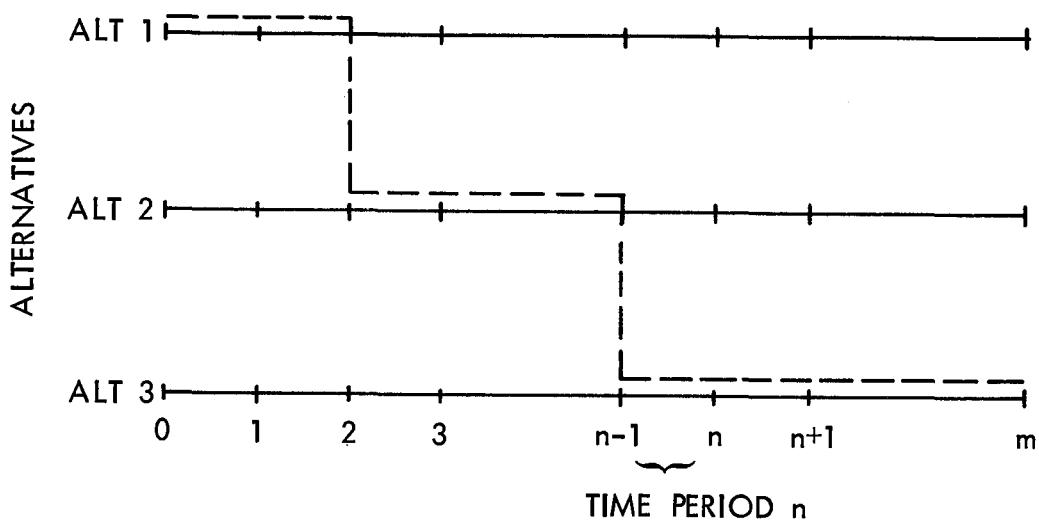
A. DYNAMIC PROGRAMMING FORMULATION OF CAPITAL INVESTMENT DECISION ANALYSIS UTILIZING THE STUDY PERIOD CONCEPT

In formulating the dynamic programming approach, the investment time periods correspond to the problem stages, while the competing capital investment decisions correspond to the decision alternatives or states. A sub-solution involves a decision regarding a capital investment during some time period given an initial state. The final optimum solution is the sequence of capital investment decisions that incur the minimum cumulative discounted total cost over the study period.

The following network oriented diagrammatical presentation of the competing capital investments process is useful as shown in Figure 1.

Consider three competing capital investments to be evaluated over a study period of m time periods. Each capital investment corresponds to the establishment of a specific facility at the beginning of some time period. Each facility corresponds to a feasible state of each stage and is referred to as an alternative (ALT) in this representation. For any final solution sequence, only one alternative may be used during any one time period.

Figure 1. Decision Process for Alternatives



The dotted line represents the solution sequence that consists of the decisions to use ALT 1 during the first two time periods, ALT 2 during time periods 3 through n-1, and ALT 3 during time periods n through m (the end of the study period).

The decision to changeover from ALT 1 to ALT 2 represents the decision to make the capital investment required to establish and use ALT 2 at the beginning of the third time period. This changeover involves the expenditure of money required to establish ALT 2 given that ALT 1 already exists and is in use.

In this terminology, a solution for any specific alternative is a set of decision sequences that results in the use of that alternative at the end of the study period. The dotted line above is termed a solution for ALT 3, not a solution for ALT 1 or ALT 2, because it results in the use of ALT 3 at the end of the study period.

There are many decision sequences (dotted lines) that are potential solutions for each alternative. By applying dynamic programming, we wish to determine the specific decision sequence that is in some sense optimum.

B. DYNAMIC PROGRAMMING SOLUTION PROCESS

In accordance with the capital investment analysis discussion, the objective of the dynamic programming formulation is to decide which alternative to use during each time period so that the discounted total cost accumulated during the study period is minimized.

The dynamic programming method approaches the final overall solution by first determining a final minimum cost solution for each and all alternatives. For each alternative (facility) a sequence of capital investment decisions is determined that minimizes the cumulative discounted total cost over the study period. From this set of individual solutions, the final overall optimum solution is obtained by selecting that alternative solution (decision sequence) which yields the minimum cumulative discounted total cost.

At this point in the discussion it is advisable to introduce the concept of the "null " alternative. The null alternative is the investment decision that is associated with the existing or current situation. The null alternative serves as a boundary condition to initiate the recursive dynamic programming solution process. The term "current situation" is loosely defined. It refers to the situation, or alternative, that in some way is the base case from which all other alternatives may be developed.

The capital investment cost of the null alternative is zero. All other capital investment costs are associated with the cost of establishing alternatives, or facilities, that do not currently exist. Although its capital investment cost is zero, the null alternative normally involves positive operating and penalty costs. (Note: If necessary the null alternative may be used as a dummy entry into the problem and may be "forced-out" of an optimum solution by assingning very, very large penalty costs to it.) In this discussion, the null alternative is always considered to be alternative one (ALT 1).

The dynamic programming solution process proceeds in a stage-wise (time period) order. It is initiated by obtaining a solution for each alternative for the first time period which is trivial because only the costs of changing over from the null alternative to each of the other alternatives are compared.

Once a first stage solution for each alternative is determined, the process proceeds to the second time period. Again each alternative is individually examined and a solution developed. However, now decisions concerning changovers from other alternatives at the beginning of the second time period are examined. A solution for an alternative during time period two implies that there is no other solution (decision sequence) available at the beginning of time period two capable of accumulating a lower discounted total cost at the end of the study period. This solution consists of the decision to use some certain alternative during the first time and the alternative under examination during the second time period so that discounted study period costs are minimized.

The process proceeds in consecutive order to time periods three, four, five, etc. until the study period is exhausted. At each stage (time period) only the optimum solution sequences (implied states) determined through the previous stage need be retained in the evaluation process. All other available solution sequences have previously been examined and found to be inferior, i.e., not minimum cost solutions. These sub-optimum solution sequences are eliminated from the dynamic programming process because they will increase the end-of-study-period cummulative discounted costs. By this method, the analytical scope of the process is systematically reduced.

The solution for an alternative at any time period (stage) is the least cost decision sequence from the beginning of the study period to that time period. That is, of all the potential decision sequences that have been examined up through that time period (stage), this solution accumulates the lowest costs. The solution for an alternative for the last time period is the optimum decision sequence for that particular alternative for the entire study period.

To clarify the above discussion, examine the solution for some time period n in the following example:

> Consider a case where only two alternatives are feasible. ALT 1 is the null alternative and ALT 2 is an additional facility that will increase service. For instance, for an airport that currently has one runway, ALT 1 represent continuing operations with the one runway only. ALT 2 may represent establishing a second runway and using both runways concurrently. The study period is m time periods in duration and all costs are to be discounted to the beginning of each time period. We may assume that a changeover from ALT 1 to ALT 2 is feasible, but this process may not be reversed.

The solution for ALT 1 is trivial. The only way to use ALT 1 during any time period is to use it at the beginning of the first time period and to continue to use it through each succeeding time period.

At the beginning of time period n, the available solutions for ALT 2 have been examined through the end of time period n-1. Suppose the optimum solution for time period n-1 is to use ALT 1 during time period 1, establish ALT 2 at the beginning of time period 2 and use it continuously through time period n-1. All other solutions available at the beginning of time period n will increase the discounted total cost accumulated to the end of the study period. Therefore, they are not examined again.

Now, at the beginning of time period n, there are only two feasible decision sequences available for ALT 2. ALT 2 may be used during time period n either by continuing the optimum solution obtained for time period n-1 (i.e., establish ALT 2 in time period 2) or by deferring the establishment of ALT 2 until the beginning of time period n. This latter solution involves the decisions to use ALT 1 from time periods 1 through n-1 and changing over to ALT 2 at the beginning of time period n. The decision concerning which of the two sequences is optimum is determined by examining all the costs relevant to the end-of-study-period cumulative dicounted total costs. (The relevant costs are discussed below.) The decision sequence associated with the lowest such cost is selected as the optimum solution for ALT 2 for time period n. The other solution is eliminated from any further consideration.

The optimum solution for ALT 1 and ALT 2 for time period n are then used to initiate solutions for the next time period, time period n+1. This process is repeated until all the time periods in the study period are analyzed. At that time, i.e., the end of time period m, one optimum solution is available for ALT 1 and one for ALT 2. The solution (decision sequence) incurring the lowest cumulative discounted total cost over the study period is the final overall optimum solution.

C. RELEVANT COSTS

In order to apply the dynamic programming solution process certain data are required as input information. The following information must be forecasted and specified:

1. The operating and penalty costs associated with each alternative (including the null alternative) must be determined. In order to evaluate the use of any alternative during a time period,

the operating and penalty costs incurred by using each alternative must be specified. In accordance with the capital investment analysis discussion, the operating and penalty costs are expressed in terms of end-of period dollar assignments.

2. The capital investment cost of feasibly changing over from each alternative to any other feasible alternative is also required. This changeover cost represents the beginning-of-period cost of changing from some ALT K to some ALT I. The dollar amount of a changeover cost that is required as input data is the cost of such a changeover at the beginning of time period 1. This same changeover cost is assumed to apply at all succeeding time periods. But, as is shown below, it is possible to increase this cost in response to inflation.

   Once an alternative (facility) is established at the beginning of some time period, the continued use of this particular alternative incurs no further capital investment cost. Capital investment costs are incurred only when changeovers between alternatives are decided upon.

3. The capital recovery life of each alternative is also required. Great care should be exercised in the formulation of a problem so that the study period duration, the capital recovery lives and the feasible changeover costs are compatible.

   The following notation is adopted:

Let:	ALT I	=	Alternative I
	C(K, I)	=	Capital investment cost of changing over from ALT K to ALT I at the beginning of some time period.
	OC(I,J)	=	Operating cost incurred by using ALT I during time period J, assigned to the end of time period J.
	PC(I,J)	=	Penalty cost incurred by using ALT I during time period J, assigned to the end of time period J.
	CRL(I)	=	Capital recovery life of ALT I
	m	=	Number of time periods in the study period
	i	=	Discount rate

As an example, for a two alternative problem, the capital investment costs may be:

C (1,1) = 0	C (1,2) = $1,000,000
C (2,1) = -1	C (2,2) = 0

C (2,1) = -1 indicates that a change from ALT 2 to ALT 1 is infeasible (e.g., It may represent changing from a two runway airport to a one runway airport).

That there are no capital investment costs associated with the continued use of an alternative once it has been previously established. Therefore, C(1,1) = 0 and C (2,2) = 0. Also, since ALT 1 is the null alternative and is assumed to be the existing situation, there is no capital investment cost associated with the use of ALT 1.

D. DYNAMIC PROGRAMMING PROCESSES RELATION TO BENEFIT-COST RATIO ANALYSIS

It will now be shown that the cumulative discounted total cost solution obtained by the dynamic programming process is equivalent to a benefit-cost ratio analysis.

Consider a solution for some alternative I (ALT I) for some time period n. Consider two solution sequences, A and B, determined for time period n-1. The relevant costs may be represented as follows:

Let: OC(S,J) = Operating cost incurred by sequence S (SEQ S) assigned to the end of time period J.

PC(S,J) = Penalty cost incurred by sequence S(SEQ S) assigned to the end of time period J.

R(S,J) = Capital recovery cost assigned to sequence S (SEQ S) at the end of time period J.

TC(S) = Discounted total cost of Sequence S (SEQ S) accumulated over the study period.

Since both sequences are solutions for the same ALT I for time period n, the operating and penalty costs for time periods n through m are equal for the two sequences.

Let: $OC'(S,J)$ = Discounted value of $OC(S,J)$

$PC'(S,J)$ = Discounted value of $PC(S,J)$

$R'(S,J)$ = Discounted value of $R(S,J)$

Then: $$OC'(S,J) = \frac{OC(S,j)}{(1+i)^J} \qquad j = 1, 2, \ldots, m$$

$$PC'(S,j) = \frac{PC(S,j)}{(1+i)^j} \qquad j = 1, 2, \ldots, m$$

$$R'(S,j) = \frac{R(S,j)}{(1+j)^j} \qquad j = 1, 2, \ldots, m$$

The cumulative discounted total costs over the study period for the two sequences, SEQ A and SEQ B, are:

$$TC(A) = \sum_{j=1}^{m} R'(A,j) + \sum_{j=1}^{n} OC'(A,j) + \sum_{j=1}^{n} PC'(A,j) + \sum_{j=n+1}^{m} (OC(I,j) + PC(I,j)$$

$$TC(B) = \sum_{j=1}^{m} R'(B,j) + \sum_{j=1}^{n} OC'(B,j) + \sum_{j=1}^{n} PC'(A,j) + \sum_{j=n+1}^{m} (OC(I,j) + PC(I,j))$$

Let: $$C'(S) = \sum_{j=1}^{m} R'(S,j) + \sum_{j=1}^{m} OC'(S,j), \quad S = A,B$$

$$P'(S) = \sum_{j=1}^{n} PC(S,j), \quad S = A, B$$

$$E' = \sum_{j=n+1}^{m} (OC(I,j) + PC(I,j)$$

Then: $$TC(A) = C'(A) + P'(A) + E'$$

$$TC(B) = C'(B) + P'(B) + E'$$

The dynamic programming cost solution is TC:

$$TC = \min \left[TC(A), TC(B)\right]$$

Let us assume SEQ A is the minimum discounted total cost solution, i.e., $TC(A) < TC(B)$

Now, consider the benefit-cost ratio solution to the sample problem:

$$TC(A) = C'(A) + P'(A) + E'$$

$$TC(B) = C'(B) + P'(B) + E'$$

Where $TC(A) < TC(B)$

Let: C= Incremental capital costs

$$C = C'(A) - C'(B) \text{ if } C'_A > C'_B$$

$$= C'(B) - C'(A) \text{ if } C'_B > C'_A$$

B= Benefits

$$= P'(B) - P'(A) \text{ if } C'_A > C'_B$$

$$= P'(A) - P'(B) \text{ if } C'_B > C'_A$$

$\frac{B}{C}$ = Benefit-Cost ratio

Applying the benefit-cost ratio method, we have:

$$TC(A) < TC(B)$$

$$C'(A) - P'(A) + E' < C'(B) + P'(B) + E'$$

$$C'(A) + P'(A) < C'(B) + P'(B)$$

If $C'(A) > C'(B)$, evaluate the case for spending additional capital to change from SEQ B to SEQ B to SEQ A:

$$C'(A) + P'(A) < C'(B) + P'(B)$$

$$C'(A) - C'(B) < P'(B) - P'(A)$$

$$C < B$$

$$1 < \frac{B}{C}$$

The benefit-cost ratio is greater than one, therefore SEQ A is the preferred SEQ B. This is the same conclusion obtained by the dynamic programming routine.

Now, if $C'(A) < C'(B)$, evaluate, using the benefit-cost method, the case for spending additional capital to change from SEQ A to SEQ B:

Again: $TC(A) < TC(B)$

$$C'(A) - P'(A) + E' < C'(B) + P'(B) + E'$$

$$P'(A) - P'(B) < C'(B) - C'(A)$$

$$B < C$$

$$\frac{B}{C} < 1$$

The benefit-cost ratio is less than one, and SEQ A is still the preferred solution. A change from A to B involves an unfavorable benefit-cost ratio. The same conclusion obtained by the dynamic programming method again results.

If this procedure is repeated for the case when $TC(A) > TC(B)$ it will show that the dynamic programming solution and the benefit-cost solution are again identical.

This procedure may be repeated for all time periods, one through m, and the same conclusions will be shown.

Repeating this procedure for time period m will show that the final optimum dynamic programming minimum discounted total cost solution for the entire study period is equivalent to the benefit-cost ratio solution.

E. REVIEW OF THE DYNAMIC PROGRAMMING PROCESS

The dynamic programming process is an efficient solution method for mulit-stage, multi-alternative capital investment problem. Dynamic programming solves the overall problem in a stage wise procedure by obtaining sub-solutions at each successive stage (time period) and state. At each stage, extraneous non-optimum solutions (decision sequences) are eliminated from the problem. This technique significantly reduces the size of the analytic solution process.

The dynamic programming method often requires less restrictive simplifying assumptions then are required by many other analytic techniques.

At each stage, the same set of basic calculations are performed with only the numbers changed. Therefore, the dynamic programming process is easily adopted to computer programming. A computer program has been designed and an example of its application is discussed later.

The dynamic programming minimum cumulative discounted total cost solution is equivalent to a benefit-cost solution. This equality is important to many organizations, particularly governments, whose capital investment decision evaluations are usually based on benefit-cost analysis.

Care should be exercised in the selection of problems appropriate to a dynamic programming application. Capital investment problems of the form discussed above are usually well suited to a dynamic programming solution. However, many of these problems may be too large for efficient dynamic programming. In such cases, one should examine the feasibility of decomposing an excessively large problem into a set of related smaller problems before utilizing (or abandoning) the dynamic programming approach.

The dynamic programming solution process proposed in this report is based on evaluating discounted (present worth) dollars. As previously discussed, any analysis method based on discounting is sensitive to the value of the discount rate used. One must be careful to select a discount rate that is, in some sense , valid.

There is also the question of the relative sensitivity of the dynamic programming solution to the accuracy of the cost forecasts. However, since this process is easily (and is) computerized, sensitivity analysis is readily applicable. The cost forecasts may be adjusted as desired and the program re-run so that the effects of the forecast adjustments on the final solution may be examined.

IV. SAMPLE APPLICATION: INSTRUMENT LANDING SYSTEM, CATEGORY IIIA INSTALLATION PROGRAM

A. SOLUTION PROCESS

To demonstrate the application of dynamic programming to capital investment decision analysis, an example involving the installation of Instrument Landing Systems, Category IIIA, at various airports in the United States was selected. This system is referred to as ILS CAT IIIA or CAT IIIA ILS. An ILS system is an electronic guidance system that enables appropriately equipped aircraft to land during unfavorable weather conditions.

The Federal Aviation Administration (FAA) owns, installs, and operates almost all the ILS facilities in operation in the United States. The ILS facilities, classified according to the service provided, are designated as Categories I, II, IIIA, IIIB, and IIIC. The level of service provided increases incrementally from CAT I to CAT IIIC. While most ILS equipment currently in use is CAT I, a program is underway to install CAT II equipment at most large airports.

The FAA must now decide whether or not to embark on a program to install any CAT IIIA ILS ground equipment. In justifying such a program, government agencies normally depend on a benefit-cost ratio analysis. Since the dynamic programming minimum discounted cost analysis method is equivalent to a benefit-cost analysis, the CAT IIIA ILS program was evaluated in this example as a dynamic programming problem. The primary guideline to an installation program is that the program with the highest benefit-cost ratio greater than unity is preferred. Equivalently, the FAA is interested in identifying the program associated with the minimum cumulative discounted total cost.

The major airlines have recently announced plans to install CAT IIIA ILS equipment in new generation aircraft. This included the two, three, and four engine wide-bodied turbojets, and the supersonic transport. This CAT IIIA ILS airborn equipment is being installed although no complementary ground equipment is now available at any domestic airport. Therefore, the airlines are investing capital in airborne CAT IIIA equipment although no benefits are currently realizablefrom the investment in the United States (Note: CAT IIIA ground equipment may currently be in service at some European airports.)

It is assumed that the FAA's cost considerations are not effected by the airlines above program. Since the airborne cost expenditure program affects each FAA ground installation program equally, the costs attributable to the airborne equipment need not be considered in an economic evaluation of the FAA programs. The revelant costs associated with competing FAA ground equipment installation programs retain their relative dollar magnitudes; thus the final minimum discounted total cost solution is not distorted by excluding the airborne equipment costs from the analysis process.

Forecasts of new generation aircraft activity indicate that a significant majority of these operations will occur at the airports designated by the FAA as "airports serving large hubs." For purposes of this demonstration example, twenty-five large hub airports were selected as potential candidates for CAT IIIA ILS ground equipment installation. It is assumed that no CAT IIIA ILS ground equipment can be installed at any airport before the beginning of 1972. See reference 4.

The additional service provided by CAT IIIA ILS over CAT II ILS was measurable in terms of the delay and diversion costs that are avoided or prevented by installation of the CAT IIIA ground equipment. These costs that are avoided by using CAT IIIA ILS were the penalty costs assigned to the decision to establish and use CAT IIIA ILS equipment. The analytical scope of this problem was reduced by dealing in terms of relative values between CAT II and CAT IIIA penalty costs. By excluding the CAT IIIA penalty cost from all the alternative programs, the relative dollar magnitude of the relevant penalty costs remained the same and the minimum discounted total cost solution was not changed (this holds true for a benefit-cost solution also).

A method of estimating the penalty costs attributable to delays and diversions has previously been developed by the FAA(5). This method is used in Appendix A to estimate the preventable penalty costs. Since estimates of future new generation aircraft activity are available only through 1981, the preventable penalty costs are forecast only for the years 1972 through 1981.

Since all available cost data are expressed in terms of 1970 dollars, it is convenient to use 1970 dollars as the basic measuring unit for the analysis process. The dynamic programming method discounts all relevant costs to 1970 dollar. Therefore, the first time period used in the dynamic programing method corresponds to 1970. With each time period corresponding to a year, the study period under consideration consists of the twelve time periods, years 1970 through 1981.

Since no CAT IIIA ILS can be installed before 1972, all installation programs (including the null alternative) incur the same operating and penalty costs during the first two time periods, 1970 and 1971. Since CAT II ILS is used as the base case in this formulation, only CAT II ILS service is assumed to be available during 1970 and 1971. (Note: Although this assumption may not precisely represent the real world situation, it is compatible with the purpose of this analysis, which is to evaluate the additional service provided by CAT IIIA ILS.) Since all potential programs incur the same operating and penalty costs in 1970 and 1971, these costs may be eliminated from consideration.

This establishment of the additional service provided by CAT IIIA ILS, over CAT II, implies the expenditure of additional operating costs. As in the case of the preventable penalty costs, an analysis involving only the incremental operating costs may be conducted without distorting the relative costs. Therefore, the additional operating costs incurred by using CAT III ILS are the only operating costs that need be considered.

The installation of CAT IIIA ILS at an airport involves the decision to incur a capital investment cost. In terms of the relative costs used in this report, this capital investment cost is the additional expenditure involved to changeover (or upgrade) from a CAT II ILS to a CAT IIIA ILS. In essence, the FAA has to decide whether it is economically feasible to incur the additional capital investment and operating costs attributable to CAT IIIA service in order to avoid the preventable penalty costs.

The CAT II ILS service is considered as the base case or null alternative. There is no capital investment cost assigned to the alternative decision to continue the use of CAT II service in the dynamic programming formulation. Continued use of CAT II ILS service at all airports corresponded to the decision not to establish any CAT IIIA ILS. The dynamic programming process compares all competing CAT IIIA programs against each other as well as against the base case. In this fashion the analysis yields a list of airports which economically justify CAT IIIA ILS and what year they qualify. This list is called an installation program. For example, one program may consist of installing two CAT IIIA ILS's at the beginning of 1972, three at the beginning of 1973, and so on. The program would include the identity of the airports involved.

There are thousands of installation programs possible from combinations of twenty-five airports and the ten installation periods. Examination of each such program even by the dynamic programming process is infeasible. However, this overall problem can be decomposed into a series of individual problems, each of which is readily solved. It is assumed that the installation of a CAT IIIA ILS at any one of the twenty-five candidate airports does not significantly affect the costs incurred or the ILS service provided at any of the other airports. Thus, each airport is analyzed individually and a solution program identified for each one. The twenty-five individual solutions are then combined into the final optimum solution program.

B. APPLICATION OF THE DYNAMMIC PROGRAMING COMPUTER PROGRAM TO THE CAT IIIA ILS PROBLEM

A computer program that performs the dynamic programming capital investment analysis is available and is reproduced in Appendix II. To demonstrate this computer program, the installation of a CAT IIIA ILS at the large hub airport serving Atlanta, Georgia, is evaluated.

In summary, the study period is twelve time periods (years) in duration, i.e., 1970 through 1981. All costs are discounted to the beginning of the first time period (1970). CAT II ILS service is the base case (null alternative) and therefore must be assumed to be in use at the beginning of time period one. This boundary condition is necessary to initiate the dynamic programming sequential solution process. CAT IIIA ILS service can first be established at the beginning time period 3 in 1972. All cost forecasts were in terms of 1970 dollars.

The FAA is to decide when to establish CAT IIIA ILS service, if at all, in order that the discounted total cost accumulated over the study period is minimized at Atlanta.

In the formulation of the dynamic programming process, two alternatives are identified. Alternative 1 (ALT 1), the null alternative, represents CAT II ILS service while alternative 2 (ALT 2) represents CAT IIIA ILS service. A changeover from ALT 1 to ATL 2 may be conducted in any of the time periods 3 through 12. In this analysis, a changeover from ALT 2 to ALT 1 is not allowed.

The capital investment cost associated with changing over from CAT II (ALT 1) service to CAT IIIA (ALT 2) service is $500,000 (expressed in 1970 dollars). Since CAT II is the base case, there is no capital investment cost associated with ALT 1.

The useful life of CAT IIIA ILS is assumed to be fifteen years. Therefore, the capital recovery life for ALT 2 is fifteen time periods. It is assumed that the useful life of the base case, CAT II ILS, will extend beyond the end of the study period. The capital recovery life of fifteen time periods is also assigned to ALT 1. (Note: The value of the capital recovery life of the null alternative, ALT I, is not critical to the computer solution process.)

The operating and penalty costs used are the relative costs discussed above. The relative penalty costs incurred by the decision to use each alternative in any and each time period are based on the preventable delay and diversion costs calculated in Appendix I. The relative operating costs are based on the incremental operating costs incurred by using CAT IIIA (ALT 2) service rather than CAT II(ALT 1) service. The end-of-period relative operating and penalty costs, in 1970 dollars, are as shown in Table 1. (Note: as discussed above, costs incurred in 1970 and 1971 are not relative to the solution.)

Table 1. Relative Operating and Penalty Costs of CAT IIIA ILS (1970 dollars)

		RELATIVE OPERATING COST		RELATIVE PENALTY COST	
TIME PERIOD	YEAR	ALT 1	ALT 2	ALT 1	ALT 2
1	1970	0	0	0	0
2	1971	0	0	0	0
3	1972	0	50000	55000	0
4	1973	0	50000	76000	0
5	1974	0	50000	106000	0
6	1975	0	50000	155000	0
7	1976	0	50000	205000	0
8	1977	0	50000	294000	0
9	1978	0	50000	401000	0
10	1979	0	50000	531000	0
11	1979	0	50000	686000	0
12	1981	0	50000	875000	0

All the above cost estimates are expressed in 1970 dollars. In this analysis, it is assumed that all costs will increase at an inflation rate of 2.5 percent per year. The computer program automatically inflates all costs at the appropriate interest rate. In accordance with current FAA capital investment analysis policy, a discount rate of ten percent is used.

Information describing the feasible periods of use for each alternative must also be specified. For CAT IIIA (ALT 2) service, the earliest feasible time period in which it can be established and used is time period 3 (1973), and the latest feasible time period in which it can be established and used is time period 12 (the last time period in the study period). For the null alternative, CAT II (ALT 1) service, the earliest use period must be set to time period 1. If the analyst neglects to do this, the computer program automatically sets the earliest use period for ALT 1 equal to time period 1. This is necessary to initiate the computer program solution process. The latest feasible time period in which CAT II (ALT 1) service can be used is time period 12 (1981).

Data are input into the computer program in the following form:

NI	=	Number of alternatives
NJ	=	Number of time periods in the study period
DISRATE	=	Discount rate
RATEINF	=	Rate of inflation
OPERCST(1,J)	=	Operating cost incurred by using alternative I during time period J
PENALTY(I,J)	=	Penalty cost incurred by using alternative I during time period J
CHGCOST(K,I)	=	Capital investment cost of changing over from alternative K to alternative I
		or
	=	-1 if a changeover from alternative K to alternative I is infeasible
LIFECR(I)	=	Capital recover life of alternative I
ISTART(I)	=	Earliest time period in which alternative I may be feasibly used

IEND(I) = Latest time period in which alternative I may be feasible used.

Note that for each alternative, the operating and penalty costs must be specified for each and all time periods. In the case where the use of an alternative is infeasible during some time periods, appropriate costs must still be specified for these time periods. Normally, during such infeasible time periods, dummy (i.e., equal to zero) operating and penalty costs are used.

The capital investment costs of changeovers, CHGCOST (I,I), need only be input when such a changeover is greater than zero. When the continued use of an alternative that has been previously established is evaluated, the program considers the situation as a changeover from the alternative to itself, i.e., K=1. In this case, the computer program automatically sets the changeover cost equal to zero, i.e., CHGCOST (,I) = 0. All remaining costs are set equal to -1, the infeasibility indicator. For instance, CHGCOST (I,2) = $500,000 is input into the program. CHGCOST (I,I) and CHGCOST (2,2) are automatically set equal to zero. The remaining capital investment cost, CHGCOST (2,1) is automatically set equal to -1. This indicates that a changeover from CAT IIIA (ALT 2) to CAT II (ALT 1) service is not to be considered by the program.

The computer program is now prepared to conduct the dynamic programming capital investment analysis. In accordance with the dynamic programming process discussed above, the computer program proceeds in a sequential manner, obtaining a solution for each time period until the last time period is solved. At the end of time period 12 (the end of the study period) a cumulative discounted total cost solution is obtained for both alternatives. A comparison of the optimum solutions for both alternatives indicates that CAT IIIA (ALT 2) ILS service is the final overall optimum solution, because it has a lower cumulative discounted total cost for the study period than does CAT II (ALT 1) service. The solution sequence shows that the optimum time to establish the CAT IIIA ILS is at the beginning of time period 6 (1975). Establishment of CAT IIIA service at any other feasible time period increases the cumulative discounted total costs.

The computer solution results, based on the relative costs are as shown in Table 2.

Table 2. Cumulative Discounted Costs of ALT 1 and ALT 2
(Thousands of 1970 Dollars)

	ALT 1	ALT 2
Penalty Cost	1692	172
Capital Cost	0	407
Total Cost	1692	579

The capital costs shown above are the sums of the discounted capital recovery and operating costs.

The benefit-cost ratio for the case of expending additional capital to changeover from ALT 1 to ALT 2 is calculated as follows:

Benefits (Reduction of Penalty Costs) = 1520

Capital Cost Increment = 407

Benefit-Cost Ratio $= \frac{1520}{407} = 3.72$

The solution sequence for ALT 1 involves continuously using CAT II service from the beginning of 1970 (time period 1) through the end of 1981 (time period 12).

The solution sequence for ALT 2 involves using CAT II service from the beginning of 1970 through the end of 1974 (time period 5), establishing CAT IIIA service at the beginning of 1975 (time period 6) and using CAT IIIA service continuously through the end of 1981.

The final overall optimum solution, ALT 2, implies that CAT IIIA service is to be continued beyond the end of the study period. This is due to the fact that the usable life, capital recovery life, of a CAT IIIA ILS established at the beginning of 1975 extends beyond the end of the study period.

C. SENSITIVITY ANALYSIS

A similar dynamic programming capital investment decision analysis is performed for all the twenty-five candidate airports. The combined solution program, which includes only seventeen airports, is as shown in Table 3.

Table 3. Installation Schedule

Cumulative Number	CAT IIIA ILS Year of Establishment	Airport Identity	Cumulative Discounted Total Cost (thousands)
1	1973	N.Y. Kennedy (JFK)	628
2	1974	Chicago O'Hare (CHI)	590
3	1974	Los Angeles (LAX)	599
4	1975	Atlanta (ATL)	580
5	1976	Seattle (SEA)	505
6	1977	San Francisco (SFO)	476
7	1978	Boston (BOS)	393
8	1978	Baltimore (BAL)	396
9	1979	Wash. Dulles (IAD)	350
10	1979	Detroit (DTW)	361
11	1979	Houston (HOU/IAH)	344
12	1979	Philadelphia (PHL)	351
13	1979	N. Y. La Guardia (LGA)	346
14	1980	New Orleans (MSY)	248
15	1980	Newark (EWR)	350
16	1981	Dallas/Ft.Worth(DAL/DFR)	213
17	1981	Pittsburgh (PIT)	236

The remaining light airports are recommended to continue CAT II ILS service during the entire study period.

This conclusion is valid only if the cost forecasts used are accurate. There may be some question as to accuracy of the penalty cost estimates. Therefore, a sensitivity analysis was conducted in + 25 percent and + 50 percent. The computer program analysis is repeated for all twenty-five candidate airports for the four adjusted penalty costs. The final combined solutions for all cases show the following results in Table 4.

Table 4. Combined Results of Sensitivity Analysis

Penalty Cost Adjustment Factor	Number of CAT IIIA ILS Established During the Study Period
0.50	13
0.75	15
1.00	17
1.25	20
1.50	20

It is seen that the number of CAT IIIA ILS installed increases as the penalty costs estimates increase (the capital investment and operating costs are held fixed in this evaluation). Since the penalty cost represent costs that are preventable by the installation of CAT IIIA ILS, they are also a measure of the benefits of establishing CAT IIIA service. Therefore, as the penalty cost estimates increase, the measured benefits increase and more CAT IIIA ILS are introduced into the installation program.

In examining the above program solutions, it appears that three basic solution sequences are potentially acceptable. Sensitivity analysis is now used in a slightly different manner in order to provide a more meaningful analysis of the three potential installation programs. The first installation program, based on the solution resulting when the penalty costs were increased by fifty percent, involves the installation of twenty CAT IIIA ILS during the study period. This referred to as program A, PROG A. The second installation program, PROG B, based on the solution resulting when the penalty costs were not adjusted and involves the installation of seventeen CAT IIIA ILS during the study period. The third installation program, PROG C, is based on the solution resulting when the penalty costs were decreased by fifty percent and involves the installation of thirteen CAT IIIA ILS.

The three installation programs are as shown in Table 5.

Table 5. Effect of Sensitivity Analysis on Installation Schedule

Cum Number	Airport Identity	CAT IIIA ILS Year of Establishment Program A	Program B	Program C
1	N.Y. Kennedy (JFK)	1972	1973	1975
2	Chicago O'Hare (ORD)	1973	1974	1976
3	Los Angeles (LAX)	1973	1974	1976
4	Atlanta (ATL)	1974	1975	1977
5	Seattle (SEA)	1975	1976	1978
6	San Francisco (SFO)	1976	1977	1979
7	Boston (BOS)	1977	1978	1980
8	Baltimore (BAL)	1977	1978	1980
9	Wash. Dulles (IAD)	1978	1979	1981
10	Detroit (DTW)	1978	1979	1981
11	Houston (HOU/IAH)	1978	1979	1981
12	Philadelphia (PHL)	1978	1979	1981
13	N.Y. LaGuardia (LGA)	1978	1979	1981
14	New Orleans (MSY)	1979	1980	-
15	Newark (EWR)	1979	1980	-
16	Dallas/Ft. Worth (DAL/DFR)	1980	1981	-
17	Pittsburgh (PIT)	1980	1981	-
18	Miami (MIA)	1981	-	-
19	St. Louis (STL)	1981	-	-
20	Cleveland (CLE)	1981	-	-

It is seen, that as the penalty cost estimates are decreased, the number of CAT IIIA ILS scheduled installations are not only reduced but are also delayed in time.

Now the cumulative discounted total cost of each of the three programs is obtained for the case when the penalty costs are not adjusted. Appropriate cost data for each of the programs are input into the computer program, and the solution sequence for each program is "forced" through the program. A solution sequence may be forced through the program by judiciously assigning appropriate capital investment costs, CHGCOST (K,I) and feasible time periods of use, ISTART(I) and IEND(I). For example, a changeover from some ALT K to some ALT I may be forced by assigning a positive capital investment cost only to CHGCOST (K,I).

All other inter-alternative changeovers to ALT I are set equal to -1 by the computer program; i.e., CHGCOST (J,I) = 1, J≠K, I. Only a changeover from K to I is considered feasible by the computer program. A similar procedure is applied to all other changeover costs. The time period of the capital investment (changeover) may also be forced by manipulating the feasible time period of use. A changeover from ALT K to ALT I may be forced in time period J by setting IEND(K) = J and ISTART (I) = J by assigning the changeover costs as shown above.

There are elevan alternatives involved in the formulation of the PROG A problem. Each alternative corresponds to the establishment of one or a group of CAT IIIA ILS facilities at the beginning of a time period. ALT I, the null alternative, represents continuing the use of CAT II service. At the beginning of time period 3 (1972), ALT 2 is forced into the solution sequence. ALT 2, in this case, corresponds to the establishment of CAT IIIA service at N. Y. Kennedy (JFK) airport. ALT 3 corresponds to the establishment of CAT IIIA service at Chicago O'Hare (ORD) and Los Angeles (ILAX) airports at the beginning of time period four (1973) and the establishment of CAT IIIA service at Kennedy in the previous time period. This procedure continues until all time periods, and all alternatives, are exhausted. Note that each alternative includes the cumulative increase in service provided by its predecessors.

This process is conducted for all three programs with the penalty costs unadjusted. The resulting cumulative discounted costs are as shown in Table 6.

Table 6. Cumulative Discounted Costs of Sensitivity Solutions
(Thousands of 1970 Dollars)

	Capital Cost	Penalty Cost	Total Cost
PROG A	5248	2895	8143
PROG B	4031	3988	8019
PROG C	2164	6676	8840

The capital costs are the sum of the cumulative discounted capital recovery and operating costs incurred.

Using the unadjusted penalty costs, PROG B is the overall optimum solution because it has the lowest cumulative discounted total costs.

It is now desired to evaluate the decision to adopt any one of these installation programs if the penalty costs actually vary from the estimates. That is, if one of these programs is undertaken, how are the total costs affected if the true penalty costs realized in the future differ from the estimated penalty costs used in this analysis.

The discounted costs listed above are the cumulative study period costs resulting when the penalty cost estimates are not adjusted. These discounted costs are expressed in a common measuring unit, 1970 dollars. Increasing or decreasing the unadjusted penalty cost forecast for each time period is the same as increasing or decreasing the equivalent discounted penalty costs. Therefore, in order to determine the effect on the study period costs of adjusting the penalty costs by some factor, the cumulative discounted penalty cost is adjusted by the same factor. For example, to evaluate the effect of increasing each penalty cost by 25 percent, the cumulative discounted penalty cost is multiplied by 1.25. This method is similarly applicable to the capital investment, operating, and total costs.

This method is used to determine the sensitivity of the three installation programs to variations in the penalty costs. The results are shown in tabular and graphical form in Tables 7 and 8 and Figure 2.

Table 7. Sensitivity of Three Installation Programs to Adjusted Penalty Costs
(Thousands of 1970 Dollars)

Program	Capital* Cost	Penalty Cost Adjustment Factor							
		.25	.50	.75	1.00	1.25	1.50	1.75	2.00
PROG A	5248	724	1448	2171	2895	3619	4343	5066	5790
PROG B	4031	997	1994	2991	3988	4985	5982	6979	7976
PROG C	2164	1669	3338	5007	6676	8345	10014	11683	13352

* Cumulative discounted capital cost is equal to the sum of the cumulative discounted capital investment and operating costs.

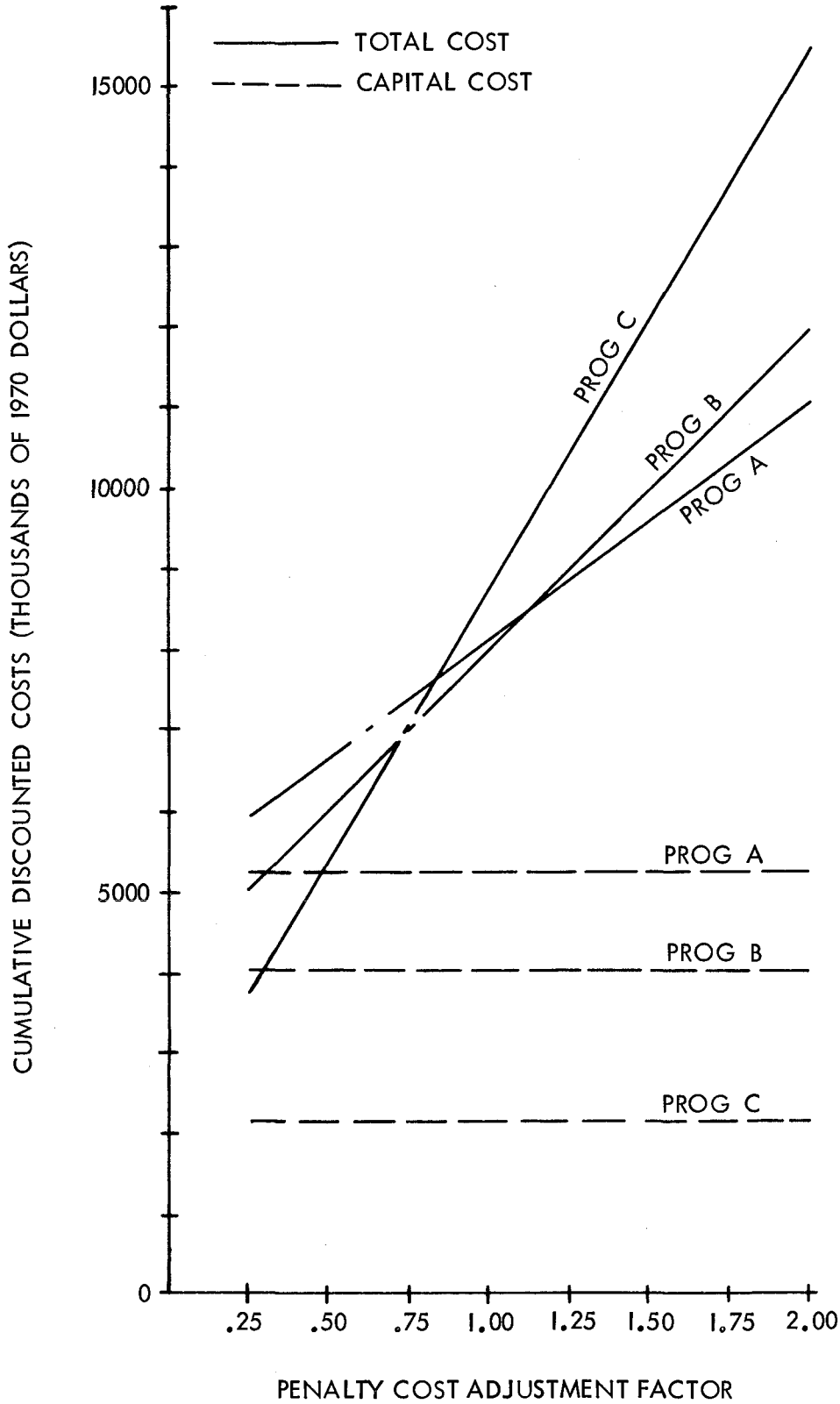


FIGURE 2. SENSITIVITY OF INSTALLATION SCHEDULES TO ADJUSTED PENALTY COST

Table 8. Sensitivity of Cumulative Discounted Total Costs to Adjusted Penalty Costs
(Thousands of 1970 Dollars)

Program	Penalty .25	.50	.75	Cost 1.00	Adjustment 1.25	1.50	Factor 1.75	2.00
PROG A	5972	6696	7419	8143	8867	9591	10314	11038
PROG B	5028	6025	7022	8019	9016	10013	11010	12007
PROG C	3833	5502	7171	8840	10509	12178	12847	15516

The difference between the total cost and capital cost graphs of one program is equal to the penalty cost associated with that program.

From Figure 2 it is seen that PROG A is optimum (i.e., least cumulative discounted total cost) if the penalty costs are at least fifteen percent higher than the original unadjusted estimate. PROG C is optimum if the penalty costs are less than seventy percent of the original forecasts. In the immediate range of the original unadjusted penalty cost forecasts, PROG B is optimum.

The sensitivity analysis is carried one step further by assigning (arbitrarily) some probability to each adjusted penalty cost. This represents the probability of the penalty cost varying from the original unadjusted estimate. The expected cumulative discounted total cost, based on the assigned probability structure, for each installment program may be estimated.

For example, an arbitrary probability structure may be assigned to the penalty cost adjustment factors for the cumulative discounted total costs shown above. The resulting expected cumulative discounted total costs are estimated as follows and are shown in Table 9.

Let: F = Penalty cost adjustment factor

$P(F=f)$ = Probability that F equals f, $\sum P(F=f) = 1$

$TC(K,F)$ = Cumulative discounted total cost incurred by program K at penalty cost adjustment factor F

$WTC(K,F)$ = Weighted cumulative discounted total cost of program K at adjustment factor F

$$WTC(K,F) = TC(K,F) \quad P(F=f)$$

$$ETC(K) = \text{Expected cumulative discounted total cost of program } K$$

$$= \sum WTC(K,F)$$

Table 9. Expected Cumulative Discounted Total Costs

		Weighted Total Costs, WTC(K,F)		
F	P(F=f)	PROG A	PROG B	PROG C
0.25	.05	298.6	251.4	191.7
0.50	.15	1004.4	903.8	825.3
0.75	.25	1854.8	1755.5	1792.8
1.00	.25	2036.0	2004.8	2210.0
1.25	.15	1330.1	1352.4	1576.4
1.50	.15	959.1	1001.3	1217.8
1.75	.04	412.6	440.4	553.9
2.00	.01	110.4	120.1	155.2
Total	1.00	8006.0	7829.7	8523.1
ETC(K)		8006.0	7829.7	8523.1

The expected cumulative discounted cost for PROG B is minimum under this probability structure. Therefore, PROG B (seventeen CAT III A ILS installations) is optimum.

The sensitivity analysis may be extended to the capital cost also. Increasing the capital costs by ten percent results in a total cost graph that is parallel to the original but vertically higher by an amount equal to ten percent of the capital cost of the program.

In terms of the above probability structure, the following results are obtained by increasing capital costs by ten percent and are shown in Table 10.

Table 10. Result of Ten Percent Increase in Capital Costs

	PROG A	PROG B	PROG C
ETC(K)	8006.0	7829.7	8523.1
Ten Percent of Cap. Cost	524.8	403.1	216.4
Total	8530.8	8232.8	8739.5

No significant difference in the expected cumulative discounted total cost is introduced, relative to the optimum solution (PROG B).

D. ADDITIONAL REMARKS

Extreme care must be excercised when assigning costs to the respective alternatives. When a changeover from one alternative to another involves replacement of the first alternative, the time period costs of the new alternative may be independent of the first alternative. If a changeover represents an expansion of one alternative into another alternative, the time period costs of the new alternative may include the costs of the first alternative. That is, the time period cost may be incrementally cumulative. The analyst must be sure that the data inputs are appropriate to the particular problem involved.

It is possible to design the computer program so that the inter-alternative changeover costs are time dependent. This is desirable if capital investment costs vary significantly with time. However, time dependent changeover costs may require extensive data input requirements. An individual changeover cost may be required for each feasible changeover for each time period.

The program may also be designed to evaluate salvage values. However, salvage value effects may be handled by the current program. Instead of using the initial capital investment cost as input data, the capital investment cost minus the discounted worth of the salvage value may be assigned to the appropriate changeover costs.

APPENDIX A

CALCULATION OF PENALTY COSTS PREVENTABLE BY CATEGORY III A INSTRUMENT LANDING SYSTEM

The calculation of costs due to delays and diversions preventable by CAT III A ILS over those preventable by CAT II ILS is based on a method developed by the FAA(5). The annual preventable penalty costs are calculated for the period, 1972-1981, for twenty-five selected airports and are listed in the Tables A-4 to A-28 at the end of this section.

Preventable delays and diversions are those delays and diversions that occur when the weather conditions are lower (worse) than CAT II weather but not lower than CAT III A weather. The fractions of time that each of the twenty-five airports are in the "preventable weather disruption conditions" (delays or diversions preventable by CAT III A service) are estimated by the FAA(5). These fractions are used in this report.

Since only new generation aircraft are assumed to have CAT III A airborne equipment, only these aircraft are involved in this analysis. The number of new generation aircraft departures and passenger enplanements are forecast for each year for each candidate airport.

Data based on informal contracts with the FAA's Office of Aviation Economics, Aviation Forecasts Division (6), are used to develop these estimates. This data includes estimates of:

1. Average seats per aircraft for each new generation aircraft type by year are shown in Table A-1.

2. Direct operating cost for each new generation aircraft tvpe are shown in Table A-2

3. Percentage of enplaned seats on each new generation aircraft type of total enplaned airline seats for each airport for 1975 and 1980 are shown in Table A-3.

Table A-1 ANNUAL AVERAGE NUMBER OF SEATS PER AIRCRAFT TYPE

	AIRCRAFT TYPE				
Year	JUMBO 4-Eng.	JUMBO 3-Eng.	AIRBUS 2-Eng.	SST Concorde	SST U.S.
1971	350	-	-	-	-
1972	350	250	-	-	-
1973	350	250	-	-	-
1974	360	250	-	-	-
1975	375	260	-	115	-
1976	375	275	-	115	-
1977	375	275	200	115	-
1978	375	300	200	115	-
1979	375	300	200	115	280
1980	375	300	200	115	280
1981	375	300	200	115	280

Table A-2 AVERAGE DIRECT OPERATING COST PER HOUR (DOC) PER AIRCRAFT TYPE
(1970 Dollars Per Hour)

AIRCRAFT TYPE	DIRECT OPERATING COST PER HOUR
Jumbo 4-Eng	1300
Jumbo 3-Eng	1000
Airbus 2-Eng	700
SST Concorde	1600
SST U.S.	2700

Table A-3 PERCENT ANNUAL ENPLANED SEATS ON NEW GENERATION AIRCRAFT OF TOTAL AIRLINE ENPLANED SEATS

Airport	Year	Total	Jumbo 4-Eng	Jumbo 3-Eng	Airbus 2-Eng	SST Concorde	SST U.S.
Atlanta	1975	12	5	7	0	0	0
	1980	40	10	15	15	0	0
Boston	1975	12	5	5	0	2	0
	1980	47	12	15	15	2	3
Chicago	1975	31	15	16	0	0	0
	1980	60	25	20	15	0	0
Cleveland	1975	10	5	5	0	0	0
	1980	49	10	17	22	0	0
Dallas/Ft.Worth	1975	19	10	9	0	0	0
	1980	57	17	20	20	0	0
Denver	1975	10	5	5	0	0	0
	1980	49	15	15	19	0	0
Detroit	1975	19	10	9	0	0	0
	1980	52	20	16	16	0	0
Houston	1975	13	5	8	0	0	0
	1980	40	8	12	20	0	0
Kansas City	1975	8	3	5	0	0	0
	1980	32	8	12	12	0	0
Los Angeles	1975	41	25	15	0	1	0
	1980	72	32	25	10	1	4
Miami	1975	31	14	15	0	2	0
	1980	64	26	22	10	2	4
Minneapolis	1975	10	5	5	0	0	0
	1980	40	14	18	8	0	0
New Orleans	1975	12	5	7	0	0	0
	1980	47	12	15	19	0	1
Newark	1975	34	7	27	0	0	0
	1980	62	10	29	23	0	0
N.Y. Kennedy	1975	44	30	13	0	1	0
	1980	78	45	14	10	2	7
N.Y. LaGuardia	1975	25	0	25	0	0	0
	1980	58	0	43	15	0	0
Philadelphia	1975	18	10	8	0	0	0
	1980	49	20	16	10	1	2
Pittsburgh	1975	13	3	10	0	0	0
	1980	41	10	21	10	0	0

Table A-3 PERCENT ANNUAL ENPLANED SEATS ON NEW GENERATION AIRCRAFT OF TOTAL AIRLINE ENPLANED SEATS (Continued)

Airport	Year	Total	Jumbo 4-Eng	Jumbo 3-Eng	Airbus 2-Eng	SST Concorde	SST U.S.
St. Louis	1975	19	12	7	0	0	0
	1980	52	20	15	17	0	0
San Francisco	1975	31	18	12	0	1	0
	1980	60	30	17	8	3	2
Seattle	1975	16	10	5	0	1	0
	1980	41	18	10	7	2	4
D.C. Dulles	1975	20	12	7	0	1	0
	1980	50	25	14	5	2	4
D.C. National	1975	0	0	0	0	0	0
	1980	25	0	0	25	0	0
Baltimore	1975	22	10	10	0	2	0
	1980	51	20	15	8	3	5

The total number of annual airline passenger enplanements for the years 1968, 1971, 1976, and 1981 at the twenty-five candidate airports is estimated by the FAA(4). A graphical projection technique (hand-drawn exponential fit) is used to estimate the passenger enplanements at each airport for the other years in the forecast period (1972 through 1981). In a similar manner, the percentage of the total enplaned seats on new generation aircraft (of total airline enplaned seats) is estimated for each airport for each year.

These two statistics are multiplied together to obtain an estimate of the total annual number of new generation aircraft passenger enplanements at each candidate airport. (Note: This calculation assumes that the new generation and conventional aircraft have similar load factors. Any error introduced by this assumption is considered insignificant in relation to accuracy of the estimates used.)

Using the annual percentage distribution of enplaned seats among the new generation aircraft and the annual average number of seats per each aircraft type estimates for each airport, the annual weighted average number of enplaned seats per new generation aircraft is estimated for each airport. In a similar manner, the annual weighted average direct operating cost for new generation aircraft is estimated at each airport. Due to differences in the mix of aircraft types, the weighted average of both the average seats per aircraft and the annual direct operating cost per aircraft vary significantly from airport to airport.

An estimate of the annual passenger load factor (percentage of seats occupied by passengers per aircraft) for new generation aircraft is listed in the tables at the end of this section. The annual weighted average number of enplaned passengers per new generation aircraft is estimated by multiplying the weighted average number of seats per aircraft by the load factor. This calculation is performed for each candidate airport for each year in the period 1972 through 1981.

The total number of annual new generation aircraft departures is estimated by dividing the number of enplaned passengers by the weighted average number of seats per aircraft. This is performed for each candidate airport for each year in the period 1972 through 1981.

In terms of new generation aircraft activity, the annual number of departures and passenger enplanements are pertinent to the method (5) used to estimate delay and diversion costs. This method assumes that the number of aircraft departures approximates the number of aircraft landings, and the number of enplaned passengers approximates the number of arriving passengers. The fraction of time (per year) that each airport is in the "preventable weather disruption condition" is multiplied by the above (two) annual activity statistics in order to estimate the annual number of aircraft and passengers delayed or diverted. (Note: Separate fractions are available for both delays and diversions.) The results are shown in the tables at the end of this section.

According to the method devised in reference (5), the following assumptions are used:

1. A delayed or diverted flight causes subsequent delays to other flights. These delays are referred to as secondary effects.

2. The average time delay assigned to a delayed passenger is 2.0 hours (including secondary effects).

3. The average time delay assigned to a diverted passenger is 4.17 hours (including secondary effects).

4. The average delay time assigned to a delayed aircraft is 1.25 hours (including secondary effects).

5. The average delay time assigned to a diverted aircraft is 0.50 hours.

6. For each diverted aircraft, the secondary effects cause an average additional cost of $1000.

Also the value of time to passengers delayed and diverted is assumed to be six dollars per hour.

All costs are expressed in terms of 1970 dollars.

The appropriate costs are applied to each annual delay and diversion estimate in order to obtain the annual delay and diversion costs for each airport. These are the penalty costs preventable by replacing CAT II service with CAT III A ILS service. The results are listed in the following Tables A-4 to A-28.

Table A-4 ATLANTA (ATL)

CAT IIIA WEATHER DISRUPTION FACTORS
FRACTION OF (NEW GEN) AC/PASS DELAYED =.000640
FRACTION OF (NEW GEN) AC/PASS DIVERTED =.001660

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS
AVE PASS DELAY TIME (HRS PER PASS) = 2.00
AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17
AVE AC DELAY TIME (HRS PER AC) = 1.25
AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)
PASS TIME COST ($ PER HOUR PER PASS) = 6.00
SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	AVE DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	800000	60	325	1250	4103
1973	1100000	59	315	1200	5919
1974	1500000	58	305	1150	8479
1975	2200000	57	300	1100	12865
1976	2900000	56	290	1080	17857
1977	4100000	55	280	1050	26623
1978	5600000	54	275	1000	37710
1979	7400000	53	270	950	51712
1980	9500000	52	265	910	68940
1981	12000000	51	260	900	90498

Table A-4 ATLANTA (ATL) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

ATLANTA (ATL)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	512	1328	6144	33226	39370	55000
	AC	3	7	4688	11375	16062	
1973	PASS	704	1826	8448	45686	54134	76000
	AC	4	10	6000	16000	22000	
1974	PASS	960	2490	11520	62299	73819	106000
	AC	6	15	8625	23625	32250	
1975	PASS	1408	3652	16896	91372	108267	155000
	AC	9	22	12375	34100	46475	
1976	PASS	1856	4814	22272	120444	142716	205000
	AC	12	30	16200	46200	62400	
1977	PASS	2624	6806	31488	170283	201771	294000
	AC	18	45	23625	68625	92250	
1978	PASS	3584	9296	43008	232582	275590	401000
	AC	25	63	31250	94500	125750	
1979	PASS	4736	12284	56832	307341	364172	531000
	AC	34	86	40375	126850	167225	
1980	PASS	6080	15770	72960	394559	467519	686000
	AC	45	115	51187	167325	218512	
1981	PASS	7680	19920	92159	498390	590550	875000
	AC	58	151	65250	218950	284200	

Table A-5 BOSTON (BOS)

CAT IIIA WEATHER DISRUPTION FACTORS
FRACTION OF (NEW GEN) AC/PASS DELAYED =.000720
FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000620

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS
AVE PASS DELAY TIME (HRS PER PASS) = 2.00
AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17
AVE AC DELAY TIME (HRS PER AC) = 1.25
AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)
PASS TIME COST ($ PER HOUR PER PASS) = 6.00
SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	AVE DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	300000	60	325	1250	1538
1973	500000	59	300	1230	2825
1974	700000	58	275	1210	4389
1975	1300000	57	240	1190	9503
1976	1900000	56	245	1170	13848
1977	2800000	55	245	1150	20779
1978	4000000	54	250	1130	29630
1979	5600000	53	250	1100	42264
1980	7800000	52	255	1090	58824
1981	10500000	51	255	1080	80738

Table A-5 BOSTON (BOS) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

BOSTON (BOS)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	216	186	2592	4654	7246	12000
	AC	2	1	3125	1625	4750	
1973	PASS	360	310	4320	7756	12076	20000
	AC	3	2	4612	3230	7842	
1974	PASS	504	434	6048	10859	16907	28000
	AC	4	3	6050	4815	10865	
1975	PASS	936	806	11233	20166	31399	51000
	AC	7	6	10412	9570	19982	
1976	PASS	1368	1178	16417	29474	45891	75000
	AC	10	9	14625	14265	28890	
1977	PASS	2016	1736	24193	43435	67628	110000
	AC	15	13	21563	20475	42037	
1978	PASS	2880	2480	34562	62050	96612	157000
	AC	22	19	31075	29735	60810	
1979	PASS	4032	3472	48387	86870	135256	220000
	AC	31	27	42625	41850	84475	
1980	PASS	5616	4836	67396	120997	188393	304000
	AC	43	37	58587	57165	115752	
1981	PASS	7560	6510	90725	162881	253606	412000
	AC	59	51	79650	78540	158190	

Table A-6 CHICAGO (ORD)

CAT IIIA WEATHER DISRUPTION FACTORS
FRACTION OF (NEW GEN) AC/PASS DELAYED =.000380
FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000380

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS
AVE PASS DELAY TIME (HRS PER PASS) = 2.00
AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17
AVE AC DELAY TIME (HRS PER AC) = 1.25
AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)
PASS TIME COST ($ PER HOUR PER PASS) = 6.00
SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	AVE DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	2700000	60	325	1250	13846
1973	4200000	59	315	1200	22599
1974	6300000	58	310	1160	35039
1975	8500000	57	305	1120	48893
1976	11000000	56	305	1060	64403
1977	14400000	55	300	1000	87273
1978	17800000	54	300	950	109877
1979	21600000	53	295	900	138152
1980	26400000	52	290	870	175066
1981	32400000	51	285	860	222910

Table A-6 CHICAGO (ORD) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

CHICAGO (ORD)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	1026	1026	12312	25671	37984	57000
	AC	6	6	9375	9750	19125	
1973	PASS	1596	1596	19153	39933	59086	87000
	AC	9	9	13500	14400	27900	
1974	PASS	2394	2394	28729	59899	88628	131000
	AC	14	14	20300	22120	42420	
1975	PASS	3230	3230	38761	80817	119578	176000
	AC	19	19	26600	29640	56240	
1976	PASS	4180	4180	50161	104586	154748	226000
	AC	25	25	33125	38250	71375	
1977	PASS	5472	5472	65666	136913	202579	296000
	AC	34	34	42500	51000	93500	
1978	PASS	6764	6764	81170	169240	250410	362000
	AC	42	42	49875	61950	111825	
1979	PASS	8208	8208	98499	205370	303868	440000
	AC	53	53	59625	76850	136475	
1980	PASS	10032	10032	120387	251007	371395	540000
	AC	67	67	72862	96145	169007	
1981	PASS	12312	12312	147748	308055	455802	669000
	AC	85	85	91375	121550	212925	

Table A-7 CLEVELAND (CLE)

CAT IIIA WEATHER DISRUPTION FACTORS
FRACTION OF (NEW GEN) AC/PASS DELAYED =.000360
FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000360

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS
AVE PASS DELAY TIME (HRS PER PASS) = 2.00
AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17
AVE AC DELAY TIME (HRS PER AC) = 1.25
AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)
PASS TIME COST ($ PER HOUR PER PASS) = 6.00
SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	AVE DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	200000	60	325	1250	1026
1973	300000	59	320	1200	1589
1974	400000	58	315	1160	2189
1975	700000	57	310	1120	3962
1976	900000	56	300	1060	5357
1977	1300000	55	290	1000	8150
1978	2100000	54	280	950	13889
1979	2900000	53	265	900	20648
1980	4000000	52	255	870	30166
1981	5000000	51	250	860	39216

Table A-7 CLEVELAND (CLE) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

CLEVELAND (CLE)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	72	72	864	1802	2666	6000
	AC	1	1	1563	1625	3188	
1973	PASS	108	108	1296	2702	3998	7000
	AC	1	1	1500	1600	3100	
1974	PASS	144	144	1728	3603	5331	8000
	AC	1	1	1450	1580	3030	
1975	PASS	252	252	3024	6305	9330	15000
	AC	2	2	2800	3120	5920	
1976	PASS	324	324	3888	8107	11995	18000
	AC	2	2	2650	3060	5710	
1977	PASS	468	468	5616	11710	17327	26000
	AC	3	3	3750	4500	8250	
1978	PASS	756	756	9073	18916	27989	41000
	AC	5	5	5938	7375	13312	
1979	PASS	1044	1044	12529	26123	38652	59000
	AC	8	8	9000	11600	20600	
1980	PASS	1440	1440	17281	36031	53313	81000
	AC	11	11	11962	15785	27747	
1981	PASS	1800	1800	21602	45039	66641	104000
	AC	15	15	16125	21450	37575	

Table A-8 DALLAS/FT. WORTH (DAL/DFR)

CAT IIIA WEATHER DISRUPTION FACTORS

FRACTION OF (NEW GEN) AC/PASS DELAYED =.000220

FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000140

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS

AVE PASS DELAY TIME (HRS PER PASS) = 2.00

AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17

AVE AC DELAY TIME (HRS PER AC) = 1.25

AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)

PASS TIME COST ($ PER HOUR PER PASS) = 6.00

SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	AVE DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	500000	60	325	1250	2564
1973	900000	59	320	1210	4767
1974	1300000	58	315	1170	7115
1975	1900000	57	310	1130	10753
1976	2600000	56	300	1070	15476
1977	3700000	55	290	1020	23197
1978	5000000	54	280	970	33069
1979	7000000	53	275	950	48027
1980	9300000	52	270	920	66239
1981	12300000	51	265	910	91010

Table A-8 DALLAS/FT. WORTH (DAL/DFR) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

DALLAS / FT.WORTH (DAL/DFR)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	110	70	1320	1752	3072	6000
	AC	1	1	1563	1625	3188	
1973	PASS	198	126	2376	3154	5530	10000
	AC	2	1	3025	1605	4630	
1974	PASS	286	182	3433	4555	7988	12000
	AC	2	1	2925	1585	4510	
1975	PASS	418	266	5017	6657	11674	19000
	AC	3	2	4237	3130	7367	
1976	PASS	572	364	6865	9110	15975	26000
	AC	4	3	5350	4605	9955	
1977	PASS	814	518	9770	12965	22734	36000
	AC	6	4	7650	6040	13690	
1978	PASS	1100	700	13202	17520	30722	48000
	AC	8	5	9700	7425	17125	
1979	PASS	1540	980	18483	24528	43010	66000
	AC	11	7	13062	10325	23387	
1980	PASS	2046	1302	24556	32587	57142	89000
	AC	15	10	17250	14600	31850	
1981	PASS	2706	1723	32477	43098	75576	118000
	AC	21	13	23887	18915	42802	

Table A-9 DENVER (DEN)

CAT IIIA WEATHER DISRUPTION FACTORS
FRACTION OF (NEW GEN) AC/PASS DELAYED =.000120
FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000100

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS
AVE PASS DELAY TIME (HRS PER PASS) = 2.00
AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17
AVE AC DELAY TIME (HRS PER AC) = 1.25
AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)
PASS TIME COST ($ PER HOUR PER PASS) = 6.00
SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	100000	60	325	1250	513
1973	200000	59	320	1200	1059
1974	300000	58	315	1160	1642
1975	600000	57	310	1120	3396
1976	1000000	56	300	1080	5952
1977	1600000	55	290	1040	10031
1978	2300000	54	280	1000	15212
1979	3300000	53	270	960	23061
1980	4500000	52	265	910	32656
1981	6200000	51	260	900	46757

Table A-9 DENVER (DEN) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

DENVER (DEN)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	12	10	144	250	394	4000
	AC	1	1	1563	1625	3188	
1973	PASS	24	20	288	501	788	4000
	AC	1	1	1500	1600	3100	
1974	PASS	36	30	432	751	1183	4000
	AC	1	1	1450	1580	3030	
1975	PASS	72	60	864	1502	2365	5000
	AC	1	1	1400	1560	2960	
1976	PASS	120	100	1439	2503	3942	7000
	AC	1	1	1350	1540	2890	
1977	PASS	192	160	2303	4005	6308	10000
	AC	2	1	2600	1520	4120	
1978	PASS	276	230	3310	5757	9067	15000
	AC	2	2	2500	3000	5500	
1979	PASS	396	330	4750	8260	13010	21000
	AC	3	3	3600	4440	8040	
1980	PASS	540	450	6477	11264	17741	28000
	AC	4	4	4550	5820	10370	
1981	PASS	744	620	8924	15519	24443	38000
	AC	6	5	6750	7250	14000	

Table A-10 DETROIT (DTW)

CAT IIIA WEATHER DISRUPTION FACTORS
FRACTION OF (NEW GEN) AC/PASS DELAYED =.000540
FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000560

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS
AVE PASS DELAY TIME (HRS PER PASS) = 2.00
AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17
AVE AC DELAY TIME (HRS PER AC) = 1.25
AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)
PASS TIME COST ($ PER HOUR PER PASS) = 6.00
SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	400000	60	325	1250	2051
1973	600000	59	320	1210	3178
1974	900000	58	315	1170	4926
1975	1300000	57	310	1130	7357
1976	1900000	56	305	1100	11124
1977	2700000	55	300	1170	16364
1978	3500000	54	295	1040	21971
1979	4600000	53	290	1000	29928
1980	6100000	52	280	960	41896
1981	8000000	51	275	950	57041

Table A-10 DETROIT (DTW) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

DETROIT (DTW)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	216	224	2592	5604	8196	15000
	AC	2	2	3125	3250	6375	
1973	PASS	324	336	3888	8406	12294	19000
	AC	2	2	3025	3210	6235	
1974	PASS	486	504	5833	12609	18442	28000
	AC	3	3	4387	4755	9142	
1975	PASS	702	728	8425	18213	26638	40000
	AC	4	5	5650	7825	13475	
1976	PASS	1026	1064	12313	26619	38932	58000
	AC	6	7	8250	10850	19100	
1977	PASS	1458	1512	17498	37827	55325	84000
	AC	9	10	13162	15850	29012	
1978	PASS	1890	1960	22682	49035	71718	107000
	AC	12	13	15600	19760	35360	
1979	PASS	2484	2576	29811	64446	94258	141000
	AC	17	17	21250	25500	46750	
1980	PASS	3294	3416	39532	85462	124994	188000
	AC	23	24	27600	35520	63120	
1981	PASS	4320	4480	51845	112081	163926	248000
	AC	31	32	36812	47200	84012	

TABLE A-11 HOUSTON (HOU/IAH)

CAT IIIA WEATHER DISRUPTION FACTORS

FRACTION OF (NEW GEN) AC/PASS DELAYED =.000820

FRACTION OF (NEW GEN) AC/PASS DIVERTED =.001300

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS

AVE PASS DELAY TIME (HRS PER PASS) = 2.00

AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17

AVE AC DELAY TIME (HRS PER AC) = 1.25

AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)

PASS TIME COST ($ PER HOUR PER PASS) = 6.00

SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	200000	60	325	1250	1026
1973	300000	59	310	1200	1640
1974	400000	58	300	1150	2299
1975	600000	57	295	1090	3568
1976	800000	56	290	1050	4926
1977	1200000	55	280	1000	7792
1978	1600000	54	275	950	10774
1979	2200000	53	260	900	15965
1980	2800000	52	250	850	21538
1981	3600000	51	245	830	28812

TABLE A-11 HOUSTON (HOU/IAH) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

HOUSTON (HOU/IAH)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	164	260	1968	6505	8473	13000
	AC	1	2	1563	3250	4813	
1973	PASS	246	390	2952	9757	12709	21000
	AC	2	3	3000	4800	7800	
1974	PASS	328	520	3936	13010	16946	25000
	AC	2	3	2875	4725	7600	
1975	PASS	492	780	5904	19514	25418	37000
	AC	3	5	4087	7725	11812	
1976	PASS	656	1040	7872	26019	33891	51000
	AC	5	7	6563	10675	17237	
1977	PASS	984	1560	11808	39029	50837	76000
	AC	7	11	8750	16500	25250	
1978	PASS	1312	2080	15744	52038	67782	99000
	AC	9	14	10687	20650	31337	
1979	PASS	1804	2860	21648	71552	93200	139000
	AC	14	21	15750	30450	46200	
1980	PASS	2296	3640	27552	91067	118619	178000
	AC	18	28	19125	39900	59025	
1981	PASS	2952	4680	35424	117086	152510	231000
	AC	24	38	24900	53770	78670	

TABLE A-12 KANSAS CITY (MKC/MCI)

CAT IIIA WEATHER DISRUPTION FACTORS
FRACTION OF (NEW GEN) AC/PASS DELAYED =.000420
FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000880

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS
AVE PASS DELAY TIME (HRS PER PASS) = 2.00
AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17
AVE AC DELAY TIME (HRS PER AC) = 1.25
AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)
PASS TIME COST ($ PER HOUR PER PASS) = 6.00
SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	100000	60	325	1250	513
1973	200000	59	315	1200	1076
1974	200000	58	305	1150	1131
1975	300000	57	295	1090	1784
1976	400000	56	290	1070	2463
1977	500000	55	285	1050	3190
1978	700000	54	280	1030	4630
1979	1000000	53	275	1020	6861
1980	1300000	52	265	910	9434
1981	1800000	51	260	900	13575

TABLE A-12 KANSAS CITY (MKC/MCI) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

KANSAS CITY (MKC/MCI)

YEAR	NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972 PASS	42	88	504	2202	2705	6000
AC	1	1	1563	1625	3188	
1973 PASS	84	176	1008	4403	5411	9000
AC	1	1	1500	1600	3100	
1974 PASS	84	176	1008	4403	5411	8000
AC	1	1	1438	1575	3012	
1975 PASS	126	264	1511	6605	8116	13000
AC	1	2	1362	3090	4452	
1976 PASS	168	352	2015	8807	10822	18000
AC	2	3	2675	4605	7280	
1977 PASS	210	440	2519	11009	13527	21000
AC	2	3	2625	4575	7200	
1978 PASS	294	616	3526	15412	18938	29000
AC	2	5	2575	7575	10150	
1979 PASS	420	880	5038	22017	27055	41000
AC	3	7	3825	10570	14395	
1980 PASS	546	1144	6549	28622	35171	53000
AC	4	9	4550	13095	17645	
1981 PASS	756	1584	9068	39631	48698	73000
AC	6	12	6750	17400	24150	

TABLE A-13 LOS ANGELES (LAX)

CAT IIIA WEATHER DISRUPTION FACTORS

FRACTION OF (NEW GEN) AC/PASS DELAYED =.000663

FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000234

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS

AVE PASS DELAY TIME (HRS PER PASS)	=	2.00
AVE PASS DIVERSION TIME (HRS PER PASS)	=	4.17
AVE AC DELAY TIME (HRS PER AC)	=	1.25
AVE AC DIVERSION TIME (HRS PER AC)	=	.50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)

PASS TIME COST ($ PER HOUR PER PASS)	=	6.00
SECONDARY AC DIVERSION COST ($ PER AC)	=	1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	2800000	60	325	1250	14359
1973	4400000	59	320	1230	23305
1974	6200000	58	315	1210	33935
1975	8200000	57	310	1190	46406
1976	10400000	56	310	1190	59908
1977	13300000	55	310	1190	78006
1978	16500000	54	305	1180	100182
1979	19400000	53	300	1170	122013
1980	22600000	52	300	1170	144872
1981	26100000	51	300	1170	170588

TABLE A-13 LOS ANGELES (LAX) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

LOS ANGELES (LAX)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	1856	655	22266	16385	38651	61000
	AC	10	4	15625	6500	22125	
1973	PASS	2916	1029	34990	25747	60737	95000
	AC	16	6	24600	9690	34290	
1974	PASS	4109	1450	49304	36280	85584	133000
	AC	23	8	34787	12840	47627	
1975	PASS	5434	1918	65208	47983	113192	177000
	AC	31	11	46112	17545	63657	
1976	PASS	6892	2432	82703	60857	143560	227000
	AC	40	15	59500	23925	83425	
1977	PASS	8814	3111	105765	77827	183591	291000
	AC	52	19	77350	30305	107655	
1978	PASS	10934	3859	131212	96552	227764	365000
	AC	67	24	98825	38160	136985	
1979	PASS	12856	4537	154274	113521	267795	432000
	AC	81	29	118462	45965	164427	
1980	PASS	14977	5286	179721	132247	311967	506000
	AC	96	34	140400	53890	194290	
1981	PASS	17296	6104	207554	152727	360281	590000
	AC	114	40	166725	63400	230125	

TABLE A-14 MIAMI (MIA)

CAT IIIA WEATHER DISRUPTION FACTORS

FRACTION OF (NEW GEN) AC/PASS DELAYED	=	.000160
FRACTION OF (NEW GEN) AC/PASS DIVERTED	=	.000120

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS

AVE PASS DELAY TIME (HRS PER PASS)	=	2.00
AVE PASS DIVERSION TIME (HRS PER PASS)	=	4.17
AVE AC DELAY TIME (HRS PER AC)	=	1.25
AVE AC DIVERSION TIME (HRS PER AC)	=	.50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)

PASS TIME COST ($ PER HOUR PER PASS)	=	6.00
SECONDARY AC DIVERSION COST ($ PER AC)	=	1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	1300000	60	325	1250	6666
1973	2000000	59	305	1230	11114
1974	2700000	58	290	1210	16052
1975	3600000	57	275	1190	22967
1976	4700000	56	275	1190	30519
1977	5800000	55	280	1185	37662
1978	7400000	54	280	1185	48942
1979	9300000	53	285	1180	61569
1980	11300000	52	285	1180	76248
1981	13700000	51	285	1180	94255

TABLE A-14 MIAMI (MIA) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

MIAMI (MIA)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	208	156	2496	3904	6399	11000
	AC	2	1	3125	1625	4750	
1973	PASS	320	240	3839	6006	9845	16000
	AC	2	2	3075	3230	6305	
1974	PASS	432	324	5183	8108	13291	21000
	AC	3	2	4537	3210	7747	
1975	PASS	576	432	6911	10810	17721	28000
	AC	4	3	5950	4785	10735	
1976	PASS	752	564	9023	14113	23136	37000
	AC	5	4	7438	6380	13817	
1977	PASS	928	696	11134	17416	28551	47000
	AC	7	5	10369	7962	18331	
1978	PASS	1184	888	14206	22221	36427	58000
	AC	8	6	11850	9555	21405	
1979	PASS	1488	1116	17854	27926	45780	73000
	AC	10	8	14750	12720	27470	
1980	PASS	1808	1356	21693	33932	55625	91000
	AC	13	10	19175	15900	35075	
1981	PASS	2192	1644	26300	41139	67439	110000
	AC	16	12	23600	19080	42680	

TABLE A-15 MINNEAPOLIS/ST. PAUL (MSP)

CAT IIIA WEATHER DISRUPTION FACTORS

FRACTION OF (NEW GEN) AC/PASS DELAYED	=	.000160
FRACTION OF (NEW GEN) AC/PASS DIVERTED	=	.000220

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS

AVE PASS DELAY TIME (HRS PER PASS)	=	2.00
AVE PASS DIVERSION TIME (HRS PER PASS)	=	4.17
AVE AC DELAY TIME (HRS PER AC)	=	1.25
AVE AC DIVERSION TIME (HRS PER AC)	=	.50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)

PASS TIME COST ($ PER HOUR PER PASS)	=	6.00
SECONDARY AC DIVERSION COST ($ PER AC)	=	1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	200000	60	325	1250	1026
1973	300000	59	320	1200	1589
1974	400000	58	315	1160	2189
1975	500000	57	310	1120	2830
1976	800000	56	310	1100	4608
1977	1200000	55	305	1080	7154
1978	1800000	54	300	1060	11111
1979	2500000	53	295	1020	15990
1980	3300000	52	290	1000	21883
1981	4200000	51	285	990	28896

TABLE A-15 MINNEAPOLIS/ST. PAUL (MSP) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

MINNEAPOLIS/ST.PAUL (MSP)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	32	44	384	1101	1485	5000
	AC	1	1	1563	1625	3188	
1973	PASS	48	66	576	1651	2228	5000
	AC	1	1	1500	1600	3100	
1974	PASS	64	88	769	2202	2970	6000
	AC	1	1	1450	1580	3030	
1975	PASS	80	110	961	2752	3713	7000
	AC	1	1	1400	1560	2960	
1976	PASS	128	176	1537	4403	5940	10000
	AC	1	2	1375	3100	4475	
1977	PASS	192	264	2306	6605	8911	15000
	AC	2	2	2700	3080	5780	
1978	PASS	288	396	3458	9908	13366	21000
	AC	2	3	2650	4590	7240	
1979	PASS	400	550	4803	13761	18564	28000
	AC	3	4	3825	6040	9865	
1980	PASS	528	726	6340	18164	24504	37000
	AC	4	5	5000	7500	12500	
1981	PASS	672	924	8069	23118	31187	48000
	AC	5	7	6188	10465	16652	

TABLE A-16 NEW ORLEANS (MSY)

CAT IIIA WEATHER DISRUPTION FACTORS

FRACTION OF (NEW GEN) AC/PASS DELAYED	=.000620
FRACTION OF (NEW GEN) AC/PASS DIVERTED	=.000700

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS

AVE PASS DELAY TIME (HRS PER PASS)	=	2.00
AVE PASS DIVERSION TIME (HRS PER PASS)	=	4.17
AVE AC DELAY TIME (HRS PER AC)	=	1.25
AVE AC DIVERSION TIME (HRS PER AC)	=	.50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)

PASS TIME COST ($ PER HOUR PER PASS)	=	6.00
SECONDARY AC DIVERSION COST ($ PER AC)	=	1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	100000	60	325	1250	513
1973	200000	59	315	1200	1076
1974	300000	58	305	1150	1696
1975	500000	57	300	1100	2924
1976	700000	56	295	1070	4237
1977	1200000	55	290	1040	7524
1978	1700000	54	280	1000	11243
1979	2300000	53	270	960	16073
1980	3200000	52	260	930	23669
1981	4300000	51	255	920	33064

TABLE A-16 NEW ORLEANS (MSY) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

NEW ORLEANS (MSY)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	62	70	744	1752	2496	6000
	AC	1	1	1563	1625	3188	
1973	PASS	124	140	1488	3503	4991	8000
	AC	1	1	1500	1600	3100	
1974	PASS	186	210	2232	5255	7487	14000
	AC	2	2	2875	3150	6025	
1975	PASS	310	350	3720	8758	12478	20000
	AC	2	3	2750	4650	7400	
1976	PASS	434	490	5208	12262	17469	26000
	AC	3	3	4012	4605	8617	
1977	PASS	744	840	8927	21020	29947	46000
	AC	5	6	6500	9120	15620	
1978	PASS	1054	1190	12647	29778	42426	63000
	AC	7	8	8750	12000	20750	
1979	PASS	1426	1610	17111	40288	57399	87000
	AC	10	12	12000	17760	29760	
1980	PASS	1984	2240	23806	56053	79860	122000
	AC	15	17	17437	24905	42342	
1981	PASS	2666	3010	31990	75322	107312	167000
	AC	21	24	24150	35040	59190	

TABLE A-17 NEWARK (EWR)

CAT IIIA WEATHER DISRUPTION FACTORS

FRACTION OF (NEW GEN) AC/PASS DELAYED =.000520

FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000200

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS

AVE PASS DELAY TIME (HRS PER PASS) = 2.00

AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17

AVE AC DELAY TIME (HRS PER AC) = 1.25

AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)

PASS TIME COST ($ PER HOUR PER PASS) = 6.00

SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	700000	60	325	1250	3590
1973	1200000	59	310	1180	6561
1974	1800000	58	295	1110	10520
1975	2400000	57	280	1050	15038
1976	3200000	56	275	1020	20779
1977	4100000	55	270	990	27609
1978	5000000	54	265	960	34941
1979	6100000	53	265	920	43432
1980	7200000	52	260	890	53254
1981	8300000	51	260	880	62594

TABLE A-17 NEWARK (EWR) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

NEWARK (EWR)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	364	140	4369	3502	7870	13000
	AC	2	1	3125	1625	4750	
1973	PASS	624	240	7489	6003	13492	23000
	AC	4	2	5900	3180	9080	
1974	PASS	936	360	11234	9005	20238	33000
	AC	6	3	8325	4665	12990	
1975	PASS	1248	480	14978	12006	26984	42000
	AC	8	3	10500	4575	15075	
1976	PASS	1664	640	19971	16008	35979	58000
	AC	11	5	14025	7550	21575	
1977	PASS	2132	820	25588	20510	46098	74000
	AC	15	6	18562	8970	27532	
1978	PASS	2600	1000	31205	25013	56218	89000
	AC	19	7	22800	10360	33160	
1979	PASS	3172	1220	38070	30516	68586	108000
	AC	23	9	26450	13140	39590	
1980	PASS	3745	1440	44935	36018	80953	128000
	AC	28	11	31150	15895	47045	
1981	PASS	4317	1660	51800	41521	93321	148000
	AC	33	13	36300	18720	55020	

TABLE A-18 NEW YORK KENNEDY (JFK)

CAT IIIA WEATHER DISRUPTION FACTORS

FRACTION OF (NEW GEN) AC/PASS DELAYED	=	.000880
FRACTION OF (NEW GEN) AC/PASS DIVERTED	=	.000540

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS

AVE PASS DELAY TIME (HRS PER PASS)	=	2.00
AVE PASS DIVERSION TIME (HRS PER PASS)	=	4.17
AVE AC DELAY TIME (HRS PER AC)	=	1.25
AVE AC DIVERSION TIME (HRS PER AC)	=	.50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)

PASS TIME COST ($ PER HOUR PER PASS)	=	6.00
SECONDARY AC DIVERSION COST ($ PER AC)	=	1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	2400000	60	325	1250	12308
1973	4000000	59	320	1230	21186
1974	5800000	58	315	1220	31746
1975	8000000	57	315	1210	44556
1976	10500000	56	310	1220	60484
1977	13300000	55	310	1240	78006
1978	16500000	54	305	1260	100182
1979	20000000	53	305	1280	123724
1980	25400000	52	300	1290	162821
1981	26200000	51	300	1300	171242

TABLE A-18 NEW YORK KENNEDY (JFK) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

NEW YORK KENNEDY (JFK)

YEAR	NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972 PASS	2112	1296	25344	32424	57767	86000
AC	11	7	17188	11375	28562	
1973 PASS	3520	2160	42239	54039	96279	145000
AC	19	12	29212	19380	48592	
1974 PASS	5104	3132	61247	78357	139604	211000
AC	28	18	42700	28980	71680	
1975 PASS	7040	4320	84478	108079	192557	293000
AC	40	25	60500	40125	100625	
1976 PASS	9240	5670	110878	141853	252731	388000
AC	54	33	82350	53130	135480	
1977 PASS	11704	7181	140445	179681	320126	497000
AC	69	43	106950	69660	176610	
1978 PASS	14520	8909	174237	222912	397149	627000
AC	89	55	140175	89650	229825	
1979 PASS	17600	10799	211196	270197	481393	766000
AC	109	67	174400	109880	284280	
1980 PASS	22352	13715	268219	343150	611369	988000
AC	144	88	232200	144760	376960	
1981 PASS	23056	14147	276667	353958	630625	1029000
AC	151	93	245375	153450	398825	

TABLE A-19 NEW YORK LAGUARDIA (LGA)

CAT IIIA WEATHER DISRUPTION FACTORS

FRACTION OF (NEW GEN) AC/PASS DELAYED =.000420

FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000200

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS

AVE PASS DELAY TIME (HRS PER PASS) = 2.00

AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17

AVE AC DELAY TIME (HRS PER AC) = 1.25

AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)

PASS TIME COST ($ PER HOUR PER PASS) = 6.00

SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	800000	60	260	1000	5128
1973	1200000	59	260	1000	7823
1974	1800000	58	260	1000	11936
1975	2500000	57	260	1000	16869
1976	3400000	56	260	1000	23352
1977	4500000	55	260	975	31469
1978	5700000	54	265	950	39832
1979	7600000	53	265	925	54112
1980	9800000	52	265	900	71118
1981	12500000	51	265	890	92490

TABLE A-19 NEW YORK LAGUARDIA (LGA) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

NEW YORK LAGUARDIA (LGA)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	336	160	4032	4003	8035	15000
	AC	3	2	3750	3000	6750	
1973	PASS	504	240	6048	6005	12053	20000
	AC	4	2	5000	3000	8000	
1974	PASS	756	360	9072	9007	18079	30000
	AC	6	3	7500	4500	12000	
1975	PASS	1050	500	12600	12510	25110	41000
	AC	8	4	10000	6000	16000	
1976	PASS	1428	680	17136	17014	34150	54000
	AC	10	5	12500	7500	20000	
1977	PASS	1890	900	22680	22518	45198	73000
	AC	14	7	17062	10412	27475	
1978	PASS	2394	1140	28728	28523	57251	89000
	AC	17	8	20187	11800	31987	
1979	PASS	3192	1520	38304	38030	76334	119000
	AC	23	11	26594	16087	42681	
1980	PASS	4116	1960	49392	49039	98431	154000
	AC	30	15	33750	21750	55500	
1981	PASS	5250	2500	63000	62550	125550	196000
	AC	39	19	43387	27455	70842	

TABLE A-20. PHILADELPHIA (PHL)

CAT IIIA WEATHER DISRUPTION FACTORS
FRACTION OF (NEW GEN) AC/PASS DELAYED =.000460
FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000700

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS
AVE PASS DELAY TIME (HRS PER PASS) = 2.00
AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17
AVE AC DELAY TIME (HRS PER AC) = 1.25
AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)
PASS TIME COST ($ PER HOUR PER PASS) = 6.00
SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	AVE DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	400000	60	325	1250	2051
1973	600000	59	320	1210	3178
1974	800000	58	315	1270	4379
1975	1100000	57	315	1140	6126
1976	1500000	56	310	1130	8641
1977	2200000	55	305	1130	13115
1978	3000000	54	300	1120	18519
1979	4000000	53	290	1120	26025
1980	5100000	52	285	1110	34413
1981	6500000	51	280	1110	45518

TABLE A-20 PHILADELPHIA (PHL) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

PHILADELPHIA (PHL)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	184	280	2208	7006	9215	14000
	AC	1	2	1563	3250	4813	
1973	PASS	276	420	3312	10509	13822	22000
	AC	2	3	3025	4815	7840	
1974	PASS	368	560	4417	14013	18429	30000
	AC	3	4	4762	6540	11302	
1975	PASS	506	770	6073	19267	25340	37000
	AC	3	5	4275	7850	12125	
1976	PASS	690	1050	8281	26274	34555	51000
	AC	4	7	5650	10955	16605	
1977	PASS	1012	1540	12146	38535	50680	76000
	AC	7	10	9887	15650	25537	
1978	PASS	1380	2100	16562	52547	69109	102000
	AC	9	13	12600	20280	32880	
1979	PASS	1840	2800	22083	70063	92146	139000
	AC	12	19	16800	29640	46440	
1980	PASS	2346	3570	28156	89330	117486	179000
	AC	16	25	22200	38875	61075	
1981	PASS	2990	4550	35885	113852	149737	229000
	AC	21	32	29137	49760	78897	

TABLE A-21 PITTSBURGH (PIT)

CAT IIIA WEATHER DISRUPTION FACTORS
FRACTION OF (NEW GEN) AC/PASS DELAYED =.000400
FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000400

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS
AVE PASS DELAY TIME (HRS PER PASS) = 2.00
AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17
AVE AC DELAY TIME (HRS PER AC) = 1.25
AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)
PASS TIME COST ($ PER HOUR PER PASS) = 6.00
SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	300000	60	325	1250	1538
1973	500000	59	310	1180	2734
1974	700000	58	295	1110	4091
1975	1000000	57	280	1050	6266
1976	1300000	56	280	1030	8291
1977	1800000	55	280	1010	11688
1978	2700000	54	280	990	17857
1979	3000000	53	280	970	20216
1980	4000000	52	280	950	27473
1981	5200000	51	280	940	36415

TABLE A-21 PITTSBURGH (PIT) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

PITTSBURGH (PIT)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	120	120	1440	3003	4443	8000
	AC	1	1	1563	1625	3188	
1973	PASS	200	200	2400	5004	7405	14000
	AC	2	2	2950	3180	6130	
1974	PASS	280	280	3360	7006	10366	16000
	AC	2	2	2775	3110	5885	
1975	PASS	400	400	4800	10009	14809	23000
	AC	3	3	3938	4575	8512	
1976	PASS	520	520	6240	13011	19252	30000
	AC	4	4	5150	6060	11210	
1977	PASS	720	720	8641	18016	26656	40000
	AC	5	5	6313	7525	13837	
1978	PASS	1080	1080	12961	27023	39984	62000
	AC	8	8	9900	11960	21860	
1979	PASS	1200	1200	14401	30026	44427	69000
	AC	9	9	10912	13365	24277	
1980	PASS	1600	1600	19201	40035	59236	89000
	AC	11	11	13062	16225	29287	
1981	PASS	2080	2080	24962	52045	77007	117000
	AC	15	15	17625	22050	39675	

TABLE A-22 ST. LOUIS (STL)

CAT IIIA WEATHER DISRUPTION FACTORS
FRACTION OF (NEW GEN) AC/PASS DELAYED =.000220
FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000320

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS
AVE PASS DELAY TIME (HRS PER PASS) = 2.00
AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17
AVE AC DELAY TIME (HRS PER AC) = 1.25
AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)
PASS TIME COST ($ PER HOUR PER PASS) = 6.00
SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	300000	60	325	1250	1538
1973	500000	59	325	1230	2608
1974	800000	58	325	1190	4244
1975	1100000	57	325	1160	5938
1976	1600000	56	315	1120	9070
1977	2200000	55	305	1080	13115
1978	2900000	54	295	1040	18205
1979	4000000	53	285	1000	26481
1980	5200000	52	275	950	36364
1981	6700000	51	270	940	48656

TABLE A-22 ST. LOUIS (STL) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

ST LOUIS (STL)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	66	96	792	2401	3193	6000
	AC	1	1	1563	1625	3188	
1973	PASS	110	160	1320	4002	5322	8000
	AC	1	1	1537	1615	3152	
1974	PASS	176	256	2112	6403	8515	13000
	AC	1	2	1487	3190	4677	
1975	PASS	242	352	2904	8804	11708	18000
	AC	2	2	2900	3160	6060	
1976	PASS	352	512	4224	12806	17030	25000
	AC	2	3	2800	4680	7480	
1977	PASS	484	704	5808	17608	23416	35000
	AC	3	5	4050	7700	11750	
1978	PASS	638	928	7656	23211	30867	45000
	AC	4	6	5200	9120	14320	
1979	PASS	880	1280	10559	32015	42575	64000
	AC	6	9	7500	13500	21000	
1980	PASS	1144	1663	13727	41620	55347	83000
	AC	8	12	9500	17700	27200	
1981	PASS	1474	2143	17687	53626	71313	108000
	AC	11	16	12925	23520	36445	

TABLE A-23 SAN FRANCISCO (SFO)

CAT IIIA WEATHER DISRUPTION FACTORS
FRACTION OF (NEW GEN) AC/PASS DELAYED =.000520
FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000200

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS
AVE PASS DELAY TIME (HRS PER PASS) = 2.00
AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17
AVE AC DELAY TIME (HRS PER AC) = 1.25
AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)
PASS TIME COST ($ PER HOUR PER PASS) = 6.00
SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	1500000	60	325	1250	7692
1973	2300000	59	315	1230	12376
1974	3300000	58	305	1210	18655
1975	4400000	57	300	1190	25731
1976	5700000	56	300	1190	33929
1977	7100000	55	300	1190	43030
1978	8800000	54	300	1190	54321
1979	10900000	53	295	1200	69715
1980	13100000	52	295	1200	85398
1981	15400000	51	295	1200	102360

TABLE A-23 SAN FRANCISCO (SFO) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

SAN FRANCISCO (SFO)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	780	300	9359	7505	16864	26000
	AC	4	2	6250	3250	9500	
1973	PASS	1196	460	14351	11508	25859	41000
	AC	7	3	10762	4845	15607	
1974	PASS	1716	660	20591	16511	37102	59000
	AC	10	4	15125	6420	21545	
1975	PASS	2288	880	27454	22015	49469	80000
	AC	14	6	20825	9570	30395	
1976	PASS	2964	1140	35566	28519	64085	102000
	AC	18	7	26775	11165	37940	
1977	PASS	3692	1420	44301	35524	79825	128000
	AC	23	9	34212	14355	48567	
1978	PASS	4576	1760	54908	44030	98938	160000
	AC	29	11	43137	17545	60682	
1979	PASS	5668	2180	68012	54537	122549	200000
	AC	37	14	55500	22400	77900	
1980	PASS	6812	2620	81739	65544	147283	244000
	AC	45	18	67500	28800	96300	
1981	PASS	8007	3080	96090	77052	173142	288000
	AC	54	21	81000	33600	114600	

TABLE A-24 OAKLAND (OAK)

CAT IIIA WEATHER DISRUPTION FACTORS
FRACTION OF (NEW GEN) AC/PASS DELAYED =.000340
FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000121

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS
AVE PASS DELAY TIME (HRS PER PASS) = 2.00
AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17
AVE AC DELAY TIME (HRS PER AC) = 1.25
AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)
PASS TIME COST ($ PER HOUR PER PASS) = 6.00
SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	200000	60	325	1250	1026
1973	300000	59	320	1210	1589
1974	400000	58	315	1180	2189
1975	500000	57	315	1150	2785
1976	700000	56	305	1110	4098
1977	1000000	55	300	1070	6061
1978	1300000	54	295	1030	8161
1979	1700000	53	285	980	11255
1980	2200000	52	275	940	15385
1981	2900000	51	270	930	21060

TABLE A-24, OAKLAND (OAK) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

OAKLAND (OAK)

YEAR	NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972 PASS	68	24	816	604	1420	5000
AC	1	1	1563	1625	3188	
1973 PASS	102	36	1224	906	2130	5000
AC	1	1	1512	1605	3117	
1974 PASS	136	48	1632	1208	2840	6000
AC	1	1	1475	1590	3065	
1975 PASS	170	60	2040	1510	3551	7000
AC	1	1	1438	1575	3012	
1976 PASS	238	85	2856	2114	4971	9000
AC	2	1	2775	1555	4330	
1977 PASS	340	121	4080	3021	7101	13000
AC	3	1	4012	1535	5547	
1978 PASS	442	157	5305	3927	9231	15000
AC	3	1	3862	1515	5377	
1979 PASS	578	205	6937	5135	12072	20000
AC	4	2	4900	2980	7880	
1980 PASS	748	266	8977	6645	15622	26000
AC	6	2	7050	2940	9990	
1981 PASS	986	350	11833	8760	20593	34000
AC	8	3	9300	4395	13695	

TABLE A-25 SEATTLE (SEA)

CAT IIIA WEATHER DISRUPTION FACTORS

FRACTION OF (NEW GEN) AC/PASS DELAYED =.001340

FRACTION OF (NEW GEN) AC/PASS DIVERTED =.002861

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS

AVE PASS DELAY TIME (HRS PER PASS) = 2.00

AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17

AVE AC DELAY TIME (HRS PER AC) = 1.25

AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)

PASS TIME COST ($ PER HOUR PER PASS) = 6.00

SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	200000	60	325	1225	1026
1973	300000	59	315	1230	1614
1974	600000	58	305	1235	3392
1975	800000	57	295	1240	4758
1976	1200000	56	290	1245	7389
1977	1500000	55	290	1250	9404
1978	2000000	54	285	1255	12995
1979	2600000	53	285	1260	17213
1980	3400000	52	275	1260	23776
1981	4700000	51	270	1260	34132

TABLE A-25 SEATTLE (SEA) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

SEATTLE (SEA)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	268	572	3216	14318	17534	25000
	AC	2	3	3063	4837	7900	
1973	PASS	402	858	4824	21476	26301	39000
	AC	3	5	4612	8075	12687	
1974	PASS	804	1717	9649	42953	52602	76000
	AC	5	10	7719	16175	23894	
1975	PASS	1072	2289	12865	57270	70135	104000
	AC	7	14	10850	22680	33530	
1976	PASS	1608	3433	19298	85905	105203	156000
	AC	10	22	15562	35695	51257	
1977	PASS	2010	4292	24122	107382	131504	196000
	AC	13	27	20313	43875	64187	
1978	PASS	2680	5722	32163	143176	175339	265000
	AC	18	38	28237	61845	90082	
1979	PASS	3484	7439	41812	186128	227940	347000
	AC	24	50	37800	81500	119300	
1980	PASS	4556	9728	54677	243399	298076	461000
	AC	32	69	50400	112470	162870	
1981	PASS	6299	13448	75583	336463	412046	644000
	AC	46	98	72450	159740	232190	

TABLE A-26 WASHINGTON DULLES (IAD)

CAT IIIA WEATHER DISRUPTION FACTORS

FRACTION OF (NEW GEN) AC/PASS DELAYED =.001220

FRACTION OF (NEW GEN) AC/PASS DIVERTED =.001040

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS

AVE PASS DELAY TIME (HRS PER PASS) = 2.00

AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17

AVE AC DELAY TIME (HRS PER AC) = 1.25

AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)

PASS TIME COST ($ PER HOUR PER PASS) = 6.00

SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	200000	60	325	1250	1026
1973	300000	59	315	1160	1614
1974	400000	58	305	1080	2261
1975	600000	57	295	1000	3568
1976	900000	56	295	1050	5448
1977	1200000	55	295	1100	7396
1978	1700000	54	295	1160	10672
1979	2400000	53	295	1220	15350
1980	3300000	52	295	1280	21512
1981	4200000	51	295	1300	27916

TABLE A-26 WASHINGTON DULLES (IAD) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

WASHINGTON DULLES (IAD)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	244	208	2928	5204	8132	15000
	AC	2	2	3125	3250	6375	
1973	PASS	366	312	4392	7806	12198	18000
	AC	2	2	2900	3160	6060	
1974	PASS	488	416	5856	10408	16264	25000
	AC	3	3	4050	4620	8670	
1975	PASS	732	624	8784	15612	24396	37000
	AC	5	4	6250	6000	12250	
1976	PASS	1098	936	13176	23418	36594	55000
	AC	7	6	9188	9150	18337	
1977	PASS	1464	1248	17568	31224	48792	75000
	AC	10	8	13750	12400	26150	
1978	PASS	2074	1768	24888	44235	69122	108000
	AC	14	12	20300	18960	39260	
1979	PASS	2928	2496	35136	62449	97584	152000
	AC	19	16	28975	25760	54735	
1980	PASS	4026	3432	48312	85867	134179	215000
	AC	27	23	43200	37720	80920	
1981	PASS	5124	4368	61488	109285	170773	277000
	AC	35	30	56875	49500	106375	

TABLE A-27 WASHINGTON NATIONAL (DCA)

CAT IIIA WEATHER DISRUPTION FACTORS

FRACTION OF (NEW GEN) AC/PASS DELAYED =.000340

FRACTION OF (NEW GEN) AC/PASS DIVERTED =.000220

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS

AVE PASS DELAY TIME (HRS PER PASS) = 2.00

AVE PASS DIVERSION TIME (HRS PER PASS) = 4.17

AVE AC DELAY TIME (HRS PER AC) = 1.25

AVE AC DIVERSION TIME (HRS PER AC) = .50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)

PASS TIME COST ($ PER HOUR PER PASS) = 6.00

SECONDARY AC DIVERSION COST ($ PER AC) = 1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	0	60	200	700	0
1973	0	59	200	700	0
1974	0	58	200	700	0
1975	0	57	200	700	0
1976	0	56	200	700	0
1977	0	55	200	700	0
1978	500000	54	200	700	4630
1979	1400000	53	200	700	13208
1980	2300000	52	200	700	22115
1981	3000000	51	200	700	29412

TABLE A-27 WASHINGTON NATIONAL (DCA) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

WASHINGTON NATIONAL (DCA)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	0	0	0	0	0	0
	AC	0	0	0	0	0	
1973	PASS	0	0	0	0	0	0
	AC	0	0	0	0	0	
1974	PASS	0	0	0	0	0	0
	AC	0	0	0	0	0	
1975	PASS	0	0	0	0	0	0
	AC	0	0	0	0	0	
1976	PASS	0	0	0	0	0	0
	AC	0	0	0	0	0	
1977	PASS	0	0	0	0	0	0
	AC	0	0	0	0	0	
1978	PASS	170	110	2040	2752	4792	9000
	AC	2	2	1750	2700	4450	
1979	PASS	476	308	5712	7706	13418	22000
	AC	5	3	4375	4050	8425	
1980	PASS	782	506	9384	12660	22044	36000
	AC	8	5	7000	6750	13750	
1981	PASS	1020	660	12240	16513	28753	47000
	AC	10	7	8750	9450	18200	

TABLE A-28 BALTIMORE (BAL)

CAT IIIA WEATHER DISRUPTION FACTORS

FRACTION OF (NEW GEN) AC/PASS DELAYED	=.000660
FRACTION OF (NEW GEN) AC/PASS DIVERTED	=.001400

PRIMARY AND SECONDARY WEATHER DISRUPTION EFFECTS

AVE PASS DELAY TIME (HRS PER PASS)	=	2.00
AVE PASS DIVERSION TIME (HRS PER PASS)	=	4.17
AVE AC DELAY TIME (HRS PER AC)	=	1.25
AVE AC DIVERSION TIME (HRS PER AC)	=	.50

ADDITIONAL DATA (ALL COST DATA IN 1970 DOLLARS)

PASS TIME COST ($ PER HOUR PER PASS)	=	6.00
SECONDARY AC DIVERSION COST ($ PER AC)	=	1000.00

ANNUAL DATA (ALL COSTS IN 1970 DOLLARS)

YEAR	TOTAL ENPL PASS NEW GEN AC	PERCNT LOAD FACTOR	WEIGHTED AVE SEATS PER AC	DOC PER AC	TOTAL DEPARTURES NEW GEN AC
1972	200000	60	325	1250	1026
1973	300000	59	305	1130	1667
1974	500000	58	285	1010	3025
1975	800000	57	265	890	5296
1976	1200000	56	265	960	8086
1977	1700000	55	265	1030	11664
1978	2400000	54	265	1110	16771
1979	3200000	53	270	1190	22362
1980	4100000	52	270	1270	29202
1981	5200000	51	270	1300	37763

TABLE A-28 BALTIMORE (BAL) (Continued)

ESTIMATED COSTS OF WEATHER CAUSED FLIGHT DISRUPTIONS
PREVENTABLE WITH CAT IIIA ILS, NEW GENERATION AIRCRAFT
(ALL COSTS IN 1970 DOLLARS)

BALTIMORE (BAL)

YEAR		NUMBER DELAYED	NUMBER DIVERTED	COST DELAYED	COST DIVERTED	SUBTOTAL COST	TOTAL COST
1972	PASS	132	280	1584	7005	8589	13000
	AC	1	2	1563	3250	4813	
1973	PASS	198	420	2376	10507	12883	20000
	AC	2	3	2825	4695	7520	
1974	PASS	330	700	3960	17512	21472	32000
	AC	2	5	2525	7525	10050	
1975	PASS	528	1120	6335	28019	34354	50000
	AC	4	8	4450	11560	16010	
1976	PASS	792	1680	9503	42028	51532	76000
	AC	6	12	7200	17760	24960	
1977	PASS	1122	2380	13463	59540	73003	109000
	AC	8	17	10300	25755	36055	
1978	PASS	1584	3360	19006	84057	103063	157000
	AC	12	24	16650	37320	53970	
1979	PASS	2112	4479	25342	112076	137418	211000
	AC	15	32	22312	51040	73352	
1980	PASS	2706	5739	32469	143597	176067	275000
	AC	20	41	31750	67035	98785	
1981	PASS	3432	7279	41181	182123	223304	351000
	AC	25	53	40625	87450	128075	

APPENDIX B

COMPUTER PROGRAM: DYNAMIC PROGRAMMING CAPITAL INVESTMENT DECISION ANALYSIS

The computer program is listed at the end of this section as Table B-1. The input data requirements are described in part IV of this report. Any method of efficiently entering data into the appropriate arrays (matrices) may be used. However, for those inexperienced with writing computer programs, a method is described to read in data cards. This method is applicable to the program listed at the end of this section.

Before entering data, the following array dimensioning requirements must be met. These are accomplished by adjusting the appropriate array subscripts in the DIMENSION statement (first statement in this computer program).

Let: The array subscripts are equal to:

NI = Number of alternatives

NJ = Number of time periods

NJ2 = Number of time periods multiplied by two

8 = eight

The minimum values of the array subscripts in the DIMENSION statement must be:

```
DIMENSION  INSTART (NI), IEND(NI),
           OPERCST(NI,NJ), PENALTY(NI,NJ),
           CHGCOST(NI,NI), LIFECR(NI),
           PATHCST(NI,NJ), LINKLAB(NI,NJ),
           CAPINV(NJ2), CRCOST(NJ2),
           IOPTLAB(NJ2), CRFACT(NI),
           RITLE(B), ID(NI,8)
```

The computer program listed is set for twenty alternatives (NI=20) and twenty time periods (NJ=20). This is applicable to any dynamic programming problem involving less than twenty time periods. For greatest programming efficiency, the subscripts should be set to their minimum acceptable value. (Note: The above DIMENSION statement requires a character punch in column six of the computer card as shown in the listing.)

For the suggested data input method, the following data cards must be used (please refer to the data card listing as shown in Figure B-1.

Card 1: This is the title card for the problem. Any alphnumeric characters may be punched in any columm. This card may be left blank, but it must be present. FORMAT (8A10).

Card 2: Number of alternatives (NI). Punch the interger value of NI in the first ten columns, (1-10), right adjusted (see listing). FORMAT (I10).

Card 3: Number of time periods (NJ). Punch the integer value of NJ in the first ten columns, (1-10), right adjusted (see listing). FORMAT (I10).

Card 4: Discount rate (DISTRATE). Punch the decimal fraction value of DISRATE in the first ten columns (1-10); the decimal point is in column 6 (see listing). FORMAT (F 10.4).

Card 5: Rate of inflation (RATEINF). Punch the decimal fraction value of RATEINF in the first ten columns (1-10); The decimal point is in columns (see listing). FORMAT F 10.4.

Card 6: This card contains the following information for alternative I: The alternative identification number (i), the first feasible time period of use (ISTART (I)), the last feasible time period of use (IEND (I), and the capital recovery life (LIFECR (I)). The interger values are punched, right adjusted, as follows: I in the first ten columns (1-10), INSTART (I) in the second ten columns (11-20), IEND (I) in the third ten columns (21-30) and LIFECR(I) in the fourth ten columns (31-40).

Card 7: This card describes alternative I. Any alphanumeric characters may be punched in any column. This card may be left bland, but it must be present. FORMAT(8A10).

Card (Set) 8: Penalty costs of alternative I for all periods J (PENALTY (I,J), J=1, NJ). Starting with the first time period, five penalty costs are punched on each card in order of increasing time period J until all PENALTY (I,J) values of PENALTY (I,J) are punched, right adjusted, in sucessive sets of fifteen columns. The first five columns are not read and any characters may be punched. The first PENALTY (I,J) value is punched in the next fifteen columns (21-35), and so on until five PENALTY (I,J) values are on the card. The decimal points are in columns 20, 35, 50, 65 and 80. This procedure is repeated until all PENALTY (I,J) values are punched. FORMAT (5X, 5F15.0).

Card (Set) 9: Operating costs of alternative I for all time periods J (OPERCST (I,J), J=1, NJ). The same procedure is used for the OPERCST (I,J) data values as is described above for the PENALTY (I,J).

Card 6, Card 7, Card (Set) 8 and Card (Set) 9 is repeated for each alternative until the data values for each and all alternatives are punched.

Card 10: This card describes the number of cards (NCARDS) in the next card set, Care (Set) 11. The intger value of NCARDS is punched, right adjusted, in the first ten columns (1-10). FORMAT (I10).

Card (Set) 11: This set contains information describing NCARDS number of capital investment costs (CHGCOST(K,I)). The integer value of K is punched, right adjusted, in the next ten columns (11-20). The real (non-integer) decimal value of CHGCOST (K,I) is punched right adjusted, in the next thirty columns; the decimal point is in column 50. This procedure is repeated until all NCARDS values of CHGCOST (K,I) are punched. FORMAT (2I10, F30.0).

The computer reads this data, performs the dynamic programming analysis, and prints out the results. The computer then attempts to read a new set of similar data for the next problem. If no such data cards are available, the computer program stops.

Note that in addition to the input arrays described in part IV of this report, two additional arrays are required. These are:

TITLE (8) = Alphanumeric title of the problem analyzed

or

= blank characters

ID (I, 8) = Alphanumeric description of alternative I

or

= blank characters

The computer prints the follwoing sets of information:

(1) A list of the capital recovery and inflation factors used in the calculations.

(2) A list of the input data adjusted for inflation.

(3) A trace of the solution sequences that represent the sub-solutions for each time period.

(4) A presentation of the final solution sequence for each alternative.

FIGURE B-1 **DATA CARDS**

COLUMN NUMBER

		6	10	20	30	35	40	50	65	80
CARD 1		ILS	CAT IIIA	PROGRAM	ANALYSIS			ATLANTA (ATL)		
CARD 2			2							
CARD 3			12							
CARD 4		.10								
CARD 5		.025								
CARD 6			1	1	12		15			
CARD 7			ALTERNATE	1	ATLANTA (ATL)		NO	ILS CAT IIIA		
CARD	1 PC		0.		0.			55000.	76000.	106000.
(Set) 8	1 PC		155000.		205000.			294000.	401000.	531000.
	1 PC		686000.		875000.					
CARD	1 OC		0.		0.			0.	0.	0.
(Set) 9	1 OC		0.		0.			0.	0.	0.
	1 OC		0.		0.					
CARD 6			2	3	12		15			
CARD 7			ALTERNATE	2	ATLANTA (ATL)			ILS CAT IIIA		
CARD	2 PC		0.		0.			0.	0.	0.
(Set) 8	2 PC		0.		0.			0.	0.	0.
	2 PC		0.		0.					
CARD	2 OC		0.		0.			50000.	50000.	50000.
(Set) 9	2 OC		50000.		50000.			50000.	50000.	50000.
	2 OC		50000.		50000.					
CARD 10			1							
CARD 11			1	2				500000.		

TABLE B-1 COMPUTER PROGRAM

```
C     INPUT SYSTEM DATA ******************************************************
    1 CONTINUE
C     READ IN ALPHANUMERIC TITLE
      READ 4, (TITLE(K),K=1,8)
    4 FORMAT( 8A10 )
C     CHECK FOR END OF PROGRAM (NO MORE DATA)
C     NOTE. EOF (END OF FILE) IS VALID FOR CDC 6000 COMPUTERS ONLY        CDC
      IF (EOF,5) 1000,5                                                   CDC
    5 CONTINUE
C     READ IN  NO.OFALTERNATES,  NO. OF TIME PERIODS,
C              DISCOUNT RATE,  RATE OF INFLATION
      READ 6, NI, NJ, DISRATE, RATEINF
    6 FORMAT( I10,/, I10,/, F10.4,/, F10.4 )
C     INITIALIZE INPUT DATA ARRAYS
      DO 8 I=1,NI
         ISTART(I)= 0
         IEND(I)=   0
         LIFECR(I)= 0
         DO 7 J=1,NJ
            PENALTY(I,J)= 0.0
            OPERCST(I,J)= 0.0
    7    CONTINUE
    8 CONTINUE
      DO 9 K=1,NI
      DO 9 I=1,NI
         CHGCOST(K,I)= -1.0
         IF( K.EQ.I ) CHGCOST(K,I)= 0.0
    9 CONTINUE
      DO 10 KK=1,8
         TITLE(KK)= 1H
         DO 10 K=1,NI
            ID(K,KK)= 1H
   10 CONTINUE
C     READ IN DATA FOR EACH AND ALL ALTERNATES
      DO 15 L=1,NI
C     READ IN  ALTERNATE ID NO. (I)  AND
C              EARLIEST STARTING TIME, LATEST USE TIME,
C              CAPITAL RECOVERY LIFE FOR  ALTERNATE I
         READ 11, I, ISTART(I), IEND(I), LIFECR(I)
   11    FORMAT( 4I10 )
C        READ IN ALPHANUMERIC DESCRIPTION FOR ALTERNATE I
         READ 12, (ID(I,J),J=1,8)
   12    FORMAT( 8A10 )
C        READ IN ALL PENALTY AND OPERATING COSTS FOR ALTERNATE I
         READ 13, (PENALTY(I,J),J=1,NJ)
         READ 13, (OPERCST(I,J),J=1,NJ)
   13    FORMAT( 5X, 5F15.0 )
   15 CONTINUE
C     READ IN FEASIBLE CHANGEOVER COSTS
      READ 17, NCARDS
   17 FORMAT( I10 )
      IF( NCARDS .EQ. 0.) GO TO 20
      READ 18,(K, I, CHGCOST(K,I) , L=1,NCARDS)
   18 FORMAT( 2I10, F30.0 )
   20 CONTINUE
```

TABLE B-1 COMPUTER PROGRAM (Continued)

```
C     DYNAMIC PROGRAMMING . MINIMUM COST- PRESENT WORTH  SOLUTION***********
C     INITIALIZE  SYSTEM PARAMETERS
   50 CONTINUE
C     SET MIN COST TEST CONSTANT.  TESTNUM= VERY LARGE POSITIVE VALUE
      TESTNUM= 10.0**300
      DO 53 J=1,NJ
         IOPTLAB(J)= 0
         DO 53 I=1,NI
            PATHCST(I,J)= 0.0
            LINKLAB(I,J)= 0
   53 CONTINUE
      PRINT 55
   55 FORMAT( 1H1 )

C     SET SYSTEM PARAMETERS FOR FIRST TIME PERIOD (J=1)
C     NOTE. ALTERNATE ONE(I=1) IS INITIAL SYSTEM STATE
C     ALT ONE(I=1) MUST BE OPERATING AT START OF STUDY PERIOD
      ISTART(1)= 1
      MAXCRL= 0
      J= 1
      K= 1
C     DETERMINE DISCOUNT AND INFLATION FACTORS AND PRINT FACTORS
      DISFACT=1./((1.+DISRATE)**J)
      FACTINF=  1.0
      PRINT 56, J, DISFACT, J, FACTINF
   56 FORMAT(1H0, 2X,*DISCOUNT FACTOR *,  I3, *=*, F10.7,
     1            10X, *INFLATION FACTOR *, I3, *=*, F10.7 )
C     DETERMINE CUMMULATIVE DISCOUNT FACTOR
         NT= NJ
         CUMDISF= (((1.+DISRATE)**NT)-1.)/(DISRATE*((1.+DISRATE)**NT))
         PRINT 66,J,CUMDISF
      DO 59 I=1,NI
C        DETERMINE CAPITAL RECOVERY FACTOR FOR ALTERNATE(I)
         CRFACT(I)= (DISRATE/(((1.+DISRATE)**LIFECR(I))-1.) )+DISRATE
         PRINT 57, I, CRFACT(I)
   57    FORMAT(1H0, 2X, *CAPITAL RECOVERY FACTOR FOR ALTERNATE*, I3,
     1          * =*, F10.7 )
C        CHECK CHANGEOVER FEASIBILTY
         IF( ISTART(I).GT.1 ) GO TO 59
         IF( CHGCOST(K,I).EQ.-1.0 )GO TO 59
C        DETERMINE PERIODIC CAPITAL RECOVERY COST (END OF PERIOD)
         CRTEMP= CHGCOST(K,I)* CRFACT(I)
C        DETERMINE PRESENT WORTH COST AND SEQUENCE LABEL
         PATHCST(I,J)= CUMDISF*CRTEMP
     1                 +((OPERCST(I,J)+PENALTY(I,J))*DISFACT)
         LINKLAB(I,J)= 1
   59 CONTINUE
```

TABLE B-1 COMPUTER PROGRAM (Continued)

```
C     PERFORM DYNAMIC PATH ANALYSIS FOR ...
C        TIME PERIOD(2) THRU TIME PERIOD(NJ), J=2,NJ
C        ALTERNATE(1) THRU ALTERNATE(NI), I= 1,N1
      DO 90 J=2,NJ
C        DETERMINE DISCOUNT AND INFLATION FACTORS AND PRINT FACTORS
         DISFCT1= DISFACT
         DISFACT=1.0/((1.0+DISRATE)**J )
         FACTINF= (1.0+RATEINF)**(J-1)
         PRINT 56, J, DISFACT, J, FACTINF
C        DETERMINE CUMMULATIVE DISCOUNT FACTOR
            NT= NJ-J+1
            CUMDISF= (((1.+DISRATE)**NT)-1.)/(DISRATE*((1.+DISRATE)
     1                **NT))
            PRINT 66,J,CUMDISF
   66       FORMAT(1H0,2X,*CUMMALATIVE DISCOUNT FACTOR*,I3,*=*,F10.7)
      DO 80 I=1,NI
C        ADJUST OPERATING AND PENALTY COSTS FOR INFLATION
         OPERCST(I,J)= OPERCST(I,J) * FACTINF
         PENALTY(I,J)= PENALTY(I,J) * FACTINF
C        CHECK TIME LIMITATIONS ON ALTERNATE(I)
         IF (J.LT.ISTART(I)) GO TO 80
         IF (J.GT.IEND(I)) GO TO 80
C        INITIALIZE OPTIMUM COST SEARCH
          PATHCST( I,J ) = TESTNUM
         SEARCH FOR OPTIMUM(MIN) COST  (K TO I) FROM OPT. ALTERNATE(K)
C           AT TIME(J-1) TO ALTERNATE(I) AT TIME(J)
         DO 70 K=1,NI
C           CHECK LINK FEASIBILITIES FOR CHANGE FROM ALT K TO ALT I
C           AT TIME(J)
            IF ( CHGCOST(K,I).EQ.-1.0 ) GO TO 70
            IF ( J.LE.ISTART(K) ) GO TO 70
            IF ( J.GT. (IEND(K)+1) ) GO TO 70
            IF ( J.EQ.ISTART(I) .AND. K.EQ.I ) GO TO 70
C           ADJUST CHANGEOVER COST FOR INFLATION
C           DETERMIN PERIODIC CAPITAL RECOVERY COSTS
            CRTEMP= CHGCOST(K,I)* FACTINF * CRFACT(I)
C           DETERMINE PRESENT WORTH CUMM. COST OF (I TO K ) AT TIME(J)
            PWCOST= PATHCST(K,J-1) + DISFCT1*CUMDISF*CRTEMP
     1              +DISFACT*(OPERCST(I,J)+PENALTY(I,J))
C           IF LINK(K,I) COST IS MINIMUM, ADJUST SYSTEM PARAMETERS
            IF ( PWCOST.GT.PATHCST(I,J) ) GO TO 70
            PATHCST(I,J)= PWCOST
            LINKLAB(I,J)= K
   70    CONTINUE
   80 CONTINUE
   90 CONTINUE
```

```
C     PRINT INPUT DATA (SYSTEM DESCRIPTION)*********************************
      PRINT DESCRIPTION OF SYSTEM ALTERNATES
      PRINT 27,(TITLE(K),K=1,8), ((ID(I,L),L=1,8),I=1,NI)
   27 FORMAT (1H1 , 8A10,////(1H0,8A10) )
   29 PRINT 30, NI,NJ,DISRATE,RATEINF
   30 FORMAT( 1H1, 5X, *SYSTEM DESCRIPTION (INPUT DATA)*,////,
     1             6X,*NUMBER OF ALTERNATIVES=*, I4,//,
     1             6X,*NUMBER OF TIME PERIODS=*, I4,//,
     1             6X,*DISCOUNT (INTEREST) RATE=*, F6.4, //,
     1             6X,*INFLATION RATE=*, F6.4, ////  )
      PRINT 31, ( I, ISTART(I), IEND(I), LIFECR(I), I=1,NI )
   31 FORMAT( 1HS, 19X, *TIME PERIOD*, 6X, *CAPITAL*, /,
     1             23X, *LIMITS*, 7X, *RECOVERY*, /,
     1              6X, *ALTERNATE*,5X,*START   END*, 7X, *LIFE*, //,
     1              ( 6X, I5, 9X, I3, 4X, I3, 8X, I3  , // ) )
C     PRINT CHANGEOVER COST DATA IN GROUPS OF NP ALTERNATES PER PAGE
      NP= 10
      NPMAX= NI
      DO 39 NP1=1,NPMAX,NP
         NP2= NP1+NP-1
         IF( NP2.GT.NPMAX ) NP2= NPMAX
         PRINT 32, (I ,I=NP1,NP2 )
   32    FORMAT(1H1,*INTER-ALTERNATE INITIAL CHANGEOVER COST*,
     1            * (UNDISCOUNTED,UNINFLATED,UNRECOVERED)  ..OR..*,
     1            /,18X, *CHANGEOVER INFEASIBILITY INDICATOR(-1)*,//,
     1            1H0, *FROM*, /,  1X,*ALTERNATE*, 40X, *TO ALTERNATE*,/
     1            2X, *NO.*, /,
     1            3X, *↓*, 2X, (10(10X,I3))// )
         DO 36 K=1,NI
            PRINT 34, K, ( CHGCOST(K,I), I=NP1,NP2 )
   34       FORMAT( 1H0, I3, 2X, (10(1X,F12.0)) )
   36    CONTINUE
   39 CONTINUE
C     PRINT OPERATING AND PENALTY COSTS IN GROUPS OF
C      NP TIME PERIODS PER PAGE
      NP= 10
      NPMAX= NJ
      DO 49 NP1=1,NPMAX,NP
         NP2= NP1+NP-1
         IF( NP2.GT.NPMAX ) NP2=NPMAX
         PRINT 42, ( J, J=NP1,NP2 )
   42    FORMAT(1H1,*ALTERNATE  OPERATING COST (OC) PER TIME PERIOD*,
     1              1X, *(UNDISCOUNTED,INFLATED)*, /,
     1              1X, 13X, *PENALTY COST (PC) PER TIME PERIOD*,
     1              1X, *(UNDISCOUNTED,INFLATED)*, //,
     1              1H0,*ALTERNATE*, 40X, *TIME PERIOD*,/,
     1              1X,*NO.*,/,
     1              2X, *↓*, 3X,  (10(10X,I3))// )
         DO 46 I=1,NI
            PRINT 44, I, ( OPERCST(I,J), J=NP1,NP2 )
   44       FORMAT( 1H0, I2, 1X, *OC*, (10(1X,F12.0)) )
            PRINT 45,  ( PENALTY(I,J), J=NP1,NP2 )
   45       FORMAT( 1HS, 3X, *PC*, (10(1X,F12.0)) )
   46    CONTINUE
   49 CONTINUE
```

```
C     PRINT SUB-SOLUTION RESULTS ********************************************

C     PRINT FEASIBLE SUB-SOLUTION RESULTS
C     PRINT RESULTS IN GROUPS OF JPRINT TIME PERIODS PER PAGE
C     NOTE.  JPRINT.LE.5
      JPRINT= 5
      J1=1
      J2= JPRINT
      IF( J2.GT.NJ ) J2=NJ
  110 PRINT 111, ( J,J=J1,J2)
  111 FORMAT( 1H1, 5X, *SUBSOLUTION RESULTS...*,
     1            3X,*(DISCOUNTED CUMMULATIVE ALTERNATE COST)*,
     1            1X, *FROM*,
     1            * (OPTIMUM ALTERNATE IN PREVIOUS TIME PERIOD)*,
     1            ////, 2X, *ALTERNATE*, 40X, *TIME PERIOD*, //,
     1             4X, ( 5(22X,I3) ) )
      DO 115  I= 1,NI
C        CHECK FOR ELIMINATED ALTERNATE    (SENSITIVITY ANALYSIS)
         IF( ISTART(I).GT.NJ ) GO TO 115
         PRINT 114, I,(PATHCST (I,J),LINKLAB(I,J), J=J1,J2)
  114    FORMAT( 1H0, I4, 3X, ( 5(3X,F14.0,1X,*FROM*,I3 ) )  )
  115 CONTINUE
C     CHECK AND/OR UPDATE  PRINT CONTROLS
      IF( J2.EQ.NJ ) GO TO 120
      J1= J1+JPRINT
      J2= J2+JPRINT
      IF( J2.GT.NJ ) J2=NJ
      GO TO  110
```

TABLE B-1 COMPUTER PROGRAM (Continued)

```
C     PRINT FINAL SOLUTION SEQUENCES ****************************************
  120 CONTINUE
C     INITIALIZE CONSTANTS AND VARIABLES
      OPTPWC= TESTNUM
      IOPTALT= 999
      NJMAX= 2*NJ
C     DETERMINE AND PRINT OPTIMUM(FINAL) SEQUENCE FOR ALTERNATE I
      DO 149 I=1,NI
      PRINT 122, I,  (ID(I,L),L=1,8)
  122    FORMAT(1H1,*FINAL OPTIMUM SEQUENCE FOR....*,
     1                 *ALTERNATE*  I3, //,  1X, 8A10, //,
     1                 24X, *BEGINNING*, 11X, *END*,4X,*OF*,4X,*PERIOD*,
     1                 4X, *UNDISCOUNTED*, 4X, *COSTS*,
     1                 8X, *END OF PERIOD DISCOUNTED COSTS*, /,
     1                 24X, *OF PERIOD*, /
     1                 2X, *TIME*, 4X, *OPTIMUM*, 4X, *UNDISCOUNTED*, 3X,
     1                 *      CAPITAL*, 6X, *OPERATING*, 8X,*PENALTY*,
     1                 7X, *TOTAL*, 10X, *TOTAL*, 8X, *CUMMULATIVE*, /,
     1                 1X, *PERIOD*, 2X, *ALTERNATE*, 1X, *CAPITAL OUTLAY*
     1                 , 3X, *RECOVERY COST*, 11X, *COST*,11X, *COST*,
     1                 4X, *PERIOD COST*, 4X, *PERIOD COST*, 11X, *COST*,/)
         CLEAR STORAGE SPACE
         DO 124 J=1,NJMAX
            CAPINV(J)= 0.0
            CRCOST(J)= 0.0
  124    CONTINUE
         COSTOT= 0.0
         CUMCR = 0.0
         CUMOC = 0.0
         CUMPEN= 0.0
         CUMTOT= 0.0
         CPWCR  = 0.0
         CPWOC  = 0.0
         CPWPEN = 0.0
         CPWTOT= 0.0
C        TRACE AND STORE SOLUTION SEQUENCE LABELS(ALT I FINAL SEQUENCE)
         IOPTLAB(NJ)= I
         K2= IOPTLAB(NJ)
         DO 126 JJ=2,NJ
            J= NJ+1-JJ
            IOPTLAB(J)= LINKLAB(K2,J+1)
            K2= IOPTLAB(J)
  126    CONTINUE
```

TABLE B-1 COMPUTER PROGRAM (Continued)

```
C           FOLLOW SEQUENCE LABEL TRACE
            K1=1
            IF( J.EQ.1 ) GO TO 131
            K1= IOPTLAB(J-1)
  131       K2= IOPTLAB(J)
C           CHECK FOR NO CAPITAL INVESTMENT AT TIME J
            IF( K1.EQ.K2 ) GO TO 137
C           DETERMINE CAPITAL INVESTMENT AT TIME J   CAPINV(J)
            CAPINV(J)= CHGCOST(K1,K2)
            IF( J.EQ.1 ) GO TO 133
C           ADJUST FOR INFLATION
            CAPINV(J)= CAPINV(J)*((1.0+RATEINF)**(J-1))
C           DETERMINE CAPITAL RECOVERY COST OF CAPINV(J)
  133       CRTEMP =  CAPINV(J)*CRFACT(K2)
C           DETERMINE PERIODIC CAPITAL RECOVERY COSTS
            NJJ= J+LIFECR(K2)-1
C           CHECK FOR STORAGE ARRAY OVERFLOW
            IF( NJJ.GT.NJMAX) NJJ= NJMAX
            DO 135 JJ=J,NJJ
               CRCOST(JJ)= CRCOST(JJ)+CRTEMP
  135       CONTINUE
            DETERMINE PERIODIC TOTAL COST
  137       COSTOT = OPERCST(K2,J)+PENALTY(K2,J)+CRCOST(J)
C           DETERMINE CUMMULATIVE COSTS
            CUMTOT= CUMTOT+COSTOT
            CUMCR= CUMCR+CRCOST(J)
            CUMOC= CUMOC+OPERCST(K2,J)
            CUMPEN= CUMPEN+PENALTY(K2,J)
C           DETERMINE DISCOUNTED(PRESENT WORTH)COSTS
            DISFACT = 1.0/((1.0+DISRATE)**J)
            PWCOST= COSTOT * DISFACT
            CPWTOT= CPWTOT+PWCOST
            CPWCR = CPWCR +( CRCOST(J) * DISFACT )
            CPWOC = CPWOC +( OPERCST(K2,J) * DISFACT )
            CPWPEN= CPWPEN+ (PENALTY(K2,J) * DISFACT )
C           CHECK FOR PREMATURE END OF LIFE AND PROVIDE -0.0 SIGNAL
            IF( J.GT.IEND(I) .AND. CAPINV(J).EQ.0.0 ) CAPINV(J)=-0.0
C           PRINT SEQUENCE COST INFORMATION FOR PERIOD J (ALT I SEQ.)
            PRINT 138, J, K2, CAPINV(J), CRCOST(J), OPERCST(K2,J),
     1                 PENALTY(K2,J), COSTOT, PWCOST, CPWTOT
  138       FORMAT(1H0, 1X, I3, 7X, I3, 3X, 1X, F14.0,1X,6(1X,F14.0) )
  139    CONTINUE
```

TABLE B-1 COMPUTER PROGRAM (Continued)

```
C         DETERMINE OPTIMUM SEQUENCE
          IF( CPWTOT.LE.OPTPWC ) IOPTALT=I
          OPTPWC= CPWTOT
C         PRINT CUMMULATIVE COST INFORMATION FOR ALT.I SEQUENCE
          PRINT 143, CUMCR, CUMOC, CUMPEN, CUMTOT
  143     FORMAT(1H0,/ , 1X, *CUMMULATIVE COSTS*, 16X, 4(1X,F14.0) )
          PRINT 144, CPWCR, CPWOC, CPWPEN, CPWTOT
  144     FORMAT(1H0, *CUMMULATIVE DISCOUNTED COSTS*, 5X, 4(1X,F14.0) )
C         DETERMINE AND PRINT BENEFIT COST INFORMATION
          CPWCAP= CPWCR + CPWOC
          PRINT 145, CPWCAP , CPWPEN
  145     FORMAT(1H0,/ , 1X, *BENEFIT COST INFORMATION FOR STUDY PERIOD*
     1           ,*...*, 5X , *CUMMULATIVE DISCOUNTED CAPITAL COSTS =*,
     1           F15.0, / , 50X,
     1           *CUMMULATIVE DISCOUNTED PENALTY COSTS =*, F15.0 )
  149 CONTINUE
C     PRINT IDENTITY OF OPTIMUM SEQUENCE
      PRINT 192, IOPTALT, (ID(IOPTALT,L),L=1,8)
  192 FORMAT( 1H1, //////////, 10X, *ALTERNATE *,I3, *  IS OPTIMUM*,
     1                    ////  10X, 8A10 )
C     RECYCLE PROGRAM (READ IN DATA FOR NEW PROBLEM)
      GO TO 1
 1000 STOP
      END
```

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