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USER'S MANUAL FOR DYNAMIC PROGRAMMING FOR HIGHWAY SAFETY IMPROVEMENT PROGRAM

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INTRODUCTION

The term, dynamic programming, was first used by Bellman to represent the mathematical theory of a multistage decision process (1). Dynamic programming is applied to allocate expenditures so that maximum benefits result. Three types of applications of dynamic programming are single-stage, multistage, and multistage with a time factor. Single-stage programming is used to evaluate a single project having several alternatives. Multistage programming involves selection of several projects having several alternatives. Multistage dynamic programming with a time factor is used where several projects and alternatives are considered and where various time periods are involved.

The Alabama Highway Department did considerable work on the application of dynamic programming to the optimization of budget allocation for the spot-safety-improvement program (2). Significant modifications were incorporated into the Alabama procedures to make it applicable to the spot-safety-improvement program in Kentucky (3). That procedure was adapted to Kentucky's needs and has been used periodically to select projects for the safety improvement program.

Another application of dynamic programming in Kentucky has been for the selection of projects for resurfacing (4). With hundreds of candidate projects recommended for resurfacing each year, it is difficult to select projects that will yield the greatest benefits to the driving public. Prior to the application of dynamic programming to resurfacing projects, it was necessary to develop reliable means of calculating benefits derived from roadway resurfacing.

Further use of the dynamic programming process in Kentucky has been for the development of a means to priority rank safety improvements for interstate and toll road facilities (5, 6). Separate reports were prepared to document the procedures used for the interstate system and the toll road system. As was the case with other applications of dynamic programming, the major task was determination of benefits expected from each improvement. For both the interstate and toll road programs, all benefits were estimated to be the result of accident reductions associated with the improvements.

The program described herein is designed specifically for highway projects. Program development was done in 1974 and several modifications have been made since then. Additional modifications were performed during the preparation of this user's manual to make the program easier to use. A current listing of the program is in Appendix A.

EXECUTING THE PROGRAM

The program described in this report is written in Fortran. Procedures and commands needed to execute this or any other Fortran program will depend on the user's computer system. Specific procedures for users of the IBM-370 in Frankfort, Kentucky, are presented in Appendix B.

OVERVIEW OF INPUT AND OUTPUT

To use this program, the user must provide certain information. One necessary item is the number of locations to be analyzed. Locations selected are generally those that have been identified as having accident problems. Methods for identifying locations vary, but often accident rates for specific locations or sections are compared to average accident rates to determine where accident rates are abnormally high. A procedure for identifying locations with accident rates above a critical level is described in another report (7). It is generally better to include too many locations than too few, since the program will select the best alternatives from among the locations included. However, additional locations will increase the cost of running the program, so some discretion is justified in selecting locations.

Also included in the input to the program are the budgets to be considered.

The program will determine, for each budget specified, the combination of alternatives that will yield the maximum possible benefit. It is possible to look at either a single budget or a range of budgets, depending on the interests of the user.

Costs associated with different accident severities must be input to the program. This includes the costs to be attributed to each fatality, each non-fatal injury, and each property-damage-only (PDO) accident. Those costs may be obtained from a recognized source, such as the National Safety Council (8). In 1981, they recommended the following costs for traffic accidents;

Each Fatality: $190,000
Each Non-Fatal Injury: 7,200
Each PDO Accident: 1,020

It is important to note that the costs listed are per fatality or injury, not per fatal or injury accident. The cost per fatal accident generally would be greater than the cost per fatality, since some fatal accidents would involve more than one fatality or a fatality and injuries or at least property damage in addition to the fatality.

Two other factors to be entered are the interest rate for economic calculations and the anticipated annual traffic growth. Those can be selected in whatever manner deemed appropriate by the user. Personnel involved in planning and development of new highway construction projects may be able to provide information on current interest rates used for economic analyses and on expected traffic growth.

The accident history of each location must be provided by the user. That involves determining, for a given location, the numbers of fatalities, non-fatal injuries, and PDO accidents at that location in a given time period. Those numbers are usually determined by studying accident reports or, possibly, the computerized accident data for the location for a period of one or more years. The time period selected will depend on the accident frequency at the site and the availability of data.

It will be necessary for the user to determine, for each location considered, alternatives for reducing or eliminating the accident problem. That is an important step and should be given special attention. All reasonable alternatives should be included, and an effort should be made not to overlook or casually dismiss alternatives. A degree of creativity is necessary for a proper approach to the task of generating alternatives.

Once alternatives have been generated, it will be necessary to assign to each alternative an expected life, an initial cost, and an annual maintenance cost. Those values will be drawn from the user's experience, from conversations with others experienced in the area, from unit bids on previous contracts, from manufacturers' information, and from other appropriate sources.

Final input items are the expected reductions in accidents for each of the alternatives. For a given alternative, the user must specify the expected reductions in fatalities, non-fatal injuries, and PDO accidents. It should be also noted that annual maintenance cost is considered in the dynamic programming process to be a negative benefit rather than a cost. Several reports are available dealing with the task of determining accident reductions associated with various types of safety improvements (3, 9, 10). Those and other reports should be reviewed by the user. The user should also consult with experienced traffic safety personnel for assistance in assigning expected reductions for each alternative.

Given all the above information, the program will calculate a benefit-cost ratio for each alternative, will rank alternatives by benefit-cost ratio, and will determine for each selected budget the optimum combination of alternatives. In other words, for a given budget, the program will determine which alternative to select at each location to obtain the maximum overall benefit.

The program will first print out information for each location, consisting of the location number, the location name, the accident history, the information input for each alternative, and the benefit/cost ratio for each alternative.

After this is completed for all locations considered, a listing will be generated of all locations, alternatives, costs, benefits, and benefit/cost ratios. That list will then be repeated in descending order of benefit-cost ratio.

Finally, the program will list, for each budget specified by the user, the selected alternative at each location (may select the zero or do-nothing alternative at some locations), the total cost of all these alternatives, the total benefit achieved, and the total benefit-cost ratio.

Detailed instructions that follow describe how to code the input data for this program and how to interpret and understand the output. An example showing how to use the program is in Appendix B.

CODING INSTRUCTIONS

The format for input data for dynamic programming is summarized in Table 1 and illustrated in Figure 1. The following is a detailed description of the input fields.

Title Card

The first card of the input deck will be the title card. This card enables the user to specify a title for the particular run. Any alphanumeric symbols desired can be placed in Columns 1 through 80. The title specified on this card will appear at the top of the program output.

Printout Card

The second card of the input deck will be the printout card. This card is used by the user to control the information calculated and printed out by the program. Columns 1 through 4 will contain the number of locations to be considered by the program. This is an integer field, and the number should be right-justified, as should all integer fields in the input data. Columns 5 through 10 on this card will be left blank. The maximum budget to be considered will be entered in Columns 11 through 20, followed by the minimum budget to be considered in Columns 21 through 30, and the increment between successive budgets in Columns 31 through 40. Each of these budget fields will be coded as a real number, with the decimal point included, if desired. If no decimal is included, it is assumed to be at the end of the field for these and all other real numbers in the input. Columns 41 through 45 will be left blank, unless the user wishes to suppress the printing of benefit-cost calculation output for individual alternatives. If any non-zero integer number is entered in this field, this printout will be suppressed. Columns 46 through 80 will be blank.

Accident Cost, Interest, and Growth Rate Card

The third card in the input deck is the accident cost,interest, and growth rate card. As with the first two cards, there will be only one card of this type in the input deck for a given run. This card is used to specify costs associated with different accident severities, as well as the interest rate and the expected traffic growth. In Columns 1 through 30 place an alphanumeric description of the accident cost criteria used. In Columns 31 through 40, 41 through 45, and 46 through 50, the user will place the average costs of a fatality, a non-fatal injury, and a PDO accident, respectively. These will be entered as real numbers, with the decimal point included. The appropriate interest rate will be entered in Columns 51 through 55, and the expected annual traffic growth rate (in decimal form) will be entered in Columns 56 through 60, i.e., 10 percent will be entered as ".10". Columns 61 through 80 will be blank.

Location Card

The accident cost card should be followed by a location card for the first location. The order in which locations are included is of no significance. This card is used to relate a particular location name to a location number for checking purposes. Columns 1 through 4 contain a location number (integer), which is simply a number designated by the user to refer to this location. Columns 5 through 44 will contain an alphanumeric name associated with the location. Columns 45 through 80 will be blank.

Accident Severity Card

The location card is followed by a severity card that describes the accident history of the location. The first four columns on this card will contain the same location reference number found in the first four columns of the location card. The time period, in years, of the accident history for the location will be entered as a real number in columns 5 through 10. The following fields on this card will be integer fields of five, using columns 11 through 15, 16 through 20, 21 through 25, and 26 through 30. The first three of these fields will contain the number of fatalities, number of non-fatal injuries, and number of PDO accidents at this location. In the final field on this card (Columns 26 through 30), the the number of alternatives for this location should be coded.

Alternative Description Card

Following the severity card will be alternative description cards, one for each alternative remedial action at this location. Each card is used to specify the costs, life, and expected benefits of a given alternative. The first four columns will contain the location reference number, as on the location card and severity card. Columns 5 through 12 will contain the initial cost of the alternative, in dollars, coded as a real number. Columns 13 and 14 will contain the estimated life of the alternative, in years (integer). Columns 15 through 20 will contain the estimated annual maintenance costs associated with the alternative, a real number with decimal point. The next three fields will be real fields of five columns each. These fields will contain the fractional reductions in fatalities, non-fatal injuries, and PDO accidents resulting from implementation of this alternative. For example, if the alternative would result in a ten percent decreased in fatalities, then Columns 21 through 25 would be filled with "000.1", "00.10", "0.100", or ".1000" (blanks may be substituted for leading or trailing zeros).

It should be noted that some alternatives may increase certain types of accidents. For example, an impact attenuator (crash cushion) will not prevent accidents but will lessen their severities. Therefore, this alternative can be expected to reduce the number of fatalities and increase the number of PDO accidents. An increase in accidents should be coded as a negative number in the field for fractional reduction in accidents. For example, a five percent increase in PDO accidents would be coded as "-0.05" in columns 31 through 35.

As previously mentioned, an alternative description card will be included for each alternative at a given location. After the last alternative description card will come the next location card. This location card would be followed by its corresponding severity card and alternative cards. This sequence will be followed until all locations have been included. Following the last alternative card for the last location, a blank card will be added to complete the input deck.

INTERPRETING THE OUTPUT

The heart of the dynamic programming output is the listing of selected projects and selected alternatives for a given budget. If a certain amount of money is designated to be spent on highway safety improvements, this listing will allow the money to be distributed so that it achieves the maximum possible benefits. Of course, this may include projects with benefit-cost ratios less than one.

If it is desired only to fund projects with high benefit-cost ratios, the listing of projects in descending order of benefit-cost ratio will be most helpful in making that selection very simple.

If the budget for highway safety improvements has not been determined, a large range in budgets can be analyzed and compared (comparing total costs and benefits), leading to selection of a budget that meets defined needs.

REFERENCES

1. Bellman, R.; "Dynamic Programming", Princeton University Press, 1957.
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4. Zegeer, C. V.; Agent, K. R.; and Rizenbergs, R. L.; "Use of Economic Analyses and Dynamic Programming in the Selection of Projects for Resurfacing," Kentucky Department of Transportation, Division of Research, Report 516, February 1979.
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8. "Estimating the Cost of Accidents, 1981;" Bulletin, National Safety Council.
9. "Evaluation of Criteria for Safety Improvements on the Highway," Roy Jorgensen and Associates and Westat Research Analysts, 1966.
10. McFarland, W. F., Griffin, L. I., Rollins, J. B., Stockton, W. R., Phillips, D. T., and Dudek, C. L.; "Assessment of Techniques for Cost-Effectiveness of Highway Accident Countermeasures," Texas Transportation Institute, Texas A&M University, 1979.

TABLE 1. INPUT CODING SUMMARY

CARD	COLUMNS	VARIABLE TYPE*	VARIABLE NAME	DESCRIPTION
A (Title Card)				
	1-80	A	TITL	Title of Run
B (Printout Card)				
	1-4	I	NLOC	Number of Locations
	5-10			Blank
	11-20	R	BUDMAX	Maximum Budget to be Considered
	21-30	R	BUDMIN	Minimum Budget to be Considered
	31-40	R	BUDINC	Increment between Successive Budgets To Be Considered
	41-45	I	IOUTBC	Enter any Non-zero Integer to Suppress Output of Individual Benefit-Cost Calculations
	46-80			Blank
C (Accident Cost Card)				
	1-30	A	CSTCRI	Accident Cost Criteria
	31-40	R	CFAT	Cost of Fatality
	41-45	R	CINJ	Cost of Non-Fatal Injury
	46-50	R	CPDO	Cost of PDO Accident
	51-55	R	RATEIN	Interest Rate
	56-60	R	RATEGR	Traffic Growth Rate
	61-80			Blank
D (Location Card)				
	1-4	I	LOC	Location Number
	5-44	A	XLOC	Location Name
	45-71			Blank
	76-80			Blank
E (Accident Severity Card)				
	1-4	I	LOC	Location Number
	5-10	R	TIME	Years of Accident History
	11-15	I	NFAT	Number of Fatalities
	16-20	I	NINJ	Number of Non-Fatal Injuries
	21-25	I	NPDO	Number of PDO Accidents
	26-30	I	NALT	Number of Alternatives (Maximum = 8)
	31-80			Blank

(Continued on next page)

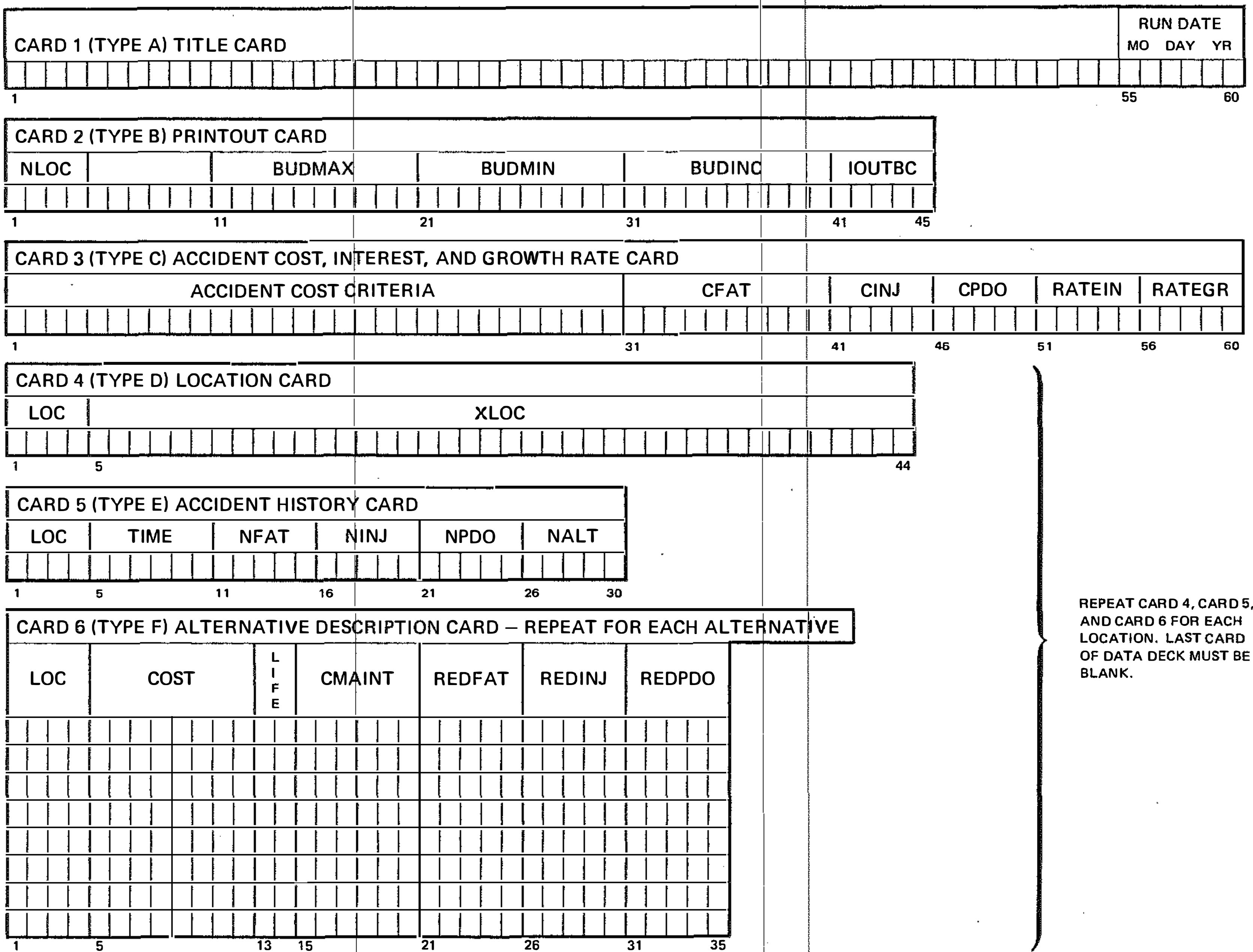
TABLE 1. (Continued)

CARD	COL-UMNS	VARI-ABLE TYPE*	VARI-ABLE NAME	DESCRIPTION
F (Alternative Description Card)				
	1-4	I	LOC	Location Number
	5-12	R	COST	Initial Cost of Alternative
	13-14	I	LIFE	Life of Alternative (Years)
	15-20	R	MAINT	Annual Maintenance Cost
	21-25	R	REDFAT	Reduction in Fatalities
	26-30	R	REDINJ	Reduction in Non-Fatal Injuries
	31-35	R	REDPDO	Reduction in PDO Accidents
	36-80			Blank

Notes: Repeat Card Type F for each alternative at a given locations
Repeat Card Types D, E, and F for each location
Last card of input deck must be blank

* Variable Types: A = alphanumeric
I = integer
R = real

Figure 1. Format for Dynamic Programming Input Data



APPENDIX A

PROGRAM LISTING

```
/*CLASS  A
//P7204 JOB 5035-51806,'MAYES',MSGLEVEL=(1,1),REGION=500K
 .INCLUDE  PASSWORD JOB
//STEP01 EXEC FORTGCLG
//FORT.SYSIN DD *
C
C   DATE:  AUGUST 5,1974
C   PROGRAMMER:  THIS PROGRAM WAS WRITTEN BY JESSE MAYES, DIVISION OF
C   RESEARCH, DEPT. OF TRANS.,COMMONWEALTH OF KY.,533 S. LIMESTONE ST.,
C   LEXINGTON, KY.  PARTS OF THE PROGRAM,INCLUDING THE DYNAMIC
C   PROGRAMMING ALGORITHUM, HAVE BEEN ADAPTED FROM A PROGRAM WRITTEN BY
C   THE STATE OF ALABAMA HIGHWAY DEPT., BUREAU OF MAINT., 1973.  SEE
C   REPORT "CORRECT: COST/BENEFIT OPTIMIZATION FOR THE REDUCTION OF ROAD
C   ENVIRONMENT CAUSED TRAGEDIES".
C   PURPOSE:  THIS PROGRAM CALCULATES COSTS AND BENEFITS FOR EACH
C   ALTERNATIVE AT EACH LOCATION THEN DETERMINES THE OPTIMAL SOLUTION
C   SET OF ALTERNATIVES TO BE IMPLEMENTED FOR A GIVEN RANGE OF BUDGETS.
C   INPUT AND OUTPUT:  SEE DIVISION OF RESEARCH REPORT: "OPTIMAL HIGHWAY
C   SAFETY IMPROVEMENTS BY DYNAMIC PROGRAMMING".
C
      DIMENSION TITL(20),XLOC(90,10),NDE(90),C(90,11),B(90,11),LOC(90)
      DIMENSION ORET(90,501),NOD(90,501)
C
      NINP = 501
      MLOC = 90
C
C   NINP = NUMBER OF INCREMENTS---MAXIMUM BUDGET EQUALS NINP*XINC
C   MLOC = MAXIMUM NUMBER OF LOCATIONS
C
      INN = 13
      IOUTPR =  3
C
C   INN,IOUTPR = LOCAL INPUT AND OUTPUT DEVICE NUMBERS
C
      READ(INN,1000) TITL
 1000 FORMAT(20A4)
      WRITE(IOUTPR,1010) TITL
 1010 FORMAT (20X,20A4//)
C
      READ(INN,2000) NLOC,BUDMAX,BUDMIN,BUDINC,IOUTBC
 2000 FORMAT(T1,I4,T11,3F10.0,T41,I5)
C
      IF(IOUTBC.NE.0) IOUTBC=8
      IF(IOUTBC.EQ.0) IOUTBC=IOUTPR
C
      I=NINP-1
      IX=BUDMAX/I + .5
      XINC=IX
      K1=BUDMIN/IX +.01+ 1
      K2=BUDINC/IX +.01
C
C   CALCULATE THE COSTS AND BENIFITS
C
      CALL COSBEN(C,B,XLOC,LOC,NDE,NLOC,MLOC,XINC,INN,IOUTBC,KIK)
```

```
      IF(KIK.EQ.1) GO TO 10
C
C   PRINT PRINTOUT PARAMETER VALUES
C
      WRITE(IOUTPR,3000)
 3000 FORMAT('1',24('*'),'PARAMETER VALUES',24('*')//)
      WRITE(IOUTPR,3010)
 3010 FORMAT(' ',17X,18('-'),'OUTPUT',18('-')/)
      WRITE(IOUTPR,3020) NLOC,BUDMIN,BUDMAX,BUDINC
 3020 FORMAT(5X,'LOCATIONS---BUDGET MINIMUM---BUDGET MAXIMUM',
     &'--BUDGET INCREMENT',/,3X,I9,4X,F12.2,4X,F12.2,4X,F12.2//)
C
C   DETERMINE THE OPTIMUM ALLOCATIONS
C
      CALL DYNAM(C,B,LOC,XLOC,NDE,NLOC,XINC,K1,K2,NINP,MLOC,
     & ORET,NOD,IOUTPR)
   10 CONTINUE
      STOP
      END
C
C
C************************************************************************
C************************************************************************
      SUBROUTINE COSBEN(PWC,PWB,XLOC,LOC,NDE,NLOC,MLOC,XINC,INN,IOUTPR,
     & KIK)
C************************************************************************
C************************************************************************
C
C   THIS SUBROUTINE CALCULATES PRESENT WORTH COSTS AND BENEFITS
C   ASSOCIATED WITH EACH ALTERNATIVE AT EACH LOCATION
C
      DIMENSION XLOC(MLOC,10),B(8),COST(8),LIFE(8),CMAINT(8),REDFAT(8),
     & REDINJ(8),REDPDO(8),NDE(MLOC),PWC(MLOC,11),PWB(MLOC,11),LOC(MLOC)
     & CSTCRI(30)
 1000 FORMAT (30A1,F10.0,4F5.0)
      READ(INN,1000) CSTCRI,CFAT,CINJ,CPDO,RATEIN,RATEGR
      WRITE(IOUTPR,1010) CSTCRI,CFAT,CINJ,CPDO,RATEIN,RATEGR
 1010 FORMAT(' ',30A1/,
     &'       COST PER FATALITY = ',F7.0/,
     &'       COST PER NON-FATAL INJURY = ',F6.0/,
     &'       COST PER PROPERTY DAMAGE ONLY ACCIDENT (PDO) = ',F5.0//,
     & ' INTEREST RATE = ',F5.3/' EXPONENTIAL GROWTH RATE = ',F5.3)
C
C   THE ABOVE READS AND PRINTS THE BASIC PARAMETERS CONSTANT FOR THE
C   ENTIRE PROGRAM
C
      NUMBER = 1
      KIK = 0
C
C     BELOW IS THE INPUT WHICH IS EXECUTED FOR EACH ACCIDENT LOCATION.
C
   10 READ(INN,1020) NO1,(XLOC(NUMBER,I),I=1,10)
 1020 FORMAT(I4,10A4)
      LOC(NUMBER) = NO1
```

```
      IF(NO1)20,180,20
   20 CONTINUE
      WRITE(IOUTPR,1030)
 1030 FORMAT(1H1)
C
C   SECOND CARD INPUT FOR EACH CRITICAL LOCATION (SEVERITIES).
C
      READ(INN,1070)NO2,TIME,NFAT,NINJ,NPDO,NALT
 1070 FORMAT(I4,F6.0,4I5)
      NDE(NUMBER) = NALT
C
      WRITE(IOUTPR,1040)
 1040 FORMAT(' LOC NO')
      WRITE(IOUTPR,1060) NO1,(XLOC(NUMBER,I),I=1,10),TIME
 1060  FORMAT(3X,I4,8X,10A4,//11X,'ACCIDENT HISTORY ',F4.2,
     &' YEARS.')
C
C     ROUTINE TO CHECK CARD SEQUENCE CODE.
C
      IF(NO1-NO2) 50,60,50
   50 WRITE(IOUTPR,1080)NO1,NO2
 1080 FORMAT('  SEQUENCE/CODE NO. ERROR. CHECK ',I5,' AND',I5,
     &' **EXECUTION TERMINATED')
      KIK = 1
      GO TO 190
   60 CONTINUE
C
C   OUTPUT OF SEVERITIES AND TOTALS.
C
      WRITE(IOUTPR,1090)
 1090 FORMAT(/,11X,'FATALITIES  NON-FATAL   PDO'/,
     &         11X,'             INJURIES   ACCIDENTS')
      WRITE(IOUTPR,1100) NFAT,NINJ,NPDO
 1100 FORMAT (11X,I6,6X,I6,6X,I6)
C
C   INPUT NEXT SET OF NALT CARDS, ONE FOR EACH ALTERNATIVE
C
      DO 110  I=1,NALT
      READ(INN,1120) NO3,COST(I),LIFE(I),CMAINT(I),REDFAT(I),
     &REDINJ(I),REDPDO(I)
 1120 FORMAT(I4,F8.0,I2,F6.0,3F5.2)
      IF(NO3-NO1)90,100,90
   90 WRITE(IOUTPR,1080) NO1, NO3
      KIK = 1
      GO TO 190
  100 CONTINUE
  110 CONTINUE
C
C   OUTPUT OF ALTERNATIVE INFORMATION.
C
      WRITE(IOUTPR,1130)
 1130 FORMAT(/' ALTERNATIVE   COST   LIFE   MAIN COST   EFFECT ON:  ',
     &/,42X,'FATALITIES  NON-FATAL   PDO',
     &/,42X,'            INJURIES    ACCIDENTS')
```

```
C
C   NUMBER COUNT CHECK OF SEVERITIES.
C
      DO 120 I=1,NALT
      WRITE(IOUTPR,1140) I,COST(I),LIFE(I),CMAINT(I),REDFAT(I),
     &REDINJ(I),REDPDO(I)
 1140 FORMAT(I7,F13.0,I8,F9.0,5X,F8.2,4X,F8.2,4X,F8.2)
  120 CONTINUE
C
C   COMPUTATION OF B(I), THE ITH ALTERNATIVE BENEFIT.
C
      DO 140  I=1,NALT
      B(I) = CFAT*NFAT*REDFAT(I)+CINJ*NINJ*REDINJ(I)
     &+CPDO*NPDO*REDPDO(I)
  140 CONTINUE
C
C   CALCULATION OF BENEFIT/COSTS AND OUTPUT.
C
      DO 150 I=1,NALT
        B(I)=B(I)*LIFE(I)/TIME
        BNCS = B(I)/COST(I)
  150 CONTINUE
      WRITE(IOUTPR,1170)
 1170 FORMAT(  ///'   BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED'/
     &' TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT'/
     &'        ---------------- NOT DISCOUNTED ----------------'/)
      WRITE(IOUTPR,1210)
      DO 160 I=1,NALT
        XMAIN=LIFE(I)*CMAINT(I)
        BENM=B(I)-XMAIN
        BNCM=BENM/COST(I)
        WRITE(IOUTPR,1220) I,XMAIN,COST(I),BENM,BNCM
  160 CONTINUE
C
      WRITE(IOUTPR,1200)
 1200 FORMAT(  ///'   BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED'/
     &' TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT'/
     &'       --------DISCOUNTED BACK TO PRESENT WORTH--------'/)
      WRITE(IOUTPR,1210)
 1210 FORMAT(' ALTERNATIVE       MAINTENANCE        COST       BENEFIT
     & BENEFIT/COST')
C
      DO 170 I=1,NALT
        X = (1.+RATEIN)**LIFE(I)
        PWF = (X-1.)/(RATEIN*X)
        Y = (1.+RATEGR)/(1.+RATEIN)
        PWEXGR = (Y**(LIFE(I)+1)-1.)/(Y-1.) - 1
        PWC(NUMBER,1) = 0
        PWB(NUMBER,1) = 0
        PWMAIN = PWF*CMAINT(I)
        PWC(NUMBER,I+1) = COST(I)
        PWB(NUMBER,I+1) = PWEXGR*B(I)/LIFE(I) - PWMAIN
        PWBC = PWB(NUMBER,I+1)/PWC(NUMBER,I+1)
        WRITE(IOUTPR,1220) I,PWMAIN,PWC(NUMBER,I+1),PWB(NUMBER,I+1),
```

```
     & PWBC
1220   FORMAT(I7,F23.2,F14.2,F11.2,5X,F11.2)
  170 CONTINUE
C
      NUMBER = NUMBER + 1
      GO TO 10
  180 CONTINUE
      NUMBER = NUMBER - 1
      IF(NUMBER.EQ.NLOC) GO TO 190
      WRITE(IOUTPR,1230)
 1230 FORMAT('1',40('*'),'  WARNING  ',40('*')//)
      WRITE(IOUTPR,1240) NUMBER,NLOC
 1240 FORMAT(' ','NUMBER OF LOCATIONS READ = ',I3/' ','NUMBER OF LOCATIO
     &NS EXPECTED = ',I3)
  190 CONTINUE
      RETURN
      END
C
C
C***********************************************************************
C***********************************************************************
      SUBROUTINE DYNAM(C,B,LOC,XLOC,NDE,NLOC,XINC,K1,K2,NINP,MLOC,
     & ORET,NOD,IOUTPR)
C***********************************************************************
C***********************************************************************
C
C   THIS SUBROUTINE USES "DYNAMIC PROGRAMMING" TO FIND THE OPTIMAL
C   SOLUTION SET ALTERNATIVES (ONE AT EACH LOCATION) GIVEN COSTS,
C   BENEFITS AND A RANGE OF BUDGETS.  THE ALGORITHUM IS BASED ON WORK BY
C   RICHARD BELLMAN (DYNAMIC PROGRAMMING,1957)
C
      DIMENSION ORET(MLOC,NINP),NOD(MLOC,NINP),NDE(MLOC),
     & C(MLOC,11),B(MLOC,11),R(11),XLOC(MLOC,5),LOC(MLOC),
     & NI(500),NCI(500)
C
C   THESE DIMENSIONS MUST BE AT LEAST AS BIG AS THE NUMBER OF LOCATIONS
C
      DIMENSION CC(200),BB(200),AA(500),BC(200),LL(500),KKK(200)
      IST=0
      VRET=0.0
      WRITE(IOUTPR,1025)
1025  FORMAT(' --- LOCATION - ALTERNATIVES')
      DO 10 I=1,NLOC
        WRITE(IOUTPR,1030) LOC(I),NDE(I)
 1030   FORMAT(7X,I5,I10)
   10 CONTINUE
      WRITE(IOUTPR,1040)
 1040 FORMAT('1',28('*'),'LOCATIONS,ALTERNATIVES,COSTS AND BENEFITS',
     & 28('*')/,16X,
     &' BENEFITS (MAINTENANCE INCLUDED) DISCOUNTED BACK TO PRESENT ',
     &'WORTH'//)
      WRITE(IOUTPR,1050)
 1050 FORMAT (1H ,'--LOCATION---LOCATION NAME',28('-'),'ALT-NUM--------C
     1OST----BENEFIT-----B/C RATIO')
```

```
C
C     FIND THE OPTIMAL ALTERNATIVE AT THE I-TH LOCATION WITH J INCREMENTS
C     AVAILABLE
C
        NATOT = 0
        DO 140 I=1,NLOC
          NDEC=NDE(I)+1
          R(1)=0.
          DO 20 IC=2,NDEC
            R(IC) = B(I,IC)
   20     CONTINUE
          DO 30 IC=2,NDEC
            NATOT = NATOT + 1
            NI(NATOT) = I
            NCI(NATOT) = IC
            ICM1 = IC-1
            BCRAT = R(IC)/C(I,IC)
            AA(NATOT)=BCRAT
            WRITE(IOUTPR,1060) LOC(I),(XLOC(I,J),J=1,10),ICM1,C(I,IC),
     &      R(IC),BCRAT
 1060       FORMAT(I9,5X,10A4,I6,3X,F11.0,F11.0,4X,F10.2,F15.0,F15.0)
   30     CONTINUE
 1070     FORMAT(8F10.0)
          DO 130 J=1,NINP
C
C     INCREMENT BUDGET
C
            XIN=(J-1)*XINC
            DUM=-1000000000000.
            NDEC=NDE(I)+1
C
C     DETERMINE THE BEST ALTERNATIVE--NOD(I,J)--AT I-TH LOCATION GIVEN
C     J-1 INCREMENTS TO SPEND ON LOCATION 1 THRU LOCATION I-----YIELDING
C     A RETURN OF--ORET(I,J)--
C
            DO 120 K=1,NDEC
              CALL XOUT(I,IST,XIN,K,KICK,XINC,C,MLOC)
              IF(KICK)50,50,40
   40         GO TO 120
   50         CONTINUE
              IF(I-1)60,60,70
   60         TEST=R(K)
              GO TO 80
   70         TEST=R(K)+ORET(I-1,IST)
              GO TO 80
   80         IF((DUM-TEST))90,100,100
   90         DUM=TEST
              ORET(I,J)=DUM
              NOD(I,J)=K
  100         GO TO 110
  110         CONTINUE
  120       CONTINUE
  130     CONTINUE
  140   CONTINUE
```

```
      CALL DATORD(AA,LL,NATOT)
      WRITE(IOUTPR,1049)
 1049 FORMAT('1',12('*'),'LOCATIONS,ALTERNATIVES,COSTS, AND BENEFITS-',
     & 'ORDERED BY BENEFIT/COST RATIO',
     & 13('*')/,16X,
     &' BENEFITS (MAINTENANCE INCLUDED) DISCOUNTED BACK TO PRESENT ',
     &'WORTH'//)
      WRITE(IOUTPR,1051)
 1051 FORMAT (1H ,'--LOCATION---LOCATION NAME',28('-'),'ALT-NUM--------C
     &OST----BENEFIT-----B/C RATIO')
      DO 149 II=1,NATOT
        III=LL(II)
        I=NI(III)
        IC=NCI(III)
        ICM1=IC-1
        R(IC)=B(I,IC)
        WRITE(IOUTPR,1060) LOC(I),(XLOC(I,J),J=1,10),ICM1,C(I,IC),
     &   R(IC),AA(II)
  149 CONTINUE
      WRITE(IOUTPR,1130)
      IPAGE = 0
C
C   CALCULATE AND PRINTOUT OPTIMUM PROJECT SELECTIONS FOR
C   VARIOUS BUDGETS
C
      DO 160 M=K1,NINP,K2
        J=M
        XIN=(J-1)*XINC
        BUDG=XIN
        IPAGE = IPAGE + 1
        IF(IPAGE.NE.1) WRITE(IOUTPR,1130)
C
C   WRITE INDIVIDUAL BUDGET OUTPUT HEADING
C
        WRITE(IOUTPR,1290) BUDG
 1290   FORMAT(' OPTIMUM PROJECT SELECTIONS FOR BUDGET = ',F12.0,/)
        WRITE(IOUTPR,1090)
 1090   FORMAT(' ',        2X,'LOCATION  ',4X,'LOCATION NAME ',21X,
     &  10X,'ALT-NUM',5X,'COST',5X,'BENEFIT',3X,'ACCUM BENEFIT',/)
 1100   FORMAT('0',6X,F15.2)
        TOTCST = 0
        TOTRTN = 0
        DO 150 L=1,NLOC
          I=NLOC+1-L
          K=NOD(I,J)
          KKK(I)=K
          CC(I)=C(I,K)
          BB(I)=B(I,K)
          CALL XOUT(I,IST,XIN,K,KICK,XINC,C,MLOC)
          J=IST
          XIN = XIN-C(I,K)
  150   CONTINUE
        DO 155 I=1,NLOC
          K=KKK(I)
```

```
          KK=K-1
          TOTRTN = TOTRTN + BB(I)
          TOTCST = TOTCST + CC(I)
          BC(I)=0
          IF(CC(I).GT..01) BC(I)=BB(I)/CC(I)
          AA(I)=BC(I)
C
C   WRITE I-TH LOCATION INFORMATION---TOTAL BUDGET OF M INCREMENTS
C
          WRITE(IOUTPR,1110) LOC(I),(XLOC(I,JJ),JJ=1,10),KK,CC(I),
     &     BB(I),TOTRTN
 1110     FORMAT(' ', 4X,I4,9X,10A4,5X,I4,2F12.0,4X,F12.0)
  155   CONTINUE
C
C   WRITE TOTALS
C
        WRITE(IOUTPR,1120) TOTCST,TOTRTN,TOTRTN
 1120   FORMAT('0',29('*'),' TOTALS ',29('*'),2F12.0,4X,F12.0)
        WRITE(IOUTPR,1130)
        WRITE(IOUTPR,1140) BUDG
 1140   FORMAT(' ','LISTING OF SELECTED PROJECTS BY B/C RATIO',
     & ' FOR BUDGET = ',F12.0,/)
        WRITE(IOUTPR,1091)
 1091   FORMAT(' ',        2X,'LOCATION  ',4X,'LOCATION NAME ',21X,
     &  10X,'ALT-NUM',5X,'COST',5X,'BENEFIT',3X,'ACCUM BENEFIT',
     & 9X,'B/C',2X,'ACCUM B/C',/)
        CALL DATORD(AA,LL,NLOC)
        TOTRTN=0
        TOTCST=0
        DO 190 II=1,NLOC
          I=LL(II)
          K=KKK(I)
          KK=K-1
          IF(BB(I).LT.1.0) GO TO 195
          TOTRTN=TOTRTN+BB(I)
          TOTCST=TOTCST+CC(I)
          ACCBC=TOTRTN/TOTCST
          WRITE(IOUTPR,1111) LOC(I),(XLOC(I,JJ),JJ=1,10),KK,CC(I),BB(I),
     &     TOTRTN,BC(I),ACCBC
 1111     FORMAT(' ', 4X,I4,9X,10A4,5X,I4,2F12.0,4X,F12.0,2X,F10.2,
     &     F10.2)
  190   CONTINUE
  195   CONTINUE
        WRITE(IOUTPR,1121) TOTCST,TOTRTN,TOTRTN,ACCBC
 1121   FORMAT('0',29('*'),' TOTALS ',29('*'),2F12.0,4X,F12.0,12X,F10.2)
  160 CONTINUE
  170 WRITE(IOUTPR,1130)
 1130 FORMAT('1')
  180 CONTINUE
      RETURN
      END
C
C
C**********************************************************************
```

```
C*************************************************************************
      SUBROUTINE XOUT(I,IST,XIN,K,KICK,XINC,C,MLOC)
C*************************************************************************
C*************************************************************************
C
C   THIS SUBROUTINE CALCULATES THE OUTPUT STATE NUMBER
C   RESULTING FROM THE INPUT XIN AND SAFETY MEASURE K.  IT
C   ALSO DETERMINES THE COST OF A PARTICULAR SAFETY MEASURE
C   CORRESPONDING TO STAGE I.
C
      DIMENSION C(MLOC,11)
      OUT=XIN-C(I,K)
      IF(OUT) 10,20,20
   10 KICK=1
      IST = 1
      GO TO 30
   20 KICK=0
      IST=(OUT/XINC) + 1.5
   30 RETURN
      END
C
C*************************************************************************
C*************************************************************************
      SUBROUTINE DATORD (D,L,M)
C*************************************************************************
C*************************************************************************
C
C   THIS SUBROUTINE SORTS THE ARRAY D(I) AND PRODUCES AN ARRAY
C   L(I) THAT GIVE THE ORIGINAL POSITION OF EACH D(I)
      DIMENSION D(M),L(M)
      DO 10 I=1,M
   10 L(I) = I
      DO 20 I=1,M
        IF(I.EQ.M) GO TO 20
        K = L(I)
        S = D(I)
        J1 = I
        DO 30 J=I,M
          IF(S.GE.D(J)) GO TO 30
          S = D(J)
          K = L(J)
          J1 = J
   30   CONTINUE
        D(J1) = D(I)
        D(I) = S
        L(J1) = L(I)
        L(I) = K
   20 CONTINUE
      RETURN
      END
/*
//GO.FT13F001 DD *
 .INC EXAMP1 DATA
/*
```

APPENDIX B

SPECIFIC PROCEDURES FOR RUNNING PROGRAM

This appendix contains information needed to run the dynamic programming module on the IBM-370 in Frankfort, Kentucky. The first part contains basic information on running the program. The second part contains more detailed information for users with programming capabilities.

BASIC INFORMATION

USING CARDS ----------

To submit the program on cards, the user must have a copy of the program on cards and should also punch the data on cards. The deck should then be assembled as shown below.

```
//jobname                JOB                (nnnn,nnnn),'user
    name',MSGLEVEL=(1,1),PASSWORD=password
//STEPA EXEC FORTGCLG,REGION=525K
/*ROUTE PRINT LOCAL
/*JOBPARM T=1,N=3
//FORT.SYSIN DD *
     -
     Insert program cards here
     -
/*
//GO.SYSIN DD *
     -
     Insert data cards here
     -
/*
```

Output from this program will be routed as designated on the 'ROUTE PRINT' card. The card shown above will route output to the default printer at the Computing Center. This can be changed, if desired, by replacing 'LOCAL' with either 'LASER' or 'RMTn' (where 'RMTn' is a remote printer designation, such as 'RMT3', 'RMT7', etc.).

The 'JOBPARM' card shown above sets a maximum of one minute CPU time and specifies that three copies of the output are desired. These parameters can be changed as needed.

SUBMITTING BATCH JOB FROM TERMINAL

The program can be submitted for batch processing from any TSO terminal. Data records should first be placed in a dataset. The user should then use ISPF edit procedures to edit the dataset named 'TTR¶.DYNAMIC.JCL'. This dataset contains only the JCL (job control language) for running the job. The actual program is located elsewhere and will be called by the

JCL. The user need change only one statement in 'TTR1.DYNAMIC.PGM'. That statement is the following:

```
//GO.FT13F001 DD DSN=datasetname,DISP=SHR
```

where 'datasetname' is the name of a dataset. The user needs only to replace 'datasetname' with the name of the dataset where the input data records are located. The job is submitted by entering the following command from the READY mode:

```
SUBMIT 'TTR1.DYNAMIC.PGM'
```

The program will run as a batch job and the output will be routed to the default printer at the Computing Center.

MORE DETAILED INFORMATION FOR PROGRAMMERS

The source module of the program as described in this manual is located in 'TTR1.DYNAMIC.FORT'. Any user interested in modifying the source module should obtain a copy of this member and edit the copy. The source module is not accessed by the batch and on-line procedures described above; each of these accesses a load module created from the source module. The load module is located in 'TTR1.DYNAMIC.LOAD'
Any user submitting the program on cards has complete freedom to change the allocations of input and output devices as desired. A user submitting a batch job from a terminal can change input and output devices by making appropriate changes in 'TTR1.DYNAMIC.JCL', but it would be preferable for the user to obtain his own copy of this dataset, make the appropriate changes in the copy, and submit it.

APPENDIX C

EXAMPLES OF PROGRAM USAGE

Example Number 1.

EXAMPLE NUMBER ONE OF DYNAMIC PROGRAMMING (Title)
Five locations
Consider budgets of $100,000 to $500,000 by $100,000.
Cost of fatality = $190,000
Cost of non-fatal injury = 7,200
Cost of PDO accident = 1,020
Interest rate = 10 percent
Traffic growth rate = 4 percent per year

Information for Location Number One:
Location number = 0001
Location name = Exit Ramp at MP 106.3
3.5 years of accident data :
4 fatalities, 11 non-fatal injuries, 12 PDO accidents

Three alternatives:	Improved Delineation	Clear Gore Area	Impact Attenuator
Initial Cost:	$3,000	$7,500	$15,000
Life:	3 years	20 years	20 years
Annual Maint. Cost:	$ 0	$ 0	$ 500
Red. in Fatalities:	10%	50%	75%
Red. in Injuries:	10%	50%	50%
Red. in PDO Acc.:	10%	0%	-65%

Information for Location Number Two:
Location number = 0002
Location name = Intersection at MP 153.6
3.5 years of accident data:
9 fatalities, 28 non-fatal injuries, 112 PDO accidents.

Two alternatives:	Install Flashing Signals	Install Warning Signs
Initial Cost:	$15,000	$ 1,200
Life:	20 years	20 years
Annual Maint. Cost:	$ 500	$ 0
Red. in Fatalities:	10%	5%
Red. in Injuries:	10%	5%
Red. in PDO Acc.:	10%	5%

Information for Location Number Three:
Location number = 0003
Location name = Curve at MP 87.9
2 years of accident data:
6 fatalities, 9 non-fatal injuries, 8 PDO accidents.

Two alternatives:	Install Guardrail	Remove Rock Outcropping
Initial Cost:	$ 8,000	$ 35,000
Life:	20 years	20 years
Annual Maint. Cost:	$ 100	$ 0
Red. in Fatalities:	15%	75%
Red. in Injuries:	15%	50%
Red. in PDO Acc.:	-40%	25%

Information for Location Number Four:

Location number = 0004

Location name = Bridge at MP 206.1

4 years of accident data:

2 fatalities, 8 non-fatal injuries, 47 PDO accidents.

One alternative:	Deslicking Pavement
Initial Cost:	$30,000
Life:	20 years
Annual Maint. Cost:	$ 0
Red. in Fatalities:	15%
Red. in Injuries:	15%
Red. in PDO Acc.:	15%

Information for Location Number Five:

Location number = 0005

Location name = Narrow bridge at MP 27.1

4 years of accident data:

5 fatalities, 15 non-fatal injuries, 17 PDO accidents.

Two alternatives:	Widen Bridge	Delineate Approach
Initial Cost:	$130,000	$ 200
Life:	20 years	5 years
Annual Maint. Cost:	$ 0	$ 0
Red. in Fatalities:	50%	5%
Red. in Injuries:	50%	5%
Red. in PDO Acc.:	50%	5%

INPUT DATA FOR EXAMPLE ONE

```
1---5---10----5---20----5---30----5---40----5---50----5---60
****START OF DATA*****
EXAMPLE NUMBER ONE OF DYNAMIC PROGRAMMING
   5        500000.00 100000.00 100000.00
1981 NATIONAL SAFETY COUNCIL      190000 7200 1020  .10  .04
0001EXIT RAMP AT MP 106.3
0001   3.5    4   11   12    3
0001    3000 3      0 0.10 0.10 0.10
0001    750020      0 0.50 0.50 0.00
0001   1500020    500 0.75 0.50-0.65
0002INTERSECTION AT MP 153.6
0002   3.5    9   28  112    2
0002   1500020    500 0.10 0.10 0.10
0002    120020      0 0.05 0.05 0.05
0003CURVE AT MP 87.9
0003   2.0    6    9    8    2
0003    800020    100 0.15 0.15-0.40
0003   3500020      0 0.75 0.50 0.25
0004BRIDGE AT MP 206.1
0004   4.0    2    8   47    1
0004   3000020      0 0.15 0.15 0.15
0005NARROW BRIDGE AT MP 27.1
0005   4.0    5   15   17    2
0005  13000020      0 0.50 0.50 0.50
0005     200 5      0 0.05 0.05 0.05

*****END OF DATA*****
```

OUTPUT FOR EXAMPLE NUMBER ONE OF DYNAMIC PROGRAMMING

1981 NATIONAL SAFETY COUNCIL
    COST PER FATALITY = 190000.
    COST PER NON-FATAL INJURY = 7200.
    COST PER PROPERTY DAMAGE ONLY ACCIDENT (PDO) = 1020.

INTEREST RATE = 0.100
EXPONENTIAL GROWTH RATE = 0.040

LOC NO

1 EXIT RAMP AT MP 106.3

ACCIDENT HISTORY 3.50 YEARS.

FATALITIES	NON-FATAL INJURIES	PDO ACCIDENTS
4	11	12

ALTERNATIVE	COST	LIFE	MAIN COST	EFFECT ON: FATALITIES	NON-FATAL INJURIES	PDO ACCIDENTS
1	3000.	3	0.	0.10	0.10	0.10
2	7500.	20	0.	0.50	0.50	0.0
3	15000.	20	500.	0.75	0.50	-0.65

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
---------------- NOT DISCOUNTED ----------------

ALTERNATIVE	MAINTENANCE	COST	BENEFIT	BENEFIT/COST
1	0.0	3000.00	72980.38	24.33
2	0.0	7500.00	2397714.00	319.70
3	10000.00	15000.00	3427965.00	228.53

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
--------DISCOUNTED BACK TO PRESENT WORTH--------

ALTERNATIVE	MAINTENANCE	COST	BENEFIT	BENEFIT/COST
1	0.0	3000.00	65304.54	21.77
2	0.0	7500.00	1401220.00	186.83
3	4256.77	15000.00	2004885.00	133.66

LOC NO

2 INTERSECTION AT MP 153.6

ACCIDENT HISTORY 3.50 YEARS.

FATALITIES	NON-FATAL INJURIES	PDO ACCIDENTS
9	28	112

ALTERNATIVE	COST	LIFE	MAIN COST	EFFECT ON: FATALITIES	NON-FATAL INJURIES	PDO ACCIDENTS
1	15000.	20	500.	0.10	0.10	0.10
2	1200.	20	0.	0.05	0.05	0.05

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
---------------- NOT DISCOUNTED ----------------

ALTERNATIVE	MAINTENANCE	COST	BENEFIT	BENEFIT/COST
1	10000.00	15000.00	1147621.00	76.51
2	0.0	1200.00	578810.25	482.34

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
--------DISCOUNTED BACK TO PRESENT WORTH--------

ALTERNATIVE	MAINTENANCE	COST	BENEFIT	BENEFIT/COST
1	4256.77	15000.00	672255.50	44.82
2	0.0	1200.00	338256.00	281.88

LOC NO
3 CURVE AT MP 87.9

ACCIDENT HISTORY 2.00 YEARS.

FATALITIES	NON-FATAL INJURIES	PDO ACCIDENTS
6	9	8

ALTERNATIVE	COST	LIFE	MAIN COST	EFFECT ON: FATALITIES	NON-FATAL INJURIES	PDO ACCIDENTS
1	8000.	20	100.	0.15	0.15	-0.40
2	35000.	20	0.	0.75	0.50	0.25

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
------------- NOT DISCOUNTED -------------

ALTERNATIVE	MAINTENANCE	COST	BENEFIT	BENEFIT/COST
1	2000.00	8000.00	1772558.00	221.57
2	0.0	35000.00	8894400.00	254.13

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
--------DISCOUNTED BACK TO PRESENT WORTH--------

ALTERNATIVE	MAINTENANCE	COST	BENEFIT	BENEFIT/COST
1	851.35	8000.00	1036198.19	129.52
2	0.0	35000.00	5197876.00	148.51

LOC NO
4 BRIDGE AT MP 206.1

ACCIDENT HISTORY 4.00 YEARS.

FATALITIES	NON-FATAL INJURIES	PDO ACCIDENTS
2	8	47

ALTERNATIVE	COST	LIFE	MAIN COST	EFFECT ON: FATALITIES	NON-FATAL INJURIES	PDO ACCIDENTS
1	30000.	20	0.	0.15	0.15	0.15

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
---------------- NOT DISCOUNTED ----------------

ALTERNATIVE	MAINTENANCE	COST	BENEFIT	BENEFIT/COST
1	0.0	30000.00	364154.25	12.14

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
--------DISCOUNTED BACK TO PRESENT WORTH--------

ALTERNATIVE	MAINTENANCE	COST	BENEFIT	BENEFIT/COST
1	0.0	30000.00	212811.25	7.09

LOC NO

5 NARROW BRIDGE AT MP 27.1

ACCIDENT HISTORY 4.00 YEARS.

FATALITIES	NON-FATAL INJURIES	PDO ACCIDENTS
5	15	17

ALTERNATIVE	COST	LIFE	MAIN COST	EFFECT ON: FATALITIES	NON-FATAL INJURIES	PDO ACCIDENTS
1	130000.	20	0.	0.50	0.50	0.50
2	200.	5	0.	0.05	0.05	0.05

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
---- NOT DISCOUNTED ----------------

ALTERNATIVE	MAINTENANCE	COST	BENEFIT	BENEFIT/COST
1	0.0	130000.00	2688350.00	20.68
2	0.0	200.00	67208.69	336.04

BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED
TOTAL COSTS AND BENEFITS FOR THE LIFE OF THE IMPROVEMENT
--------DISCOUNTED BACK TO PRESENT WORTH--------

ALTERNATIVE	MAINTENANCE	COST	BENEFIT	BENEFIT/COST
1	0.0	130000.00	1571068.00	12.09
2	0.0	200.00	56978.82	284.89

*************************PARAMETER VALUES*************************

-----------------OUTPUT-----------------

LOCATIONS	BUDGET MINIMUM	BUDGET MAXIMUM	BUDGET INCREMENT
5	100000.00	500000.00	100000.00

--- LOCATION - ALTERNATIVES

LOCATION	ALTERNATIVES
1	3
2	2
3	2
4	1
5	2

******************************LOCATIONS,ALTERNATIVES,COSTS AND BENEFITS******************************

BENEFITS (MAINTENANCE INCLUDED) DISCOUNTED BACK TO PRESENT WORTH

LOCATION	LOCATION NAME	ALT-NUM	COST	BENEFIT	B/C RATIO
1	EXIT RAMP AT MP 106.3	1	3000.	65305.	21.77
1	EXIT RAMP AT MP 106.3	2	7500.	1401220.	186.83
1	EXIT RAMP AT MP 106.3	3	15000.	2004885.	133.66
2	INTERSECTION AT MP 153.6	1	15000.	672256.	44.82
2	INTERSECTION AT MP 153.6	2	1200.	338256.	281.88
3	CURVE AT MP 87.9	1	8000.	1036198.	129.52
3	CURVE AT MP 87.9	2	35000.	5197876.	148.51
4	BRIDGE AT MP 206.1	1	30000.	212811.	7.09
5	NARROW BRIDGE AT MP 27.1	1	130000.	1571068.	12.09
5	NARROW BRIDGE AT MP 27.1	2	200.	56979.	284.89

************LOCATIONS,ALTERNATIVES,COSTS, AND BENEFITS-ORDERED BY BENEFIT/COST RATIO*************

BENEFITS (MAINTENANCE INCLUDED) DISCOUNTED BACK TO PRESENT WORTH

LOCATION	LOCATION NAME	ALT-NUM	COST	BENEFIT	B/C RATIO
5	NARROW BRIDGE AT MP 27.1	2	200.	56979.	284.89
2	INTERSECTION AT MP 153.6	2	1200.	338256.	281.88
1	EXIT RAMP AT MP 106.3	2	7500.	1401220.	186.83
3	CURVE AT MP 87.9	2	35000.	5197876.	148.51
1	EXIT RAMP AT MP 106.3	3	15000.	2004885.	133.66
3	CURVE AT MP 87.9	1	8000.	1036198.	129.52
2	INTERSECTION AT MP 153.6	1	15000.	672256.	44.82
1	EXIT RAMP AT MP 106.3	1	3000.	65305.	21.77
5	NARROW BRIDGE AT MP 27.1	1	130000.	1571068.	12.09
4	BRIDGE AT MP 206.1	1	30000.	212811.	7.09

OPTIMUM PROJECT SELECTIONS FOR BUDGET = 100000.

LOCATION	LOCATION NAME	ALT-NUM	COST	BENEFIT	ACCUM BENEFIT
1	EXIT RAMP AT MP 106.3	3	15000.	2004885.	2004885.
2	INTERSECTION AT MP 153.6	1	15000.	672256.	2677140.
3	CURVE AT MP 87.9	2	35000.	5197876.	7875016.
4	BRIDGE AT MP 206.1	1	30000.	212811.	8087827.
5	NARROW BRIDGE AT MP 27.1	2	200.	56979.	8144805.
****************************** TOTALS ******************************			95200.	8144805.	8144805.

LISTING OF SELECTED PROJECTS BY B/C RATIO FOR BUDGET = 100000.

LOCATION	LOCATION NAME	ALT-NUM	COST	BENEFIT	ACCUM BENEFIT	B/C	ACCUM B/C
5	NARROW BRIDGE AT MP 27.1	2	200.	56979.	56979.	284.89	284.89
3	CURVE AT MP 87.9	2	35000.	5197876.	5254854.	148.51	149.29
1	EXIT RAMP AT MP 106.3	3	15000.	2004885.	7259739.	133.66	144.62
2	INTERSECTION AT MP 153.6	1	15000.	672256.	7931994.	44.82	121.66
4	BRIDGE AT MP 206.1	1	30000.	212811.	8144805.	7.09	85.55
****************************** TOTALS ******************************			95200.	8144805.	8144805.		85.55

OPTIMUM PROJECT SELECTIONS FOR BUDGET = 200000.

LOCATION	LOCATION NAME	ALT-NUM	COST	BENEFIT	ACCUM BENEFIT
1	EXIT RAMP AT MP 106.3	3	15000.	2004885.	2004885.
2	INTERSECTION AT MP 153.6	1	15000.	672256.	2677140.
3	CURVE AT MP 87.9	2	35000.	5197876.	7875016.
4	BRIDGE AT MP 206.1	0	0.	0.	7875016.
5	NARROW BRIDGE AT MP 27.1	1	130000.	1571068.	9446084.
****************************** TOTALS ******************************			195000.	9446084.	9446084.

LISTING OF SELECTED PROJECTS BY B/C RATIO FOR BUDGET = 200000.

LOCATION	LOCATION NAME	ALT-NUM	COST	BENEFIT	ACCUM BENEFIT	B/C	ACCUM B/C
3	CURVE AT MP 87.9	2	35000.	5197876.	5197876.	148.51	148.51
1	EXIT RAMP AT MP 106.3	3	15000.	2004885.	7202761.	133.66	144.06
2	INTERSECTION AT MP 153.6	1	15000.	672256.	7875016.	44.82	121.15
5	NARROW BRIDGE AT MP 27.1	1	130000.	1571068.	9446084.	12.09	48.44
****************************** TOTALS ******************************			195000.	9446084.	9446084.		48.44

OPTIMUM PROJECT SELECTIONS FOR BUDGET = 300000.

LOCATION	LOCATION NAME	ALT-NUM	COST	BENEFIT	ACCUM BENEFIT
1	EXIT RAMP AT MP 106.3	3	15000.	2004885.	2004885.
2	INTERSECTION AT MP 153.6	1	15000.	672256.	2677140.
3	CURVE AT MP 87.9	2	35000.	5197876.	7875016.
4	BRIDGE AT MP 206.1	1	30000.	212811.	8087827.
5	NARROW BRIDGE AT MP 27.1	1	130000.	1571068.	9658895.
****************************** TOTALS ******************************			225000.	9658895.	9658895.

LISTING OF SELECTED PROJECTS BY B/C RATIO FOR BUDGET = 300000.

LOCATION	LOCATION NAME	ALT-NUM	COST	BENEFIT	ACCUM BENEFIT	B/C	ACCUM B/C
3	CURVE AT MP 87.9	2	35000.	5197876.	5197876.	148.51	148.51
1	EXIT RAMP AT MP 106.3	3	15000.	2004885.	7202761.	133.66	144.06
2	INTERSECTION AT MP 153.6	1	15000.	672256.	7875016.	44.82	121.15
5	NARROW BRIDGE AT MP 27.1	1	130000.	1571068.	9446084.	12.09	48.44
4	BRIDGE AT MP 206.1	1	30000.	212811.	9658895.	7.09	42.93
****************************** TOTALS ******************************			225000.	9658895.	9658895.		42.93

OPTIMUM PROJECT SELECTIONS FOR BUDGET = 400000.

LOCATION	LOCATION NAME	ALT-NUM	COST	BENEFIT	ACCUM BENEFIT
1	EXIT RAMP AT MP 106.3	3	15000.	2004885.	2004885.
2	INTERSECTION AT MP 153.6	1	15000.	672256.	2677140.
3	CURVE AT MP 87.9	2	35000.	5197876.	7875016.
4	BRIDGE AT MP 206.1	1	30000.	212811.	8087827.
5	NARROW BRIDGE AT MP 27.1	1	130000.	1571068.	9658895.
****************************** TOTALS ******************************			225000.	9658895.	9658895.

LISTING OF SELECTED PROJECTS BY B/C RATIO FOR BUDGET = 400000.

LOCATION	LOCATION NAME	ALT-NUM	COST	BENEFIT	ACCUM BENEFIT	B/C	ACCUM B/C
3	CURVE AT MP 87.9	2	35000.	5197876.	5197876.	148.51	148.51
1	EXIT RAMP AT MP 106.3	3	15000.	2004885.	7202761.	133.66	144.06
2	INTERSECTION AT MP 153.6	1	15000.	672256.	7875016.	44.82	121.15
5	NARROW BRIDGE AT MP 27.1	1	130000.	1571068.	9446084.	12.09	48.44
4	BRIDGE AT MP 206.1	1	30000.	212811.	9658895.	7.09	42.93
****************************** TOTALS ******************************			225000.	9658895.	9658895.		42.93

OPTIMUM PROJECT SELECTIONS FOR BUDGET = 500000.

LOCATION	LOCATION NAME	ALT-NUM	COST	BENEFIT	ACCUM BENEFIT
1	EXIT RAMP AT MP 106.3	3	15000.	2004885.	2004885.
2	INTERSECTION AT MP 153.6	1	15000.	672256.	2677140.
3	CURVE AT MP 87.9	2	35000.	5197876.	7875016.
4	BRIDGE AT MP 206.1	1	30000.	212811.	8087827.
5	NARROW BRIDGE AT MP 27.1	1	130000.	1571068.	9658895.
****************************** TOTALS ******************************			225000.	9658895.	9658895.

LISTING OF SELECTED PROJECTS BY B/C RATIO FOR BUDGET = 500000.

LOCATION	LOCATION NAME	ALT-NUM	COST	BENEFIT	ACCUM BENEFIT	B/C	ACCUM B/C
3	CURVE AT MP 87.9	2	35000.	5197876.	5197876.	148.51	148.51
1	EXIT RAMP AT MP 106.3	3	15000.	2004885.	7202761.	133.66	144.06
2	INTERSECTION AT MP 153.6	1	15000.	672256.	7875016.	44.82	121.15
5	NARROW BRIDGE AT MP 27.1	1	130000.	1571068.	9446084.	12.09	48.44
4	BRIDGE AT MP 206.1	1	30000.	212811.	9658895.	7.09	42.93
****************************** TOTALS ******************************			225000.	9658895.	9658895.		42.93