UMTA-MI-11-0008-01

UMTRI 86-17

archive 73332

Optimal Equipment Replacement Strategies

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MAY 1986
FINAL REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION

URBAN MASS TRANSPORTATION ADMINISTRATION
Office of Technical Assistance
Washington, D.C. 20590

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-86-17		

4. Title and Subtitle	5. Report Date
Optimal Equipment Replacement Strategies	May 1986
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
James C. Bean, Jack R. Lohmann, Robert L. Smith	UMTRI-86-17
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Center for Transit Research and Management Development - UMTRI 2901 Baxter Road Ann Arbor, MI 48109	11. Contract or Grant No. UMTA-MI-11-0008
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation Office of Technical Assistance Washington, D.C. 20590	Final Report
	14. Sponsoring Agency Code URT-33

15. Supplementary Notes

16. Abstract

The purpose of this report is to describe research on optimal strategies for replacing capital equipment, especially transit buses. The problem of when and how to replace buses is one of the most important fiscal decisions facing transit agencies today. Life cycle costing was the prescribed method for deciding among bidders in the bus procurement process for a short while. It fell into disfavor primarily because agencies felt they couldn't trust life cycle cost data provided by the manufacturers and because those life cycle costs were likely to change over the life of the bus.

The authors of this report have dealt with the problem of uncertainty in life cycle cost data in a number of types of capital purchase decisions. In this report, they discuss the applications of these methods to the transit industry and describe a computer program written to assist transit personnel in making these decisions. The program was written to be used easily by people unfamiliar with computers. It is written in BASIC so that it can be easily implemented on any type of personal computer.

17. Key Words	18. Distribution Statement
bus purchase, capital decision-making, computer, life cycle costing	Document is avilable to the U.S. public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
unclassified	unclassified	35	

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1. Introduction

The problem of replacing capital equipment is one of the most important fiscal decisions facing public transit properties. Such decisions are qualitatively changing due to reduced federal involvement in funding and regulation of capital procurement projects. The problems facing properties now are much closer to equipment replacement problems found in the private sector.

The replacement methods most commonly used in the public transit industry are lowest bid and life cycle costing. Life cycle costing is the only rational alternative. The lowest bid technique is mathematically equivalent to assuming that fuel efficiency, maintenance, and other operating expenses have no fiscal impact. Cases are abundant where lowest bid selection leads to uneconomical decisions--for example, whenever two replacement alternatives have substantially different fuel or maintenance costs. However, life cycle costing is much more difficult to implement due to greater data requirements and data uncertainty.

As the federal government reduces involvement in capital projects, it becomes increasingly important that valid engineering economic criteria, i.e., life cycle costing, be used in decision making. Failure to do so may lead to great financial losses for public transit properties.

Research on this problem must then concentrate on the problems associated with life cycle costing. Besides the data uncertainty mentioned above, the state of the art in engineering economic techniques, prior to this study, was unable to solve problems with the generality found in the transit industry. Specifically, no technique was able to handle both changing technologies (improved fuel efficiency, increased maintenance on more sophisticated systems, etc.) and consider a time frame sufficient to accurately balance effects such as high purchase cost versus reduced fuel cost. Both of these abilities are necessary to make economic decisions in the problems faced by transit properties.

Even if all of these shortcomings are sufficiently addressed, engineering economics cannot hope to provide a complete solution to the capital replacement problem. These decisions are managerial in nature. That is, they are affected by two classes of problem characteristics: qualitative constraints and effects such as political and social considerations, and quantitative effects such as economic impact. For the forseeable future, the qualitative aspects of these decisions are best made by experienced managers and are not addressed in this study. We restrict ourselves to the quantitative parts of the problem. If we can develop a computer based system to evaluate these impacts quickly and accurately, the manager is freed to devote more time to the qualitative aspects of the problem. The overall effect should be a better, more informed equipment replacement decision.

The objectives of this project were:

1) Extend the state of the art in engineering economics to the point where problems with the complexity found in the transit industry can be solved quickly and accurately on a microcomputer.

2) Describe a method by which this system can be used to deal with uncertain data.

3) Develop a prototype microcomputer code implementing this research to prove that the techniques described in 1) can be implemented to run fast enough to be of use in 2).

Section two follows with a discussion of the engineering economic background of the equipment replacement problem. Section three deals with an approach to data uncertainty. The fourth section describes the prototype code developed. Finally, section five presents a summary and conclusions.

2. The Equipment Replacement Problem

Equipment replacement has been studied in the field of engineering economics since the 1940's. Important contributions to this problem include Terbough [1949] and Alchian [1952]. The initial models assume that technology is stationary. That is, the equipment available tomorrow is identical to that available today. The question was simply when do maintenance costs get sufficiently high to warrant replacing the equipment with an identical, though newer, copy.

For most problems faced today this simple assumption is too constraining. For example, in deciding when and what microcomputer to buy, the driving factor is the anticipated obsolescence of any machine purchased. In bus replacement, newer buses can be expected to have better fuel efficiency. As the federal government imposed many design restrictions on bus manufacturers in the 1970's, in maintenance costs, this industry faced the opposite of technological improvement called technological degradation. That is, the new buses available cost more to maintain. Technological degradation also requires the ability to model changing technology.

Models such as those of Wagner [1975], and Oakford, Lohmann, and Salazar [1984] began to incorporate changing technology. However, the disadvantage was that they were unable to solve the indefinite horizon version of the problem. That is, they assumed some fixed study horizon without determining if this choice affected the solution. The effect of this shortcoming is that the model has the potential of making myopic decisions. Any equipment replacement model evaluates the trade-off between purchase price and operating expenses. It is assumed that the more expensive the equipment, the more durable, reliable, or flexible it will be. In order to accurately make this trade-off a sufficiently long study horizon must be used. As the study horizon is shortened, the savings induced by, for example, better fuel efficiency are attenuated. However, the higher cost of the more efficient equipment is not. This induces a bias in favor of less expensive, less efficient equipment. If a long enough study horizon is used, this effect is eliminated. Mathematical techniques developed in the field of operations research can be used to determine a sufficiently long horizon. These techniques are presented in Bean and Smith [1984].

In order to make an accurate assessment of the economic impact of alternative replacement scenarios it is necessary to model both changing technology and an indefinite time horizon. The first model to successfully address these tasks is Bean, Lohmann, and Smith [1985]. This work was supported in part by this grant.

The basic technique used to solve the model is dynamic programming (see Wagner [1975]). Given some study horizon, this technique considers all possible sequences of replacements over that horizon in order to choose the most economic. The number of such sequences is very large. However, the technique considers only a small subset in solving the problem. The key to this technique is the <u>principle of optimality</u>. If the optimal replacement strategy for some horizon has a replacement in year n, for any n, then the solution consists of the optimal solution for years 1 through n, concatenated with the optimal solution from n through the horizon. Hence, any sequence of replacements including a replacement at year n can be disregarded if it is not made up of a concatenation of two optimal segments. The algorithm proceeds by solving a one-period problem, then a two-period problem, etc., until a problem of the desired horizon is solved. The intermediate results are used to speed up solution of the last problem. The result is a computationally efficient algorithm for considering all potential solutions to problems with that study horizon.

The study horizon can be shown to affect the solution in some cases. Hence, it is necessary to choose a sufficiently long study horizon to clear the initial replacement decisions of these errors. The model does this automatically, using the stopping rule proposed in Bean and Smith [1984].

Though this model does not explicitly handle uncertain data, the following section discusses how it can be used to help overcome this obstacle.

3. Data Uncertainty

Transit personnel report that much of the data necessary to do life cycle costing is not available, particularly for maintenance and fuel efficiency. Indeed, much of the ill will toward life cycle costing in the industry seems to have been generated by the fact that such data, provided by suppliers, has been inaccurate.

This has led many to take the attitude that if the dataare not known for some aspect of the problem, that aspect should be ignored. Unfortunately, this simplistic view has undesirable implications. Fuel efficiency is important to the equipment replacement decision, whether or not it is explicitly considered by the decision maker. The decision to ignore it is mathematically equivalent to assuming that the actual fuel cost is zero! While, for a new model bus, a transit manager may not know the exact fuel economy, it _is_ known that the fuel cost is not zero. In fact, managers commonly know a range in which it is nearly certain to fall. For example, one could assume a fuel efficiency between three and four miles per gallon. This sort of "distributional" information can be used to make much more enlightened decisions than can be made by ignoring fuel efficiency entirely.

There are two general approaches to dealing with data uncertainty. While the actual fuel economy is deterministic, since it is unknown, some approximation must be made. The error in this approximation can be viewed as a random effect. This randomness can be incorporated directly into the model as in Hopp, Bean, and Smith [1984], and Bean, Higle, and Smith [1984]. The solution to this stochastic model will "hedge" for the uncertainty. However, such models get extremely complicated and are not yet to the point of being implementable in transit properties.

Alternatively, a deterministic model, such as that presented in section 2, can be used to do sensitivity analysis on the solution. For example, consider the unknown fuel efficiency problem from above. The model could be solved with efficiency set at three miles per gallon, and then again with efficiency at four miles per gallon. If in both cases the same replacement decision is chosen, that decision would not be sensitive to fuel efficiencies in the range of three to four miles per gallon. Even though the exact efficiency is not known, the decision can still be confidently held to be optimal. If the decisions change over this range of values, one could compare the economic impact of the change. If it is very small, the decision is still insensitive to this uncertain value.

At times the range in which some datum falls will be wide enough that the solution is sensitive. This is an indication that more research must be done to get a better estimate of the true value. Even if no better value is available, at least the manager is aware of the potential consequences of this uncertainty, rather than ignoring it, as is done in the low-bid approach.

Realistically there are many uncertain values. The model can be rerun with combinations of these values to determine sensitivity to their uncertainty. With a non-computer-based system for economic analysis, this approach is prohibitively time consuming. However, with a microcomputer system such as that presented here, dozens of scenarios can be evaluated in the time it would take to do one by hand. This points out the need for an efficient code, as mentioned in objective number 3.

4. BUSREP A Prototype Bus Replacement System

Appendix A contains a printout of BUSREP, a code to solve bus replacement problems. The code is written in BASIC for an IBM PC. This language is sufficiently transportable that, with minor modifications, it could be run on any microcomputer system that supports BASIC.

This code incorporates the state-of-the-art engineering economic technology for equipment replacement. However, it is implemented in such a way that anyone experienced with microcomputers and bus replacement problems should be able to use it after viewing the user's guide in Appendix D.

This code is designed to establish the feasibility of using state-of-the-art engineering economic and operations research techniques to solve actual transit problems. To be widely used by transit property personnel, the code must go through a development phase. This involves tailoring the front end and back end of the code to fit closely with the jargon and conventions currently used by transit personnel. The code has been designed so that such alterations should be straightforward.

One area of extension is the potential types of changing technology. The code currently contains three types commonly found in equipment replacement problems. As this system is further developed, other types of particular interest in the transit industry will be discovered. These extensions can easily be added to the system.

The system can also be used to study various scenarios of future federal assistance programs. For example, the input data could reflect only the transit-property's portion of costs for each future year. Each scenario would lead to a different data set, based on a changing federal contribution. Currently, this type of study must be done by altering the data file to reflect each scenario. In the development phase, the ability to do such analysis could be included as an automatic feature.

There are many other potential enhancements of this basic system. However, as they are added, the system will get slower and less transportable. One of the primary tasks of a development phase will be determining which enhancements are worth this cost.

5. Summary and Conclusions

In the past two years we have attempted to evaluate the equipment replacement problems facing transit properties, and use techniques from engineering economics and operations research to improve the capability to solve these problems. The primary deficiencies in current solution methods were seen to be data unavailability and uncertainty, and lack of sophistication in the state-of-the-art models. This resulted in the use of simplistic and inaccurate approaches such as lowest bid.

New models, such as those of Bean, Lohmann, and Smith [1985], were developed to handle both changing technology and indefinite study horizons, so that, for the first time, problems of the complexity found in the transit industry could be solved accurately.

This model can be used to do sensitivity analysis on the uncertain data points. In this way decisions can be made by knowing only ranges of values for data such as fuel efficiency and maintenance, rather than needing exact values. However, this technique is computer-intensive and requires fast microcomputer codes.

Finally, a code was written in BASIC on an IBM PC that is fast enough to do this analysis.

Following is a listing of the code and a user's guide. The guide includes a general description of the code and a detailed run-through of the input requirements. Also included is a sample of input and output.

Acknowledgement

We would like to thank Koth Ganesh for creating the code BUSREP.

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APPENDIX A: IBM PC BASIC CODE <u>BUSREP</u>


```
10 REM:A DYNAMIC REPLACEMENT PROGRAM FOR UMTA WRITTEN FOR
20 REM:PROFS.BEAN, LOHMANN AND SMITH,  FEBRUARY 1985.
25 REM:WRITTEN BY KOTH GANESH.
30 REM:THIS PROGRAM READS IN DATA FOR VARIOUS ALTERNATIVES, IN THE
40 REM:FORM OF BUSES,COMPUTES THEIR PRESENT VALUES,USES A
50 REM:DYNAMIC PROGRAM TO IDENTIFY AN "OPTIMAL"SEQUENCE OF REPLACEMENTS.
60 REM
70 DIM BTCF(5,6,100),PWF(100),PXSTM(100),IVAL(100),NAGE(5),TITLE$(5)
80 DIM FCOST(5),SV(5),PERCOST(5),COST$(5,6),N(6,5),VALUE(6,5),R$(5)
90 DIM ANNUALCOST(5),TOTCOST(5),CRC(5),IKEY(5)
100 DIM A(6,5),G(6,5),B(6,5),C(6,5),INDEX(5)
110 DIM FUN(5,6,100),JSEQ(100),TSEQ(100),IDEC(100),NPV(5,100)
120 REM:*************************************************
130 REM:THIS PART OF THE PROGRAM READS IN THE INPUT DATA.
140 REM
150 CLS
160 PRINT
170 PRINT "--------------------------------------------------------------";
180 PRINT "------------------"
190 PRINT "WELCOME TO BUSREP,A PROGRAM THAT AIDS IN REPLACEMENT";
200 PRINT " ECONOMY DECISION MAKING"
210 PRINT "--------------------------------------------------------------";
220 PRINT "------------------": PRINT:PRINT
230 PRINT " Main program menu "
240 PRINT "      Run new data.......Enter 1"
250 PRINT "      Run old data.......Enter 2"
253 PRINT "      Change old data....Enter 3"
260 INPUT " Enter number of your choice " ;CHOICE
270 IF CHOICE<>1 THEN IF CHOICE<>2 THEN IF CHOICE<>3 THEN PRINT "Incorrect Selection":GOTO 260
280 ON CHOICE GOTO 290,1660,1674
290 INPUT " Enter name of file in which data will be stored ";NEWFILE$:PRINT
300 OPEN NEWFILE$ FOR OUTPUT AS #1
310 PRINT " Enter Study period for the analysis(in years,between 0 and 100)"
320 INPUT STUDYPER : PRINT
330 IF STUDYPER > 0 THEN IF STUDYPER < 100 THEN 360
340 PRINT "**ERROR**  Study period should be a non-zero, positive entry"
350 PRINT "Current value of Study period is " STUDYPER :BEEP : GOTO 310
360 PRINT #1,STUDYPER
370 PRINT " Enter Interest rate to be used in calculations(as a decimal)"
380 INPUT RATE : PRINT : IF RATE < 0 THEN 370
390 PRINT #1,RATE
400 PRINT " Do you want savings reported (Y/N)"
410 INPUT SAVING$ :PRINT: IF SAVING$<>"Y" AND SAVING$<>"N" THEN 400
420 PRINT #1,SAVING$
430 PRINT " Do you want to use the stopping rule (Y/N)"
440 INPUT SLFH$:PRINT: IF SLFH$<>"Y" AND SLFH$<>"N" THEN 430
450 PRINT #1,SLFH$
460 PRINT " Do you want the longer version of the output printed (Y/N) "
470 INPUT LONG$ :PRINT: IF LONG$<>"Y" AND LONG$<>"N" THEN 460
480 PRINT #1,LONG$
490 PRINT " Does a defender exist for this analysis(Y/N)"
500 INPUT NFLAG$ : PRINT:IF NFLAG$<>"Y" AND NFLAG$<>"N" THEN 490
510 PRINT #1,NFLAG$
520 IF (NFLAG$ = "N") THEN 600
530 PRINT " If a defender exists,its data is read first ."
540 PRINT " Enter number of defender(s),(maximum of 2) "
550 INPUT NUM :PRINT
560 IF (NUM > 0 AND NUM <= 2) THEN 590
```

```
570 PRINT "**ERROR**  Maximum number of defenders must be two(2)"
580 PRINT " Current value is " NUM : BEEP : GOTO 540
590 PRINT #1,NUM
600 PRINT "How many bus vendors are involved?(maximum of 4)"
610 INPUT NUMCHALL : NOMC =NUMCHALL + NUM
620 PRINT #1,NUMCHALL
630 CLS
640 FOR J = NOMC TO 1 STEP -1
650   IF J >  NUMCHALL THEN 790
660   PRINT " Enter name of prospective bus for service"
670   INPUT TITLE$(J) : PRINT
680   PRINT #1,TITLE$(J)
690   PRINT"Enter maximum service life of the bus(in years,between 0 and 100)"
700   INPUT NAGE(J) : PRINT
710   IF NAGE(J) > 0 THEN 740
720   PRINT "**ERROR**  Service Life must be a non-zero, positive entry"
730   PRINT " Current value of service life is " NAGE(J):BEEP:GOTO 690
740   PRINT #1,NAGE(J)
750   PRINT " Enter purchase costs of the new bus"
760   INPUT FCOST(J) : PRINT : IF FCOST < 0 THEN 750
770   PRINT #1,FCOST(J)
780   GOTO  890
790   PRINT " Enter name of current bus in operation "
800   INPUT TITLE$(J) : PRINT
810   PRINT #1,TITLE$(J)
820   PRINT " Enter maximum service life of current bus (in years,between 0 and 100)"
830   INPUT NAGE(J) : PRINT : IF NAGE(J) > 0 THEN 850
840   PRINT " Current value of service life is " NAGE(J) : BEEP:GOTO 820
850   PRINT #1,NAGE(J)
860   PRINT" Enter salvage value of current bus (if any)"
870   INPUT SV(J) : PRINT : IF SV(J) < 0 THEN 860
880   PRINT #1,SV(J)
890   PRINT " Enter costs which occur periodically (Not yearly costs)" : PRINT
900   PRINT " Enter number of periodic costs (Maximum of 3)"
910   INPUT PERCOST(J)
920   PRINT #1,PERCOST(J)
930   FOR I = 1 TO PERCOST(J)
940     PRINT " Enter name of periodic cost number " I
950     INPUT COST$(J,I)
960     PRINT #1,COST$(J,I)
970     PRINT " Enter current " COST$(J,I)" costs,Interval(in years)between expenditure "
980     INPUT BTCF(J,I,0),N(I,J) : IF BTCF(J,I,0) < 0 THEN 970
990     IF N(I,J) > 0 THEN 1020
1000     PRINT " **ERROR**  Interval should be a non-zero, positive entry "
1010     PRINT " Current value of interval is " N(I,J):BEEP:GOTO 970
1020     PRINT #1,BTCF(J,I,0),N(I,J)
1030     PRINT " Enter " COST$(J,I)" cost at future periods "
1040     INPUT VALUE(I,J) : PRINT : IF VALUE(I,J) < 0 THEN 1030
1050     PRINT #1,VALUE(I,J)
1060     FOR T = N(I,J) TO NAGE(J) STEP N(I,J)
1070       BTCF(J,I,T) = VALUE(I,J)
1080       NEXT T
1090     NEXT I
1100     FOR I = 1 TO PERCOST(J)
1110       BTCF(J,I,NAGE(J)) = 0
1120       NEXT I
1130     PRINT " Now enter Operating Costs, which occur yearly" : PRINT
1140     PRINT " Enter number of annual costs (Maximum of 3)"
```

```
1150      INPUT ANNUALCOST(J)
1160      PRINT #1,ANNUALCOST(J)
1170      TOTCOST(J) = PERCOST(J) + ANNUALCOST(J)
1180      FOR I = (PERCOST(J)+1) TO TOTCOST(J)
1190        PRINT " Enter name of annual cost number" (I - PERCOST(J))
1200        INPUT COST$(J,I) : PRINT
1210        PRINT #1,COST$(J,I)
1220        PRINT " Enter " COST$(J,I) " costs "
1230        INPUT BTCF(J,I,1) : PRINT : IF BTCF(J,I,1) < 0 THEN 1220
1240        PRINT #1,BTCF(J,I,1)
1250        FOR T = 2 TO NAGE(J)
1260          BTCF(J,I,T) = BTCF(J,I,T-1)
1270          NEXT T
1280        NEXT I
1290 REM:***********************************************
1300 REM:ENTER FUNCTIONAL RELATIONSHIPS FOR SUCCESSORS.
1310 REM:INITIALIZE FUNCTIONS
1320 REM
1330        IF J >NUMCHALL THEN 1630:'FOR DEFENDER(S),SKIP FUNCTIONAL EQUATIONS
1340        PRINT " Do Cost Histories repeat (Y/N)"
1350        INPUT R$(J) : PRINT
1360        PRINT #1,R$(J)
1370        IF R$(J)="N" THEN 1440
1380        FOR T = 0 TO STUDYPER
1390          FOR I = 0 TO TOTCOST(J)
1400            FUN(J,I,T) = 1
1410            NEXT I
1420          NEXT T
1430        GOTO 1630
1440        PRINT " Enter technological coefficients(as a decimal)" : PRINT
1450        INPUT " Do Purchase costs have coefficients(Y/N)" ;P$
1460        PRINT #1,P$: IF P$ ="N" THEN 1500
1470        PRINT " Enter coefficients for Purchase costs " : PRINT
1480        INPUT A(0,J),G(0,J),B(0,J),C(0,J)
1490        PRINT #1,A(0,J),G(0,J),B(0,J),C(0,J)
1500        FOR I = 1 TO TOTCOST(J)
1510          PRINT " Do " COST$(J,I) " costs have coefficients(Y/N)"
1520          INPUT C$ : PRINT #1,C$
1530          IF C$ = "N" THEN 1570
1540          PRINT " Enter coefficients for " COST$(J,I) " costs "
1550          INPUT A(I,J),G(I,J),B(I,J),C(I,J) : PRINT
1560          PRINT #1,A(I,J),G(I,J),B(I,J),C(I,J)
1570          NEXT I
1580        FOR T = 0 TO STUDYPER
1590          FOR I = 0 TO TOTCOST(J)
1600            FUN(J,I,T)=(1+A(I,J)*T)*((1+G(I,J))^T)*(1+B(I,J)*(1-C(I,J)^T))
1610            NEXT I
1620         NEXT T
1630  NEXT J
1640 CLOSE #1
1650 GOTO 1710
1660 REM:****IF DATA ALREADY EXISTS,READ IT FROM APPROPRIATE DATA FILE
1670 GOSUB 3820
1672 GOTO 1710
1674 REM:****GO TO CHANGE ROUTINE IF ONLY SOME DATA IS TO BE ALTERED
1675 GOTO 5000
1676 REM :WRITE ALL DATA BACK INTO FILE
1677 GOSUB 6000
```

```
1678 GOSUB 3830
1680 REM:***************************************************
1690 REM:ECHO INPUT DATA FOR ALL BUSES
1700 REM
1710  LPRINT TAB(10):LPRINT CHR$(14)+CHR$(27)+CHR$(71);" BUS REPLACEMENT ANALYSIS ": LPRINT CHR$(27)+CHR$(72): LPRINT : LPRINT: LPRINT
1720  LPRINT TAB(10):LPRINT CHR$(27);"E";" Department of Industrial and Operations Engineering ": LPRINT TAB(10): LPRINT " The University of Michigan "
1730  LPRINT TAB(10) : LPRINT " Ann Arbor, Michigan 48109. " :LPRINT CHR$(27);"F": LPRINT : LPRINT
1740  LPRINT " DATE OF RUN :   "  DATE$ : LPRINT
1750  LPRINT " TIME OF RUN :   "  TIME$ : LPRINT : LPRINT
1760  LPRINT " *********************************************"
1770  LPRINT CHR$(14); "       INPUT DATA ECHO "
1780  LPRINT " *********************************************"
1790  LPRINT
1800  LPRINT  " NUMBER OF BUSES : ",NOMC  :  LPRINT
1810  LPRINT  " STUDY PERIOD : ",STUDYPER " Years" :  LPRINT
1820  LPRINT  " INTEREST RATE : ",RATE :  LPRINT
1830  FOR J = 1 TO NOMC
1840    LPRINT " *********************************************"
1850    LPRINT
1860    LPRINT " NAME OF BUS : ",TITLE$(J) :  LPRINT
1870    LPRINT " SERVICE LIFE OF BUS : ",NAGE(J) " Years" : LPRINT
1880    IF J <= NUMCHALL THEN 1910
1890    LPRINT " SALVAGE VALUE OF BUS : ",SV(J) " Dollars" : LPRINT: LPRINT
1900    GOTO 1920
1910    LPRINT " PURCHASE COST OF BUS : ",FCOST(J) " Dollars" : LPRINT:LPRINT
1920    LPRINT TAB(35) " PERIODIC COSTS "
1930    LPRINT TAB(35)"-----------------"
1940    LPRINT
1950    LPRINT TAB(30) " CURRENT           FUTURE          INTERVAL"
1960    LPRINT TAB(30) "(Dollars)         (Dollars)         (Years)
1970    FOR I = 1 TO PERCOST(J)
1980      LPRINT TAB(5)
1990      LPRINT USING"\                       \";COST$(J,I);:LPRINT USING "       ##,###";BTCF(J,I,0);:LPRINT USING "  ##,###";VALUE(I,J);:LPRINT USING "          ##";N(I,J)
2000      LPRINT
2010      NEXT I
2020       LPRINT TAB(35)" ANNUAL COSTS "
2030       LPRINT TAB(35)"--------------"
2040       LPRINT
2050       LPRINT TAB(30) " CURRENT"
2060       LPRINT TAB(30) "(Dollars)"
2070       FOR I = PERCOST(J)+1 TO TOTCOST(J)
2080         LPRINT TAB(5)
2090         LPRINT USING "\                       \";COST$(J,I);:LPRINT USING "       ##,###";BTCF(J,I,1)
2100         LPRINT
2110         NEXT I
2120    NEXT J
2130 FH = 1 : ITIM = 1
2140 NMAX = NAGE(1)
2150 FOR J = 2 TO NOMC
2160  IF NAGE(J) <= NMAX THEN 2180
2170  NMAX = NAGE(J)
2180  NEXT J
2190 REM:**************************************************
2200 REM: COMPUTE DISCOUNT FACTORS
2210 REM
```

```
2220 PWF(O) = 1
2230   FOR T = 1 TO STUDYPER : PWF(T) = PWF(T-1)/(1 + RATE) : NEXT
2240 REM:*******************************************
2250 REM MAKE ALL COSTS NEGATIVE
2260 FOR J = 1 TO NOMC
2270  FOR I = 1 TO TOTCOST(J)
2280    FOR T = O TO NAGE(J)
2290      BTCF(J,I,T) = - (BTCF(J,I,T))
2300      NEXT T
2310    NEXT I
2320   NEXT J
2330 REM:*******************************************
2340 REM:COMPUTE PRESENT VALUES OF CASH FLOWS
2350 PRINT
2360 PRINT"BEGIN COMPUTATIONS OF PRESENT WORTH " : PRINT
2370 FOR J = 1 TO NOMC
2380   IF FCOST(J) > O THEN FCOST(J) = -(FCOST(J))
2390   CRC(J) = FCOST(J) + SV(J)
2400  REM:*****************************************
2410  REM:COMPUTE PRESENT VALUE OF CAPITAL RECOVERY AND COSTS
2420  REM
2430   BTCF(J,O,O) = CRC(J) : NPV(J,O) = BTCF(J,O,O)
2440   FOR T = 1 TO NAGE(J)
2450     FOR I = O TO TOTCOST(J)
2460       BTCF(J,I,T) = BTCF(J,I,T-1) + BTCF(J,I,T)*PWF(T)
2470       NPV(J,T) = NPV(J,T) + BTCF(J,I,T)
2480       NEXT I
2490     NEXT T
2500   IF J <=NUMCHALL THEN 2520
2510   FOR T = (NAGE(J) + 1) TO STUDYPER : NPV(J,T) = -1E+31 : NEXT T
2520   NEXT J
2530 PRINT"END COMPUTATIONS OF PRESENT WORTH":PRINT:PRINT
2540 REM:************************************************
2550 REM
2560 REM:USE DYNAMIC PROGRAMMING AND COMPUTE RESULTS
2570 REM
2580 IF (NFLAG$ ="Y") AND (NUM = 1) THEN 2640
2590 IF (NFLAG$ ="Y") AND (NUM = 2) THEN 2680
2600 FOR T = O TO STUDYPER
2610 JSEQ(T) = O : TSEQ(T) = O : PXSTM(T) = -1E+31 : NEXT
2620 NJ = NOMC
2630 GOTO 2780
2640 FOR T = O TO STUDYPER
2650 JSEQ(T) = NOMC : TSEQ(T) = -1 : PXSTM(T) = NPV(NOMC,T) : NEXT
2660 NJ = NOMC - 1
2670 GOTO 2780
2680 FOR T = O TO STUDYPER
2690   TSEQ(T) = -1
2700   IF NPV(NOMC,T) <= NPV(NOMC-1,T) THEN 2740
2710   JSEQ(T) = NOMC
2720   PXSTM(T) = NPV(NOMC,T)
2730   GOTO 2760
2740   JSEQ(T) = NOMC - 1
2750   PXSTM(T) = NPV(NOMC -1,T)
2760   NEXT T
2770 NJ = NOMC - NUM
2780 PXSTM(O) = O
2790 REM:*******************************************
```

```
2800 REM:COMPUTE VALUES OF JSEQ(T),TSEQ(T),P(XS,T,M)
2810 REM
2820  PRINT "CONSIDERING PERIOD NUMBER: "
2830  PRINT "--------------------------"
2840  FOR TA = 1 TO STUDYPER : PRINT TA ;
2850    FOR J = 1 TO NJ
2860      IF (TA - NMAX) < O THEN X = O ELSE X =(TA - NMAX)
2870      FOR TR = X TO (TA - 1)
2880        N = TA - TR
2890        IF R$(J) = "N" THEN 2920
2900        PJTN = PXSTM(TR) + NPV(J,N)*PWF(TR)
2910        GOTO 2960
2920        PJTN = PXSTM(TR)
2930        FOR I = O TO TOTCOST(J)
2940          PJTN = PJTN + BTCF(J,I,N)*(FUN(J,I,TR))*PWF(TR)
2950          NEXT I
2960        IF PJTN <= PXSTM(TA) THEN 2990
2970        PXSTM(TA) = PJTN
2980        JSEQ(TA) = J : TSEQ(TA) = TR
2990        NEXT TR
3000      NEXT J
3010 REM:*********************************************
3020 REM:STOPPING RULE
3030 REM
3040    IF SLFH$="N" THEN 3170
3050    K = TA
3060    IF TSEQ(K) <= O THEN 3090
3070    K = TSEQ(K)
3080    GOTO 3060
3090    IDEC(TA) = JSEQ(K)
3100    IF (IDEC(FH) <>IDEC(TA)) OR (ITIM <>K) THEN 3140
3110    ISTP = TA - FH + 1
3120    IF ISTP = NMAX THEN 3210
3130    GOTO 3160
3140    FH = TA
3150    ITIM = K
3160    IF TA = STUDYPER  THEN 3210
3170    NEXT TA
3180 REM
3190 REM:END OF STOPPING RULE
3200 REM:**********************************************
3210 PH = TA
3220 STUDYPER = PH
3230 PRINT :PRINT:PRINT "CALCULATIONS OVER" : PRINT : PRINT
3240 BEEP
3250 REM:**************************************************
3260 REM:PRINT RESULTS OF THE DYNAMIC PROGRAM
3270 REM
3280 IDEC(O) = O
3290 IF LONG$ = "N" THEN 3400
3300 LPRINT CHR$(12)
3310 LPRINT "*******************************************************"
3320 LPRINT CHR$(14); "          RESULTS    "
3330 LPRINT "*******************************************************"
3340 LPRINT : LPRINT CHR$(27); "E"
3350 LPRINT " TIME        ASSET       TIME INSTALLED    PRESENT VALUE  "
3360 LPRINT " -------------------------------------------------------"
3370  FOR T = O TO STUDYPER
```

```
3380   LPRINT T,JSEQ(T),TSEQ(T),PXSTM(T)
3390   NEXT T
3400 IF SLFH$="N" THEN 3700
3410 IF ISTP <> NMAX THEN 3700
3420  LPRINT
3430  LPRINT " ASSET TO BE INSTALLED "
3440  LPRINT " --------------------- "
3450  LPRINT " Name of Bus : " TITLE$(IDEC(FH))
3460  LPRINT " Economic Life : " ITIM " Years"
3470  LPRINT " Forecast Horizon :" FH " Years"
3480  LPRINT " Net Present Value : " PXSTM(ITIM) " Dollars"
3490  LPRINT : LPRINT
3500  IF SAVING$ ="N" THEN 3800
3510   FOR K = 1 TO NOMC
3520     NPVMAX = -1E+31
3530     FOR II = 1 TO NOMC
3540       IF ( IKEY(II) > 0 ) THEN  3580
3550       IF (NPVMAX > NPV(II,ITIM)) THEN 3580
3560       JMAX = II
3570       NPVMAX = NPV(II,ITIM)
3580       NEXT II
3590     INDEX(K) = JMAX : IKEY(JMAX) = 1
3600     NEXT K
3610 PRINT: PRINT
3620 PRINT TAB(38) " SAVINGS(Dollars) " : PRINT TAB(38) " --------------- "
3630 LPRINT TAB(38) "SAVINGS(Dollars) ":LPRINT TAB(38) "--------------- "
3640  FOR K = 1 TO NOMC
3650  PRINT " Buy Bus "TITLE$(INDEX(1))" versus buy Bus "TITLE$(INDEX(K+1));:COLOR 31:PRINT USING "        ###,###";NPV(IN
DEX(1),ITIM)- NPV(INDEX(K+1),ITIM) :COLOR 7,0 : PRINT
3660  LPRINT " Buy Bus "TITLE$(INDEX(1))" versus buy Bus "TITLE$(INDEX(K+1));:LPRINT USING "        ###,###";NPV(INDEX(1),
ITIM)-NPV(INDEX(K+1),ITIM) : LPRINT
3670  IF (K + 1) = NOMC THEN 3795
3680  NEXT K
3690  GOTO 3795
3700 LPRINT :LPRINT:LPRINT " NO FORECAST HORIZON FOUND "
3710 LPRINT: LPRINT
3720 T = STUDYPER
3730 IF TSEQ(T)<= 0 THEN 3750
3740 T = TSEQ(T) : GOTO 3730
3750 LPRINT  " ASSET TO BE INSTALLED "
3760 LPRINT  " --------------------- "
3770 LPRINT " Name of Bus : "TITLE$(IDEC(T))
3780 LPRINT " Economic Life :"T "Years"
3790 LPRINT " Net Present Value :" PXSTM(T) "Dollars"
3795 INPUT " Do you want to run more data " ;M$
3796 IF M$ = "Y" THEN 230
3800 END
3810 REM :*****READ DATA FROM EXISTING DATA FILE
3820 INPUT " Enter name of file in which data is stored " ;OLDFILE$
3830 OPEN OLDFILE$ FOR INPUT AS #2
3840 INPUT #2,STUDYPER
3850 INPUT #2,RATE
3860 INPUT #2,SAVING$
3870 INPUT #2,SLFH$
3880 INPUT #2,LONG$
3890 INPUT #2,NFLAG$
3891 IF NFLAG$ ="N" GOTO 3910
3900 INPUT #2,NUM
```

```
3910 INPUT #2,NUMCHALL
3920 NOMC = NUM + NUMCHALL
3930 FOR J = NOMC TO 1 STEP -1
3940   IF J > NUMCHALL THEN 3990
3950   INPUT #2,TITLE$(J)
3960   INPUT #2,NAGE(J)
3970   INPUT #2,FCOST(J)
3980   GOTO 4020
3990   INPUT #2,TITLE$(J)
4000   INPUT #2,NAGE(J)
4010   INPUT #2,SV(J)
4020   INPUT #2,PERCOST(J)
4030   FOR I = 1 TO PERCOST(J)
4040     INPUT #2,COST$(J,I)
4050     INPUT #2,BTCF(J,I,O),N(I,J)
4060     INPUT #2,VALUE(I,J)
4070     FOR T = N(I,J) TO NAGE(J) STEP N(I,J)
4080       BTCF(J,I,T) = VALUE(I,J)
4090       NEXT T
4100     NEXT I
4110   FOR I = 1 TO PERCOST(J)
4120     BTCF(J,I,NAGE(J)) = O
4130     NEXT I
4140   INPUT #2,ANNUALCOST(J)
4150   TOTCOST(J) = PERCOST(J) + ANNUALCOST(J)
4160   FOR I = (PERCOST(J)+1) TO TOTCOST(J)
4170     INPUT #2,COST$(J,I)
4180     INPUT #2,BTCF(J,I,1)
4190     FOR T = 2 TO NAGE(J)
4200       BTCF(J,I,T) = BTCF(J,I,T-1)
4210       NEXT T
4220     NEXT I
4230   IF J > NUMCHALL THEN 4450
4240   INPUT #2,R$(J)
4250   IF R$(J)="N" THEN 4320
4260   FOR T = O TO STUDYPER
4270     FOR I = O TO TOTCOST(J)
4280       FUN(J,I,T) = 1
4290       NEXT I
4300     NEXT T
4310   GOTO 4450
4320   INPUT #2,P$
4330   IF P$ = "N" THEN 4350
4340   INPUT #2,A(O,J),G(O,J),B(O,J),C(O,J)
4350   FOR I = 1 TO TOTCOST(J)
4360     INPUT #2, C$
4370     IF C$ = "N" THEN 4390
4380     INPUT #2,A(I,J),G(I,J),B(I,J),C(I,J)
4390     NEXT I
4400   FOR T = O TO STUDYPER
4410     FOR I = O TO TOTCOST(J)
4420       FUN(J,I,T) = (1+A(I,J)*T)*((1+G(I,J))^T)*(1+B(I,J)*(1-C(I,J)^T))
4430       NEXT I
4440     NEXT T
4450 NEXT J
4460 CLOSE #2
4470 RETURN
4999 REM:CHANGE OLD DATA APPROPRIATELY
```

```
5000 REM:PROGRAM INITIALLY PRINT A MENU
5001 FLAG = 0
5002 CLS
5005 PRINT " This is a change menu "
5006 PRINT "       Change initial options for program....Enter 1"
5009 PRINT "       Change service life and cash flows....Enter 2"
5012 PRINT "       Change tech. coefficients.............Enter 3"
5013 PRINT "       No more changes.......................Enter 4"
5015 INPUT " Enter a number of your choice " ; CHANGE
5018 IF CHANGE<>1 THEN IF CHANGE<>2 THEN IF CHANGE<>3 THEN IF CHANGE<>4 THEN PRINT " Incorrect Selection " :GOTO 5015
5021 ON (CHANGE+FLAG) GOSUB 5100,5400,5700,1676,5107,5402,5702,1676
5025 GOTO 5002
5100 REM:*****THIS ROUTINE CHANGES INITIAL OPTIONS FOR THE ANALYSIS
5103 GOSUB 3810
5106 REM : ASK USER FOR CHANGES TO BE MADE
5107 CLS
5108 PRINT " Current value of study period is " STUDYPER
5109 INPUT " Do you want to change the study period(Y/N) ";ANS$
5112 IF ANS$ ="N" THEN 5117
5115 INPUT " Enter new value of study period ";STUDYPER :PRINT
5116 IF STUDYPER < 0 OR STUDYPER > 100 THEN 5115
5117 PRINT :PRINT " Current value of interest rate is " RATE
5118 INPUT " Do you want to change the interest rate(Y/N) "; ANS$
5119 IF ANS$ = "N" THEN 5123
5121 INPUT " Enter new value of interest rate ";RATE :PRINT
5122 IF RATE <`0 THEN 5121
5123 PRINT :INPUT " Is there any change for the defender(Y/N) " ;ANS$
5124 IF ANS$ = "N" THEN 5141
5127 INPUT " Does a defender exist for this analysis(Y/N) "; NFLAG$
5130 IF NFLAG$<>"Y" AND NFLAG$<>"N" THEN 5127
5133 IF NFLAG$ ="N" THEN 5141
5136 INPUT " Enter number of defender(s),(maximum of 2) "; NUM :PRINT
5139 IF NUM > 0 AND NUM <= 2 THEN 5141
5140 GOTO 5136
5141 PRINT :PRINT " Current number of bus vendors is " NUMCHALL
5142 INPUT " Do you want to change number of bus vendors(Y/N) " ;ANS$
5143 IF ANS$ ="N" THEN 5152
5145 INPUT " How many bus vendors are involved?(maximum of 4)";NUMCHALL
5148 IF NUMCHALL > 0 AND NUMCHALL <=4 THEN 5152
5151 GOTO 5145
5152 FLAG = 4
5154 RETURN
5400 REM:*****THIS ROUTINE CHANGES CASH FLOW DATA
5401 GOSUB 3810
5402 CLS
5403 FOR J = NOMC TO 1 STEP -1
5407  PRINT " Are there any changes to be made for bus " TITLE$(J) "(Y/N)"
5410  INPUT ANS$
5411  IF ANS$ = "N" THEN 5529
5412  PRINT :PRINT " Current value of service life for bus " TITLE$(J) "is" NAGE(J)
5414  INPUT " Do you want to change service life of the bus(Y/N)";ANS$
5417  IF ANS$ ="N" THEN 5423
5420  INPUT " Enter new service life of bus " ; NAGE(J) :PRINT
5423  IF J > NUMCHALL THEN 5440
5424  PRINT :PRINT " Current purchase cost of bus is " FCOST(J)
5426  PRINT " Do you want to change purchase cost of bus " TITLE$(J) "(Y/N)"
5429  INPUT ANS$
5432  IF ANS$ ="N" THEN 5438
```

```
5435 INPUT " Enter new purchase cost for bus " ; FCOST(J) : PRINT
5438 GOTO 5454
5440 PRINT :PRINT " Current salvage value of bus is " SV(J)
5441 PRINT " Do you want to change salvage value of bus " TITLE$(J) "(Y/N)"
5442 INPUT ANS$
5445 IF ANS$ = "N" THEN 5454
5448 INPUT " Enter new salvage value for the bus " ; SV(J) : PRINT
5451 REM:CHANGE PERIDIC CASH FLOW DATA
5454 INPUT "Do you want to change any periodic cash flow data(Y/N)";ANS$
5457 IF ANS$ ="N" THEN 5502
5460 FOR I = 1 TO PERCOST(J)
5463  PRINT :PRINT "Do you want to change data for " COST$(J,I) " costs(Y/N)"
5466   INPUT ANS$
5469   IF ANS$ ="N" THEN 5499
5470   PRINT :PRINT "Current costs are " BTCF(J,I,0)
5472   INPUT "Do you want to change current costs(Y/N)" ;ANS$
5475   IF ANS$="N" THEN 5480
5478   INPUT "Enter new value for current costs " ;BTCF(J,I,0)
5480   PRINT :PRINT "Current value of interval of expenditure(in years) is " N(I,J)
5481   INPUT "Do you want to change interval of expenditure(Y/N)" ;ANS$
5484   IF ANS$ = "N" THEN 5489
5487   INPUT "Enter new value for interval of expenditure ":N(I,J)
5489   PRINT :PRINT "Current value of future costs is " VALUE(I,J)
5490   INPUT "Do you want to change future costs(Y/N)" ; ANS$
5493   IF ANS$ ="N" THEN 5499
5496   INPUT "Enter new value for future costs "; VALUE(I,J)
5499   NEXT I
5502 REM:CHANGE ANNUAL COST DATA
5503 PRINT
5505 INPUT "Do you want to change any annual cash flow data(Y/N)" ; ANS$ : PRINT
5508 IF ANS$ ="N" THEN 5529
5511 FOR I = (PERCOST(J)+1) TO TOTCOST(J)
5512   PRINT :PRINT "Current value of " COST$(J,I) " costs is " BTCF(J,I,1)
5514   INPUT "Do you want to change data for this cost(Y/N)";ANS$
5520   IF ANS$ ="N" THEN 5526
5523   INPUT "Enter new value for this cost" ;BTCF(J,I,1)
5526   NEXT I
5529 NEXT J
5530 FLAG = 4
5532 RETURN
5700 REM:***** CHANGE TECHNOLOGICAL COEFFICIENTS
5701 GOSUB 3810
5702 CLS
5703 FOR  J = NOMC TO 1 STEP -1
5704   IF J > NUMCHALL THEN 5742
5705   IF R$(J)="Y" THEN PRINT "Cost histories repeat for bus " TITLE$(J):GOTO 5707
5706   PRINT "Cost histories do not repeat for bus "TITLE$(J) :PRINT
5707   INPUT "Do you want to change this assumption(Y/N)";A1$: PRINT
5708   IF A1$="N" AND  R$(J)="Y" THEN 5742
5709   IF A1$="N" AND  R$(J) ="N" THEN 5714
5710   IF A1$ ="Y" AND R$(J)="N" THEN  5712
5711   IF A1$="Y" AND R$(J) ="Y" THEN 5713
5712   R$(J) = "Y" :GOTO 5742
5713   R$(J) = "N"
5714   PRINT "Do you want to change any coefficients for bus " TITLE$(J) "(Y/N)"
5715   INPUT ANS$ :PRINT: IF ANS$ ="N" THEN 5742
5716   PRINT :PRINT " Current coefficients for purchase costs are " A(0,J);G(0,J);B(0,J);C(0,J)
5717   INPUT "Do you have new coefficients for purchase cost(Y/N)";P$
```

```
5718   IF P$ ="N" THEN 5724
5722   PRINT " Enter new values for purchase costs coefficients"
5723   INPUT A(O,J),G(O,J),B(O,J),C(O,J):PRINT
5724   FOR I = 1 TO TOTCOST(J)
5728    PRINT :PRINT "Current coefficients for " COST$(J,I) " are " A(I,J);G(I,J);B(I,J);C(I,J)
5730    INPUT "Do you have new coefficients for this cost(Y/N)";C$
5733    IF C$ ="N" THEN 5739
5735    PRINT " Enter new values for these coefficients "
5736    INPUT A(I,J),G(I,J),B(I,J),C(I,J)
5739    NEXT I
5742  NEXT J
5743 FLAG = 4
5745 RETURN
6000 REM:*****WRITE ALL DATA BACK INTO FILE
6003 REM:*** FIRST CLEAR ALL OLD DATA FROM DATA FILE
6006 KILL OLDFILE$
6009 OPEN OLDFILE$ FOR OUTPUT AS #3
6012 PRINT #3,STUDYPER
6013 PRINT #3,RATE
6015 PRINT #3,SAVING$
6018 PRINT #3,SLFH$
6021 PRINT #3,LONG$
6024 PRINT #3,NFLAG$ :IF NFLAG$ ="N" THEN 6028
6027 PRINT #3,NUM
6028 PRINT #3,NUMCHALL
6033 FOR J = NOMC TO 1 STEP -1
6036   IF J > NUMCHALL THEN 6051
6039   PRINT #3,TITLE$(J)
6042   PRINT #3,NAGE(J)
6045   PRINT #3,FCOST(J)
6048   GOTO 6060
6051   PRINT #3,TITLE$(J)
6054   PRINT #3,NAGE(J)
6057   PRINT #3,SV(J)
6060   PRINT #3,PERCOST(J)
6063   FOR I = 1 TO PERCOST(J)
6066     PRINT #3,COST$(J,I)
6069     PRINT #3,BTCF(J,I,O),N(I,J)
6072     PRINT #3,VALUE(I,J)
6084     NEXT I
6096   PRINT #3,ANNUALCOST(J)
6102   FOR I = (PERCOST(J)+1) TO TOTCOST(J)
6105     PRINT #3,COST$(J,I)
6108     PRINT #3,BTCF(J,I,1)
6120     NEXT I
6123   IF J > NUMCHALL THEN 6174
6126    PRINT #3,R$(J)
6129    IF R$(J) ="N" THEN 6141
6140    GOTO 6174
6141    PRINT #3,P$
6142    IF P$ = "N" THEN 6150
6147    PRINT #3,A(O,J),G(O,J),B(O,J),C(O,J)
6150    FOR I = 1 TO TOTCOST(J)
6151     PRINT #3,C$
6152     IF C$ ="N" THEN 6156
6153     PRINT #3,A(I,J),G(I,J),B(I,J),C(I,J)
6156     NEXT I
6174    NEXT J
```

```
6177 CLOSE #3
6179 RETURN
```

APPENDIX B: SAMPLE DATA INPUT

```
--------------------------------------------------------------------------------
WELCOME TO BUSREP,A PROGRAM THAT AIDS IN REPLACEMENT ECONOMY DECISION MAKING
--------------------------------------------------------------------------------



 Main program menu
      Run new data.......Enter 1
      Run old data.......Enter 2
      Change old data....Enter 3
 Enter number of your choice ? 1
 Enter name of file in which data will be stored ? BUS.DAT

 Enter Study period for the analysis(in years,between 0 and 100)
? 50

 Enter Interest rate to be used in calculations(as a decimal)
? .1

 Do you want savings reported (Y/N)
? Y


 Enter Study period for the analysis(in years,between 0 and 100)
? 50

 Enter Interest rate to be used in calculations(as a decimal)
? .1

 Do you want savings reported (Y/N)
? Y

 Do you want to use the stopping rule (Y/N)
? Y

 Do you want the longer version of the output printed (Y/N)
? Y

 Does a defender exist for this analysis(Y/N)
? Y

 If a defender exists,its data is read first .
 Enter number of defender(s),(maximum of 2)
? 1

How many bus vendors are involved?(maximum of 4)
? 1
```

```
Enter name of current bus in operation
? OLDBUS

 Enter maximum service life of current bus (in years,between 0 and 100)
? 7

 Enter salvage value of current bus (if any)
? 2000

 Enter costs which occur periodically (Not yearly costs)

 Enter number of periodic costs (Maximum of 3)
? 1
 Enter name of periodic cost number  1
? ENGINE OVERHAUL
 Enter current ENGINE OVERHAUL costs,Interval(in years)between expenditure
? 5000,5
 Enter ENGINE OVERHAUL cost at future periods
? 5000

 Enter number of annual costs (Maximum of 3)
? 1
 Enter name of annual cost number 1
? FUEL

 Enter FUEL costs
? 30000

 Enter name of prospective bus for service
? GM

Enter maximum service life of the bus(in years,between 0 and 100)
? 15

 Enter purchase costs of the new bus
? 150000

 Enter costs which occur periodically (Not yearly costs)

 Enter number of periodic costs (Maximum of 3)
? 1
 Enter name of periodic cost number  1
? ENGINE OVERHAUL
 Enter current ENGINE OVERHAUL costs,Interval(in years)between expenditure
? 0,5
 Enter ENGINE OVERHAUL cost at future periods
? 5000
```

```
 Now enter Operating Costs, which occur yearly

 Enter number of annual costs (Maximum of 3)
? 1
 Enter name of annual cost number 1
? FUEL

 Enter FUEL costs
? 24000

 Do Cost Histories repeat (Y/N)
?



 Enter number of annual costs (Maximum of 3)
? 1
 Enter name of annual cost number 1
? FUEL

 Enter FUEL costs
? 24000

 Do Cost Histories repeat (Y/N)
? N

 Enter technological coefficients(as a decimal)

 Do Purchase costs have coefficients(Y/N)? Y
 Enter coefficients for Purchase costs

? 0,.05,0,0
 Do ENGINE OVERHAUL costs have coefficients(Y/N)
? N
 Do FUEL costs have coefficients(Y/N)
? Y
 Enter coefficients for FUEL costs
? 0,-.05,0,0
```

BUS REPLACEMENT ANALYSIS

Department of Industrial and Operations Engineering
The University of Michigan
Ann Arbor, Michigan 48109.

DATE OF RUN : 06-24-1985

TIME OF RUN : 00:13:27

****
INPUT DATA ECHO
****

NUMBER OF BUSES : 2

STUDY PERIOD : 50 Years

INTEREST RATE : .1

****

NAME OF BUS : GM

SERVICE LIFE OF BUS : 20 Years

PURCHASE COST OF BUS : 150000 Dollars

PERIODIC COSTS

	CURRENT (Dollars)	FUTURE (Dollars)	INTERVAL (Years)
ENGINE OVERHAUL	0	5,000	5

ANNUAL COSTS

	CURRENT (Dollars)
FUEL	24,000

****

NAME OF BUS : OLDBUS

SERVICE LIFE OF BUS : 7 Years

SALVAGE VALUE OF BUS : 2000 Dollars

PERIODIC COSTS

	CURRENT (Dollars)	FUTURE (Dollars)	INTERVAL (Years)
ENGINE OVERHAUL	5,000	5,000	5

ANNUAL COSTS

	CURRENT (Dollars)
FUEL	30,000

****

RESULTS

****

TIME	ASSET	TIME INSTALLED	PRESENT VALUE
0	2	-1	0
1	2	-1	-30272.73
2	2	-1	-55066.11
3	2	-1	-77605.56
4	2	-1	-98095.95
5	2	-1	-119828.2
6	2	-1	-136762.4
7	2	-1	-152157.2
8	1	4	-264949.9
9	1	6	-274995.2
10	1	6	-281797
11	1	7	-287729.5
12	1	7	-294662.9
13	1	7	-299517.8
14	1	7	-303931.2
15	1	7	-307943.4
16	1	7	-311590.9
17	1	7	-315896
18	1	7	-318910.5
19	1	7	-321650.9
20	1	7	-324142.2
21	1	7	-326407
22	1	7	-329080.1
23	1	7	-330951.8
24	1	7	-332653.4
25	1	7	-334200.3
26	1	7	-335606.6
27	1	7	-336885
28	1	27	-380018.4
29	1	27	-380397.2
30	1	27	-380741.5

	SAVINGS(Dollars)
Buy Bus OLDBUS versus buy Bus GM	117,790

Do you want to run more data ?

APPENDIX D: BUSREP User's Guide

INSTRUCTIONS FOR USING BUSREP

INTRODUCTION

BUSREP is a computer program, written in BASIC for the IBM PC, that can be used in replacement economy studies involving buses.

Purchase Options

All replacement options are considered to be in one of three categories. A defender is the bus currently being used. One option is to continue using the old bus. A rehabilitated old bus is considered another type of defender. A challenger is a new bus that may be chosen to replace the defender. Buses available in the future are called successors. They may differ from challengers because of lower fuel costs or different maintenance characteristics. Such changes are called technological improvement (if things are getting cheaper) or technological degradation (if they are getting more expensive). Successors are important because the choice to keep an old bus implies a future purchase of some successor.

Equipment Lives

There are two types of lives important to equipment: physical life and economic life. Physical life is the length of time the equipment is capable of providing the desired service. This is a known characteristic of the equipment. The economic life of equipment is the length of time until it is economically superior to replace the equipment. This life can be less than or equal to the physical life. Economic life is a decision variable that must be determined as part of the equipment replacement problem.

BUSREP solves either fixed or indefinite horizon dynamic programs to determine which bus should be in service at any time, its purchase time and its economic service life.

BUSREP is an interactive program which prompts the user for all required data. The data is then stored in a permanent file. Given below is a listing of each prompt by BUSREP, a brief explanation and appropriate replies by the user.

GETTING STARTED

After initiating the BUSREP program, the user will be asked to choose between old data and new data.

The computer gives the menu:

```
RUN NEW DATA.....ENTER 1
RUN OLD DATA.....ENTER 2
CHANGE OLD DATA..ENTER 3
```

New data means that the data will be requested from the terminal and stored automatically. In order to recall such a file, request old data. The third option, change old data, puts the user in the built in editor.

If the user chooses new data, the system asks:

ENTER NAME OF FILE IN WHICH DATA IS TO BE STORED

The user should input any file name legal on their system.

If the user chooses old data, the system asks:

ENTER NAME OF FILE IN WHICH DATA IS STORED

To change old data the user is then allowed to alter individual data. This process is described in a later section.

If new data is requested the system then begins its data query. Following is a detailed description of these requests.

REVIEW OF INPUTS

1) ENTER STUDY PERIOD FOR THE ANALYSIS (IN YEARS, BETWEEN 0 AND 100)

The study period is that span of time over which the user is interested in doing a replacement analysis. For fixed horizon studies, the study period is the number of years for which the service is required. For an indefinite horizon study, the study period is used as a cut-off time after which the program terminates if a forecast horizon has not been found.

The user inputs a number between 0 and 100 (the maximum number permitted).

Example : 40

2) ENTER INTEREST RATE TO BE USED IN CALCULATION (AS A DECIMAL)

This is the discount rate or cost of capital to be used in the analysis.

The user inputs a decimal between 0 and 1.

Example : .10

3) DO YOU WANT SAVINGS REPORTED (Y/N)

This option prints savings (in net present value) accrued by choosing the economically optimal bus over other available alternatives.

The user inputs Y(=Yes) if he/she wants savings printed, else the input is N(=No).

4) DO YOU WANT TO USE THE STOPPING RULE (Y/N)

The purpose of the rule is to terminate program execution when enough data has been generated to guarantee that there is no error in the initial decision due to too short a horizon. The program stops at the horizon specified in 1) if not before. The user inputs Y to use the stopping rule, else N. In applications this question should always be answered Y.

5) DO YOU WANT THE LONGER VERSION OF THE OUTPUT PRINTED (Y/N)

This option prints a longer version of the output which includes the condensed version too. It is recommended that the condensed version be used for all practical purposes.

The user inputs Y for the longer version, N for the condensed version. In applications this question should always be answered N.

6) DOES A DEFENDER EXIST FOR THE ANALYSIS (Y/N)

As defined above, a defender is any bus that is currently in service.

The user inputs Y if such a bus does exist, else N. For all replacement problems the answer should be Y. N is appropriate when a new fleet is being purchased so that there are no old buses.

7) ENTER NUMBER OF DEFENDER(S), (MAXIMUM OF 2)

Normally there is only one defender. The exception is if one option is rehabilitating the bus. Then one defender could be the bus rehabilitated and the other defender is the bus in current condition.

8) HOW MANY BUS VENDORS ARE INVOLVED (MAXIMUM OF 4)

This question refers to the number of different types of new buses that could provide the same service. For example, GM, FLEXIBLE, etc.

The user inputs a number between 1 and 4, inclusive.

Cost Data Input

The next data section deals with cost data for the various buses. There are two types of costs: annual and periodic. Annual costs include driver, fuel, routine maintenance, etc. Periodic costs are less frequent such as engine overhaul. The user is prompted to give names and values for periodic and annual costs for each defender and challenger. All costs are input as positive numbers. Do not include dollar signs. It is important to note that data for the defender(s) should be input first. Almost all prompts are the same for both defender and challengers.

9) ENTER NAME OF CURRENT BUS IN OPERATION

This normally refers to the manufacturer's name for the defender.

The user inputs the relevant name. If one option is a rehabilitated GM bus then the user may input...

Example : REHAB/GM

10) ENTER MAXIMUM SERVICE LIFE OF CURRENT BUS (IN YEARS, BETWEEN 0 AND 100)

This refers to the remaining physical life of the defender after which it must be scrapped.

The user inputs the remaining physical life of the defender.

Example : 20

11) ENTER SALVAGE VALUE OF CURRENT BUS (IF ANY)

This is the amount that can be obtained on disposal of the defender, for example as scrap.

Example : 2000

12) ENTER NUMBER OF PERIODIC COSTS

These are costs that do not occur every year such as engine overhaul. The maximum number of such costs is 3.

13) ENTER NAME OF PERIODIC COST NUMBER____

The name given to a particular cost type.

Example : ENGINE OVERHAUL

14a) ENTER CURRENT ____ COSTS, INTERVAL (IN YEARS) BETWEEN EXPENDITURE

This asks for the cost (in dollars) incurred at time zero, and how often this cost incurred (in years).

For example : If the defender incurs say, ENGINE OVERHAUL costs of $5000 at time zero, and this cost is incurred every 10 years, then the data would be input as ?5000, 10. If no cost is incurred at time zero, then 0 should be input.

14b) ENTER _____ COST AT FUTURE PERIODS

This is related to the above question. The user should input the cost (in dollars) which will be incurred at every n^{th} year, where n is the number of years input above.

For example, if ENGINE OVERHAUL costs are 5000 every time such a cost is incurred, the user inputs ?5000. Thus, the data structure for a periodic cost is as follows:

Cost now, period of occurrence

Cost in future periods

This sequence is repeated as many times as there are such cost types.

NOTE: Rehabilitating buses is handled in this manner. For cost now input rehab cost. For period of occurrence input any positive integer. For cost in future periods input zero.

15) ENTER NUMBER OF ANNUAL COSTS

These are costs that occur annually such as fuel and routine maintenance. The user inputs a number between 1 and 3. The maximum number is 3.

16) ENTER NAME OF ANNUAL COST NUMBER_____

The user supplies a name to an annual cost type.

Example : FUEL

17) ENTER ____ COSTS

The user inputs the annual cost (in dollars)

Example : 30000.

This question is repeated as many times as there are annual cost types.

The above sequence of prompts are the same for new buses except that question 11 is replaced by

11') ENTER PURCHASE COST OF NEW BUS

The user inputs the appropriate cost amount, as a positive number.

Technological Change

The last section of data input requires the user to input values for "technological coefficients". These coefficients represent the effect of technological change on future new buses in terms of their cash flows. It is important to note that the user can input these values only for challengers. Functional relationships do not exist for the defender.

BUSREP provides for four pre-programmed functional relationships. The user can use only one of these four for each cost flow type.

These relationships are best understood through examples:

Cost Histories Repeat: This option assumes that cash flows of future buses are identical to those of buses available today.

Example: The purchase cost of a bus today as well as ten years from now is $100,000.

BUSREP prompts the user thus DO COST HISTORIES REPEAT (Y/N)

Depending upon the assumptions used in the analysis, the user inputs either Y or N. BUSREP will prompt for technological coefficient values only when the user inputs N to the question.

Technological change is manifested either as an improvement or as degradation. The user should input negative values for technological improvement and positive values for degradation. BUSREP uses the following format to prompt for these coefficients:

ENTER COEFFICIENTS FOR ____ COSTS

Input four values representing linear, geometric and bounded geometric change over time. Examples of each follow.

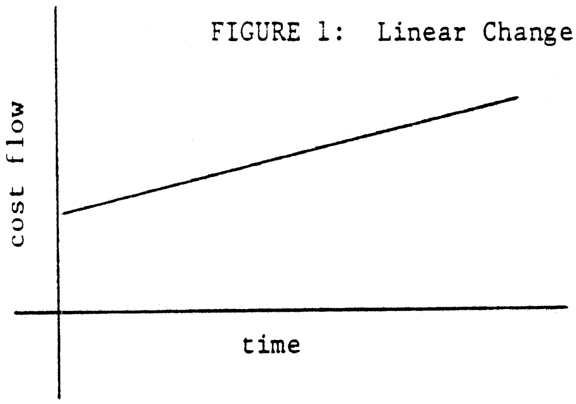
Examples of their use:

1) Linear effect: This option assumes that cash flows of future buses vary linearly with respect to those of current buses.

Example: Suppose the purchase cost of a new bus today is $100,000. Further suppose that this cost increases by $10,000 every year, i.e., it costs $110,000 next year, $120,000 two years from now etc. Then the user would input a non-zero value in the first position. Specifically for this example the value is .10 since the cost increases each year by .10 times 100000. It is positive since costs increase. Thus, the format for data input would be

Note: the user should input zeroes for the other three coefficients. In general, if one coefficient is non-zero, the others should be zero.

FIGURE 1: Linear Change



2) Exponential effect: This assumes that a cash flow is varying by a constant percentage every year with respect to its current value.

Example: Let fuel costs for a current bus, made by GM, be $30000 annually. If fuel costs for a new bus, also made by GM, decrease by 10% every year, then the dollar amounts would be $27000 next year, $24300 two years from now, etc. The user would input

0,-.10,0,0.

The coefficient is negative since we assumed fuel costs decrease.

Note that this does not imply that fuel costs are changing on the bus in operation. Rather, the fuel costs for buses sold new in future years will be lower that costs for the current bus.

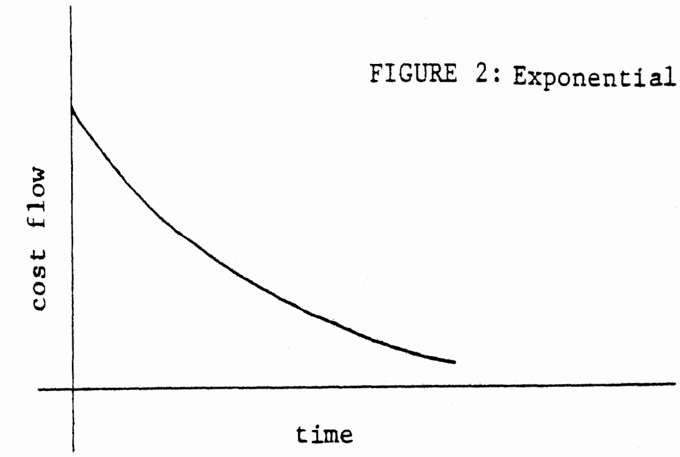


FIGURE 2: Exponential Change

3) Bounded exponential effect: This option assumes technology changes decrease at a given rate, C, converging to some total change B.

Note that C always takes a value between 0 and 1. If B > 0 then it is an increasing function, else B < 0 implies a decreasing function.

Use of these coefficients is illustrated through 2 examples:

Example #1: Suppose fuel costs of future buses have an overall decrease of 25%. Each year's decrease is 90% of the decrease in the previous year.

Then,

C = .90

B = -.25

Thus, the user would input

0,0,-.25,.90.

Example #2: Suppose fuel costs ultimately gain 100% of its current value (i.e., double). The increase each year is 80% of the previous year's increase.

Then,

C = .8

B = 1.0

The format then is

0,0,1.0,.8

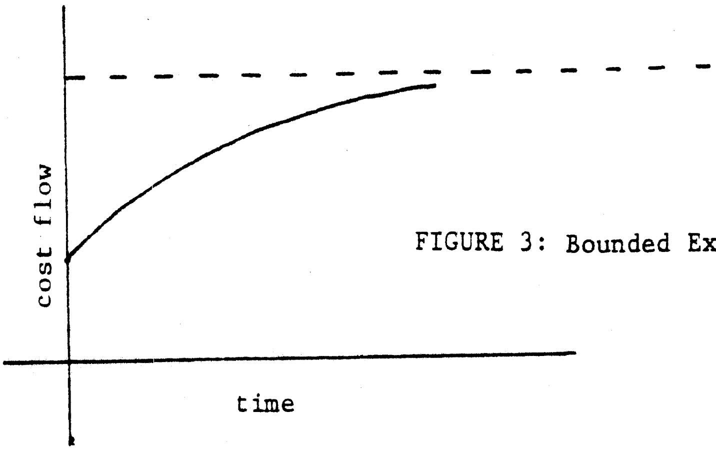


FIGURE 3: Bounded Exponential Change

Thus for each cash flow, if there is any technological change, the corresponding coefficients are input as described above.

In this fashion, the entire process is repeated for all buses in the analysis.

Changing Old Data

The option to edit old data allows the user to choose which section of the data to examine and then leads through each datum stating the old value and asking for a replacement. The initial menu is:

```
CHANGE INITIAL OPTIONS...............ENTER 1
CHANGE SERVICE LIFE AND CASH FLOWS...ENTER 2
CHANGE TECH. COEFFICIENTS............ENTER 3
NO MORE CHANGES......................ENTER 4
```

The initial options section is comprised of horizon, discount rate, and number of defenders or challengers. The other sections are clear.

Once a section is chosen, the data for that section is run through in the same order as the initial input. The format is:

CURRENT VALUE FOR _______ IS ###.

DO YOU WANT TO CHANGE _______?

If N (=NO), this is repeated for the next datum. If Y (=YES), the user is instructed:

ENTER NEW VALUE FOR _______.

When this process is completed, the section choice menu is displayed so that another section may be altered.