Spacing of Grade Separations on Rural Freeways

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This paper proposes methods for economic analysis to aid in determining where to provide grade separations on new freeways. Three hypothetical situations were investigated, with estimates made of reorganization of travel, and changes in travel costs, using a net present worth economic analysis. Results indicate that presently used methods tend to overestimate travel benefits from grade separations.

•THIS paper describes an investigation of the warrants for spacing of grade separations on rural freeways. The study dealt mainly with warrants based on economic criteria which are only a portion of the relevant criteria. There are three general classifications of pertinent criteria:

1. Continuity. To perform their function in the road system many roads must be continuous. For example, if the road intersecting the freeway is an arterial or collector then for continuity it should be grade separated.
2. Public Interest (non-economic). The public interest of the area local to grade separation locations, includes: (a) division of communities, (b) disruption of public services, such as fire protection and school districts, and (c) the level of local road service.
3. Economic Considerations. The balancing of the cost of the grade separations against the additional travel costs, the value of landlocked properties, and other economic costs of not providing the grade separations.

The first criterion generally overrules the others. If a grade separation is warranted because of route continuity then that is sufficient justification. If this criterion does not apply then the decision must be made by applying criterion 2 (comparing non-monetary costs and benefits), in conjunction with an economic analysis (applying criterion 3).

This research is concerned only with applying criterion 3; the problems of quantifying the non-monetary considerations and making the final decision are outside the scope of this investigation (1).

MAIN ASSUMPTIONS

1. It was assumed that the rural highway system would be classified into four basic road systems: freeway, arterial, collector and local (e.g. freeway, state primaries, state secondary and county primaries, and local roads). Any intersection of freeway with freeway or freeway with arterial, because of the first criterion, would warrant an interchange, which includes a grade separation. Since a collector road requires continuity, it was assumed that freeway-collector intersections would be grade separated.
2. Intersections of local roads with a rural freeway never require interchanges but may be grade separated or terminated. Connection of a terminated local road to a frontage road can also be treated by the analysis.

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TABLE 1

COSTS AND BENEFITS FOR RURAL GRADE SEPARATIONS

Costs	Benefits
Cost of grade separation:	Reduction in circuity of travel:
Construction	Time savings
Maintenance	Vehicle operating costs
	Comfort and convenience
Loss of property tax revenues	Accident costs
Increased maintenance costs on approach roads	Decreased maintenance costs on terminated road

3. After a freeway is constructed, the travel patterns of people residing in the vicinity of the freeway will change from the pre-freeway pattern. These changes will take place over a number of years and once completed the resulting travel behavior can be modeled by a traffic model such as the gravity model.

ECONOMIC ANALYSIS

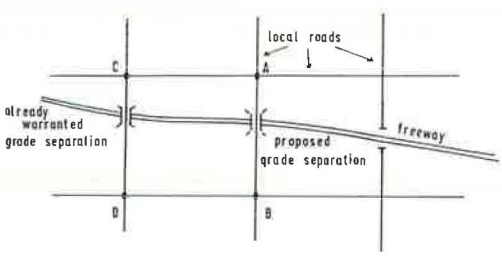
The factors to be considered in the economic analysis are given in Table 1. For most rural areas the most important are the cost of the grade separations and the costs or benefits of circuity of travel. Comparisons of costs and benefits were carried out by the Net Present Worth method. The interest rate used was 7 percent but this was varied to test the sensitivity of the results. A 20-yr analysis period was used and it was not varied (3) because a similar study indicated the analysis period was not critical (2). The travel benefits were measured as changes in vehicle-miles and vehicle-minutes of travel. The former were evaluated by applying the unit monetary values given in Woods (3) for 0 to 3 percent composite grades and 15 percent single-unit trucks. The value of travel time used was $1.20 per vehicle-hour (4). As recommended by AASHO (5) a convenience cost of one cent per mile of travel on the local gravel roads and zero cents on all paved roads was assumed.

ESTIMATES OF ADDITIONAL TRAVEL

The central concern of the investigation was the estimation of the additional vehicle-miles and vehicle-minutes of circuitous travel if any given combination of grade separations were or were not provided.

The existing method for estimating circuity of travel is shown in Figure 1. The additional travel cost is based on rerouting all traffic from the nearest intersection on one side of the freeway to the nearest intersection on the other side of the freeway by the nearest grade separation. There are two difficulties with this estimate. First, the interaction between adjacent grade separations is not considered. Second, not all traffic is necessarily required to be completely rerouted and may, in fact, suffer no excess travel if a particular grade separation is not provided. In the proposed method these difficulties are overcome by treating a system of grade separations and considering the whole route of a trip rather than a small segment of its route.

The travel costs considered in the analysis were limited to trips made by existing or future inhabitants of the existing stock of dwelling units. The future travel benefits generated by dwelling units constructed in the future should not be counted, since in locating these units, due consideration would be given to the travel costs involved, regardless of the spacing and location of grade separations decided upon.



BENEFITS = travel cost (path ACDB − path AB)(vol. AB)

Figure 1. Current practice in measuring travel benefits for grade separations

It was postulated that immediately after the construction of the freeway, if any local roads were terminated, the local pattern of trip origins and destinations would be the same as before the freeway. Later, because of the longer travel distances, changes in family life cycles, changes in occupants, etc., this travel pattern would, over a period of time, reorganize to some stable level. Furthermore, this reorganization of travel could be simulated by a traffic model. One further assumption was that the change in the

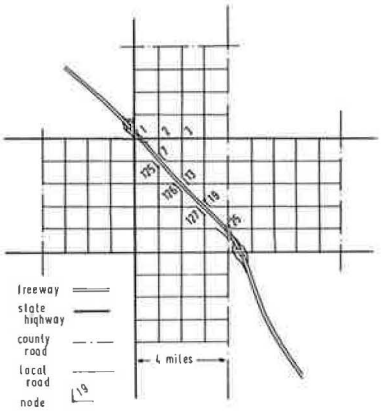


Figure 2. Example problem

TABLE 2

TRAVEL CHARACTERISTICS OF ONE-WAY DAILY PERSON TRIPS FOR RURAL AREAS OF OZAUKEE AND WASHINGTON COUNTIES, WISCONSIN

(Excluding Truck Drivers)[a]

Trip Purpose		No. of Trips (per day)	Average Trip Length (miles)	Average Trip Speed[b] (mph)	Average Generation, Trips per Household
To home:	car driver	2493	10.81	30.6	1.95
	car passenger	1019	9.09	30.9	0.80
	school bus	555	4.61	10.0	0.43
	truck passenger	18	14.18	31.8	0.014
Work:	car driver	1373	13.21	33.0	1.072
	car passenger	153	11.35	32.1	0.119
	truck passenger	11	13.59	32.0	0.009
Personal Business:	car driver	897	6.99	27.0	0.70
	car passenger	253	9.77	30.8	0.198
	truck passenger	9	12.23	33.7	0.007
Medical:	car driver	81	11.60	30.4	0.063
	car passenger	28	16.08	32.6	0.022
School:	car driver	63	17.25	38.5	0.049
	car passenger	352	3.84	19.2	0.275
	school bus	572	4.63	10.0	0.447
	truck passenger	2	—	—	—
Social Eat meal:	car driver	192	8.97	29.9	0.150
	car passenger	119	10.83	33.9	0.093
Shop:	car driver	451	7.17	26.8	0.352
	car passenger	156	8.61	30.0	0.122
	truck passenger	1	—	—	—
Recreation:	car driver	89	18.01	59.3	0.070
	car passenger	69	28.89	85.0	0.054

[a]Sample—1261 households.
[b]Average trip speed includes terminal time.

level of travel would be at a uniform rate from completion of the freeway until complete reorganization of trip ends.

EXAMPLE PROBLEM

The hypothetical situation in Figure 2 was used as an example. The section of freeway being analyzed is between node 1 and node 25. At these locations grade separations are warranted because of continuity of the state highway and county road systems. The grade separation spacing problem is to determine which combinations of the three possible grade separation sites, 7-125, 13-126 and 19-127, are economically justified. The combinations tested were (a) no grade separations, (b) only grade separation 13-126, (c) grade separations 7-125 and 19-127, and (d) all three grade separations.

Figure 2 also shows the extent of the detailed analysis area. In this area all local roads were included in the coded network and every intersection was a loading node. The boundary of this area is defined by locations of the points of cost indifference, for trips desiring to cross the freeway, in the area between points 1 and 25. Trips originating outside the boundaries are not affected from the cost standpoint by presence of a potential grade separation. This detailed analysis area was surrounded by a buffer area in which the zones gradually increased in size.

Rural trip generation rates, trip length distributions, and trip time distributions were extracted from the home interview data of the Southeastern Wisconsin Regional Planning Study for two rural counties (Table 2). These generation rates were applied to the households in the example area. The population density was about 70 persons per square mile. The siting of the sample area corresponds to the actual rural framework approximately 30 miles from Milwaukee.

RESULTS WITH CONVENTIONAL TRAFFIC MODELS

Two traffic models, an uniterated gravity model (i.e., attractions were not normalized to input values) and a revised version of the opportunity model were calibrated to the Wisconsin travel data, using in each case a four-trip-purpose model. (In the revised model the opportunities are discounted over distance to obtain a fit to the trip length distribution without using the concept of short and long trips; a test of this model in urban areas is presently being carried out.) An uniterated gravity model was used as it was considered desirable for the trip destinations to be unconstrained. Trip generation rates were held constant and the two trip distribution models along with a minimum path assignment were used to simulate the travel behavior of the pre-freeway

situation. They were then applied to the post-freeway networks being tested. The differences between the pre-freeway vehicle-miles and minutes of travel and those for each of the post-freeway networks provided the estimates of the circuity of travel.

At this point a comparison of these additional travel estimates was made against a logical upper limit. This upper limit was the additional travel found from an assignment of the pre-freeway O-D table to the post-freeway grade separation combinations being tested. This assumed that all trips would be made to their original distinations in spite of the excess travel involved (no reorganization of trip ends).

The traffic model estimates of additional travel in all cases were two or three times greater than these upper limit estimates. This meant that the total vehicle-miles and vehicle-minutes predicted by both the gravity and the revised opportunity models were very sensitive to small changes in the network. This was found to be due mainly to the nature of the trips involved. Both models attempt to reproduce the calibrated trip distribution or "average" trip. In the case of grade separations on local roads the trips involved are "non-average" as they are as a group shorter than the average trip. In effect, this characteristic led in the application of the gravity and opportunity models to replacing some shorter non-average trips by longer average trips (6). The remedy suggested was to look for a model which simulated only the shorter, non-average group of trips, i.e., those using the potential grade separation locations.

This sensitivity of predicted total vehicle-miles and minutes of travel to changes in the road network that affect non-average trips indicates extreme caution should be used when utilizing outputs of these traffic models to evaluate networks (7, 8). For example, in comparing two possible urban networks, an extensive freeway system and an all-arterial system, the differences in the networks affect longer than average trips and the differences in total travel estimated would probably be greater than might be expected. This sensitivity of the uniterated, gravity model and the opportunity model came to light in the grade separation case because a logical check on the answer was available in the form of the upper limit estimate. Logical checks for predictions in urban areas are more difficult to obtain.

An interated gravity model (i.e., model attractions made equal to input values) was also used to simulate travel and estimate the additional travel costs. On the basis of the results of models described later the iterated gravity model underestimated the additional travel costs by about 40 percent, but it was much better than the uniterated gravity model or the opportunity model. It is clear that more work is required in this area and that caution is necessary in using traffic models to predict differences in travel between different road networks.

TRAFFIC MODELS FOR GRADE SEPARATION TRIPS ONLY

Two methods were used to simulate travel behavior for only those trips using the potential grade separation locations (7-125, 13-126 and 19-127). The first method was to isolate the origins and destinations of these "grade separation" trips and calibrate a gravity model to these trips. This was done by utilizing the trip origins as generations in the model and the trip destinations as attractions. The calibrated model reproduced the trip length distributions satisfactorily but was 13 percent low in predicting trips that crossed the freeway.

The second method, called a heuristic model, was again derived from the pre-freeway traffic using the potential grade separation locations. It was hypothesized that these trips were a model of the traffic behavior. That is, the set of individual trips made before the freeway is constructed are a representative set of all likely trip patterns that would be described by a traffic model of local travel behavior, given the local land use and road network. Then the additional travel for any post-freeway situation, after complete reorganization of trip ends, is simulated by considering the possible changes for the set of pre-freeway trips. For each trip the maximum additional travel for the post-freeway trip would be a trip between the same origin and destination. The minimum additional travel would be zero under conditions where an alternative destination, equal in all respects, and the same travel distance is available to the trip. This could be the pre-freeway destination. In between these two limits it was assumed

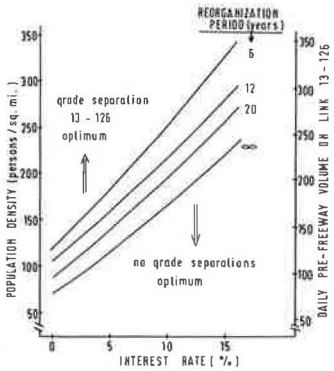


Figure 3. Solution space for example problem.

that the expected additional travel, after complete reorganization of trip ends, for any trip in the model set, would be one-half of the upper limit. All traffic models indicate a preference for shorter trips that would suggest an expected value less than one-half. On the other hand, many of the alternative destinations for any trip would have a longer travel distance in the post-freeway network. These tendencies were assumed to balance each other.

This model is a heuristic "guestimate" that requires checking. There is some evidence that travel does reorganize and at a lower level than the upper limit (9, 10). However, the importance of the assumed value of one-half is moderated by the time period selected for complete reorganization of trip ends.

RESULTS FOR THE EXAMPLE PROBLEM

The two models of grade separation trips were used to estimate the additional travel for the four combinations of grade separations tested in the example. These travel estimates were evaluated at $1.20 per vehicle-hour and the appropriate operating costs for the vehicle-miles. Then the additional travel cost for each combination of grade separations being tested was calculated for each of the 20 years of the analysis period. Three periods for complete reorganization of trip ends were used: 6, 12 and 20 years. The present worth of each series was found and the construction cost of the grade separations subtracted to find the net present worth.

The optimum solution was taken as the maximum net present worth for a given interest rate and reorganization period. One further step was to solve for the breakpoint between selection of the no-grade-separation solution as optimum and the central grade separation, 13-126 as optimum, both in terms of population density and pre-freeway traffic volumes. Figure 3 is the solution space for the example problem. Results are shown for the heuristic model for three reorganization periods and for the upper limit estimate of no reorganization of trip ends which corresponds to an infinite reorganization period. The grade separation gravity model not shown gave slightly higher estimates of additional travel than the heuristic model, thus requiring less traffic to justify the central grade separation. The discrepancy between the two models is relatively negligible in comparison with the effect of changes in the interest rate.

When the average population density reaches 1,200 persons per square mile, the optimum solution for the example problem is construction of all three grade separations, assuming an interest rate of zero percent and a reorganization period of 12 years.

The breakpoint between the no-grade-separation solution and the one-grade-separation solution being optimum is given by the following empirical equation.

$$\text{Average pre-freeway volume on central grade separations} = \frac{K \cdot C \cdot e^{-.021RP}}{e^{-(.038I + .1068\sqrt{I})}} \qquad (1)$$

where

K = a constant for a particular class of freeway alignment, distance between warranted grade separations, etc.;

C = cost of the central grade separation less any construction costs incurred if it were not built ($1,000);

I = interest rate (%); and

RP = reorganization period (years) (up to 30 years).

Three cases have been investigated, as follows: (a) a diagonal freeway with 4 miles between continuity-warranted grade separations (Fig. 2), (b) the case of a freeway paralleling a complete-grid local road system and 5 miles between continuity-warranted grade separations, and (c) a freeway paralleling an irregular grid of local roads with 4 miles between warranted grade separations. The values of K for the three cases are 1.0, 1.97 and 2.50, respectively.

In each case, the heuristic model was used to estimate the completely reorganized trip ends. This method was used because of its ease for practical applications. Field measurements can be made to establish the O-D pattern of the pre-freeway traffic at potential grade separation locations. This trip matrix can then be assigned to the proposed configurations of grade separations to yield an estimate of both the initial additional travel as well as the additional travel after reorganization of trip ends.

A computer program was written to make a selected O-D minimum path assignment for this type of field data. It is given in the Appendix. The outputs of the program are the vehicle-minutes of travel and the vehicle-miles of travel by road system, as well as a link volume table.

GENERAL DISCUSSION

It is expected that by taking field measurements of O-D trip patterns, utilizing the assignment program and applying appropriate values of travel costs, an agency could develop K-values for a variety of local characteristics (see Appendix for methodology). After the initial development period then Eq. 1 could be used directly to provide the economic indicator for optimizing grade separation locations on new freeways.

As previously mentioned, non-economic warrants must also be considered. The investigation indicated that for most rural areas the number of grade separations on local roads warranted by an economic analysis is small, with most local roads needing to be terminated. A recent study in Illinois (11) found that in practice the reverse is true; more local roads are grade separated than terminated. There are two explanatory factors. Consideration of non-economic factors will tend to justify more grade separations than indicated by the economic analysis. Also, existing methods as outlined in Figure 1 overestimate the additional travel costs. For example the existing methods applied to the problem in Figure 2 overestimated the additional travel costs of not providing the grade separation by about 300 percent.

With regards to non-economic costs and benefits it should be remembered that the breakpoints in Figure 3 are points of economic indifference between two solutions. Movement away from a breakpoint strengthens the economic benefit to be obtained from the indicated solution, but in the region of the breakpoint the economic warrant is relatively weak and more importance should be attached to non-economic criteria.

For the example problem solution space in Figure 3, with 7 percent interest rate and 12-yr reorganization period the economic indifference point is at a pre-freeway volume of 170 vehicles per day crossing the freeway. At a volume of 70 vehicles per day the cost of selecting the uneconomic solution—providing the grade separation—is $86,000. At a volume of 140 vehicles per day the cost is $32,000. Such costs as these must be balanced against non-economic benefits.

CONCLUSIONS

1. The investigation indicated that for a 4-mi spacing between continuity-warranted grade separations, a diagonal freeway and a 1-mi grid of local roads, an interest rate of 7 percent, 12 years for complete reorganization of trip ends and grade separation costs of $140,000 each, additional grade separations are not economically warranted on local roads at pre-freeway volumes of less than 170 vehicles per day desiring to cross the freeway. In the example problem, this represented a population density of about 170 persons per square mile.

2. The economic warrant for grade separations is sensitive to the angle of the freeway with the local road network and also to the interest rate assumed.

3. The use of traffic models to estimate changes in total vehicle-miles and vehicle-minutes of travel between networks which affect non-average trips is subject to error and should only be done with caution.

4. The concept of reorganization of trip ends over time and the resulting decrease in travel benefits has a significant effect on the economic warrant for grade separations.

ACKNOWLEDGMENT

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REFERENCES

1. Jessiman, W., et al. A Rational Decision-Making Technique for Transportation Planning. Highway Research Record 180, pp. 71-80. 1967.
2. Satterly, G. T., Jr., and Berry, D. S. Spacing of Interchanges and Grade Separations on Urban Freeways. Highway Research Record 172, pp. 54-93, 1967.
3. Woods, K. B., Ed. Highway Engineering Handbook, McGraw-Hill, New York, 1960.
4. Haney, Dan. G. The Value of Travel Time for Passenger Cars; A Preliminary Study. Stanford Research Institute, Menlo Park, Calif., 1963.
5. American Association of State Highway Officials. Road User Benefit Analysis for Highway Improvements. Washington, D.C., 1960.
6. Shortreed, J. H. Location of Grade Separations on Rural Freeways. PhD dissertation, Northwestern Univ., 1966.
7. Metropolitan Toronto Planning Board. The Metropolitan Toronto Transportation Plan, Toronto, 1964.
8. A. M. Voorhees and Associates. Evaluation of Alternatives, Erie Area Transportation Study. Washington, D.C., 1965. [Also the London (England) Transportation Study is using these outputs to evaluate networks.]
9. McKinney, D. The Division of Rural Land by Limited-Access Highway. Bureau of Business Research, Univ. of Mississippi, 1961.
10. Hovey, R. M., and Pine, W. H. Impacts of Interstate and Turnpike Highways on Kansas Farms. Agriculture Economics Report No. 104, Kansas State Univ., 1964.
11. Wegmann, F. J., et al. Existing Practice-Location of Interchanges and Grade Separations in the State of Illinois. Northwestern Univ., 1966.

Appendix

ANALYSIS PROCEDURE AND COMPUTER PROGRAM

Analysis Procedure

To carry out the analysis of a particular situation, the following procedure is suggested.

1. Obtain roadside O-D information for vehicles using all local roads between the already warranted grade separations.
2. Code the O-D information and also code as large a local road network as necessary.

TABLE 3

FACTORS TO CONVERT ANNUAL TRAVEL COSTS TO NET PRESENT WORTH WITH REORGANIZATION OF TRIP ENDS[a]

Time for Complete Reorganization of Trip Ends (years)	Interest Rate (%) 0	7	15
6	11.50	6.57	4.20
12	13.00	7.55	4.84
20	15.00	8.52	5.34

[a]Assuming a linear decline in annual cost until it is one-half its initial value, and a 20 year analysis period.

3. For each of the potential grade-separation spacings, run the computer analysis program, deleting links which represent terminated roads.

4. Apply unit costs of vehicle operation and travel time to the outputed vehicle-miles and vehicle-minutes, to give an annual travel cost by road system.

5. Convert annual travel cost to Net Present Worth using the factors in Table 3. For each solution find the reduction in net present worth of travel costs from the no-grade separation solution less the construction cost for the solution. The solution with the largest positive value is optimum. If none are positive the no-grade separation solution is optimum.

Computer Analysis Program

Inputs (with Fortran Format)

1. Title Card, 55H.
2. Proportion of travel time, F10.0, The proportion of travel time (0.0 to 1.0) in the linear combination of travel time and travel distance used to build the cost trees. A value of 0.5 is suggested for rural conditions.
3. Trees to be printed out, 25I3, up to 25 trees arranged in numerical order.
4. Travel speeds on road systems, 5F10.0, a single speed for each classification of road system, in order.
5. Coded road network—node from, node to, road system classification, link length: 3I5, F10.0, one card for each link with a dummy link, node from = 999, to end.
6. O-D trips to be loaded—origin node, destination node, number of trips: 3I5, one card for each O-D movement with a dummy origin = 999, to end.

Outputs

1. Listing of minimum cost trees.
2. Volumes assigned to links—directional.
3. Vehicle-miles and vehicle-minutes by road system and for the total area.

PROGRAM LISTING FOR ASSIGNMENT OF ORIGINS AND DESTINATIONS

```
$JOB    WATFOR   P0251J.B.KERR,PAGES=150
$TIME            6
C       ASSIGNMENT PROGRAM FOR AN EXAMPLE CITY
        DIMENSION  I(225),J(225),NLINK(225),DIST(225),TMDS(225),LF(100),
      1  NSEE(25),VOL(225),NSYS(225),VEHTIM(5),VEHMIL(5),SPEED(5),
      2  NORDR(100)
        READ(5,5)
        READ(5,24)C
   24   FORMAT(F10.0,I5)
C       READ TREES TO SEE IN ORDER
        READ(5,939)(NSEE(N),N=1,25)
  939   FORMAT(25I3)
        READ(5,940) (SPEED(K),K=1,5)
  940   FORMAT(5F10.0)
        NX=1
 5      FORMAT(55H COMMENTS
        WRITE(6,5)
C       READ NETWORK LINKS
        DO 21 IT=1,3000
```

```
      READ(5,2)I(IT),J(IT),NSYS(IT),DIST(IT)
    2 FORMAT(3I5,F10.0)
      IF (I(IT).EQ.999) GO TO 22
      N=NSYS(IT)
      TMDS(IT)=C*(DIST(IT)*SPEED(N))+((1.-C)*DIST(IT))
 21   CONTINUE
 22   LL=IT-1
      WRITE(6,23)LL
   23 FORMAT(13H NO. OF LINKSI5)
      NFRMO=0
C     SET UP LF REGISTER
      LF(1)=I(1)
      NODES=1
      KN=1
      DO 1001 KNL=1,LL
      IF(I(KNL)-KN)1002,1001,1004
 1002 WRITE(6,1005)I(KNL)
 1005 FORMAT(20H ERROR IN NETWORK I=I5)
      GO TO 1001
 1004 KN=I(KNL)
      NODES=NODES+1
      LF(KN)=KNL
 1001 CONTINUE
      KNOD = NODES
      WRITE(6,715)NODES
  715 FORMAT(14H NO. OF NODES=I5)
C     BUILD TREE
      VTIM = 0.0
      VDIST=0.0
      DO 6002  NNN=1,225
 6002 VOL(NNN)=0.0
 1207 READ(5,1202)NFRM,NTO,NTRP
 1202 FORMAT(3I5)
      IF(NFRM-999)1204,1203,1204
 1204 FNTP=NTRP
      IF(NFRM-NFRMO)1206,1205,1206
 1206 CALL TREE(I,J,NLINK,DIST,TMDS,LF,NSEE,NODES,LL,NORDR,C,KNOD,NFRM)
C     ASSIGN VOLUMES
 1205 NN=NTO
   60 NNN=NLINK(NN)
      VOL(NNN)=VOL(NNN)+FNTP
      NN=I(NNN)
      IF(NLINK(NN))601,601,60
  601 NFRMO=NFRM
      GO TO 1207
 1203 CONTINUE
C     WRITE OUT LINK VOLUMES
      WRITE(6,260)
  260 FORMAT(86H FROM    TO        VOL    TO        VOL    TO        VOL    TO
     1    VOL     TO       VOL          )
      ITM=I(1)
      DO 6011 K=1,5
      VEHTIM(K)=0.0
 6011 VEHMIL(K)=0.0
      IK=1
      DO 261 IT=1,LL
      K=NSYS(IT)
      VEHMIL(K)=VEHMIL(K)+VOL(IT)*DIST(IT)
      VEHTIM(K)=VEHTIM(K)+(VOL(IT)*DIST(IT)*SPEED(K))
      IF(I(IT+1)-ITM)263,262,263
  262 IK=IK+1
      GO TO 261
  263 IKT=IT-IK+1
      WRITE(6,264)I(IT),(J(KT),VOL(KT),KT=IKT,IT)
```

```
  264 FORMAT(1H I5,6(I5,F 10.3))
      IK=1
      ITM=I(IT+1)
  261 CONTINUE
C     WRITE VEH MILES AND VEH MINUTES
      TOTMIN=0.0
      TOTMIL=0.0
      DO 401 K=1,5
      WRITE(6,267)K
  267 FORMAT(22H TOTALS FOR ROAD CLASSI4)
      TOTMIN=TOTMIN+VEHTIM(K)
      TOTMIL=TOTMIL+VEHMIL(K)
      WRITE(6,8)VEHTIM(K)
      WRITE(6,15)VEHMIL(K)
    8 FORMAT(22H TOTAL VEHICLE MINUTESF10.1)
   15 FORMAT(20H TOTAL VEHICLE MILESF12.1)
  401 CONTINUE
      WRITE(6,402)
  402 FORMAT(24H TOTAL-ALL TRIP PURPOSES)
      WRITE(6,8)TOTMIN
      WRITE(6,15)TOTMIL
      WRITE(6,1504)VTIM,VDIST
 1504 FORMAT(17H TOTAL VEH. MILESF10.2,16H TOTAL VEH. MIN.F10.2)
      CALL EXIT
      END
      SUBROUTINE TREE(I,J,NLINK,TIME,TMDS,LF,NSEE,NODES,LL,NORDR,C,KNOD,
     1  IT)
C     MINIMUM TIME AND DISTANCE TREE PROGRAM
      DIMENSION  I(225),J(225),NLINK(225),NORDR(100),TTIME(225),TTMDS(22
     15),TIME(225),TMDS(225),LF(100),NSEE(25),NK(225),TMDSS(225),IS(225)
     2 ,JS(225),NLS(225),TTS(225)
C     BUILD TREE
      DO 1000  N=1,KNOD
      TTIME(N)=0.0
 1000 TTMDS(N)=0.0
      DO 599 K=1,225
  599 NK(K)=0
      TDMIN=0.0
      TMIN=0.0
      NLINK(IT)=0
      NORDR(1)=IT
      TTMDS(IT)=.000001
      TTIME(IT)=0.0
      N=IT
      NS=1
      NO=2
      NNC=2
C  ADD LINKS FROM NODE JUST ADDED
  402 L=LF(N)
      K=1
  405 IF(I(L)-N)403,404,403
  404 IF(NK(K))502,501,502
  501 NE=NS
      NS=NS+1
      GO TO 503
  502 NE=NK(K)
      K=K+1
  503 JS(NE)=J(L)
      NLS(NE)=L
      TMDSS(NE)=TDMIN+TMDS(L)
      TTS(NE)=TMIN+TIME(L)
      L=L+1
      GO TO 405
  403 TEST=999999999.0
```

```
      K=1
      NST=NS-1
      DO 406 NSS=1,NST
      IF(JS(NSS).NE.0) GO TO 509
  508 NK(K)=NSS
      K=K+1
      GO TO 406
  509 NT=JS(NSS)
      IF(TTMDS(NT).LE.0.0) GO TO 407
      JS(NSS)=0
      GO TO 508
  407 IF(TMDSS(NSS).GE.TEST) GO TO 406
      TEST=TMDSS(NSS)
      NTEST=NSS
  406 CONTINUE
      N=JS(NTEST)
      NLINK(N)=NLS(NTEST)
      TTMDS(N)=TMDSS(NTEST)
      TTIME(N)=TTS(NTEST)
      NORDR(NO)=N
      NO=NO+1
  582 TDMIN=TTMDS(N)
      TMIN=TTIME(N)
      JS(NTEST)=0
      NK(K)=NTEST
      K=K+1
      NK(K)=0
      IF(NNO.GE.NODES) GO TO 523
      NNO=NNO+1
      GO TO 402
  523 CONTINUE
C     WRITE OUT MINIMUM PATH TREE
      WRITE(6,97)
   97 FORMAT(1H0,18H MINIMUM PATH TREE)
      WRITE(6,94)C
   94 FORMAT(37H TTMDS=SUM(C.TIME+(1-C)DIST),WHERE C=F7.3)
      WRITE(6,96)(N,NORDR(N),TTMDS(N),TTIME(N),NLINK(N),N=1,KNOD)
   96 FORMAT(5(2I3,2F7.1,I3))
   32 CONTINUE
  521 CONTINUE
      RETURN
      END
$ENTRY
```