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16. Abstract

This report documents a PC computer program that will analyze proposed interchange, railroad grade separation, and bypass projects. The Program is called TRIP, Texas Ranking of Interchange Projects. The evaluation includes calculations of motorist savings in user costs over a planning period. These user costs include delay costs, vehicle operating costs, and accident costs. The final output is a benefit-cost ratio.

TRIP is a menu driven program that includes a data input and editing process, data analysis, output display, and procedures to save both the input and output data. The menus allow for changes and modifications of the data at any stage, and a great deal of flexibility in changing the assumptions used to make the calculations.

The methods used to input data, analyze a problem, and output the results are described in the report. The user cost calculations are described, along with an example of the input and output.

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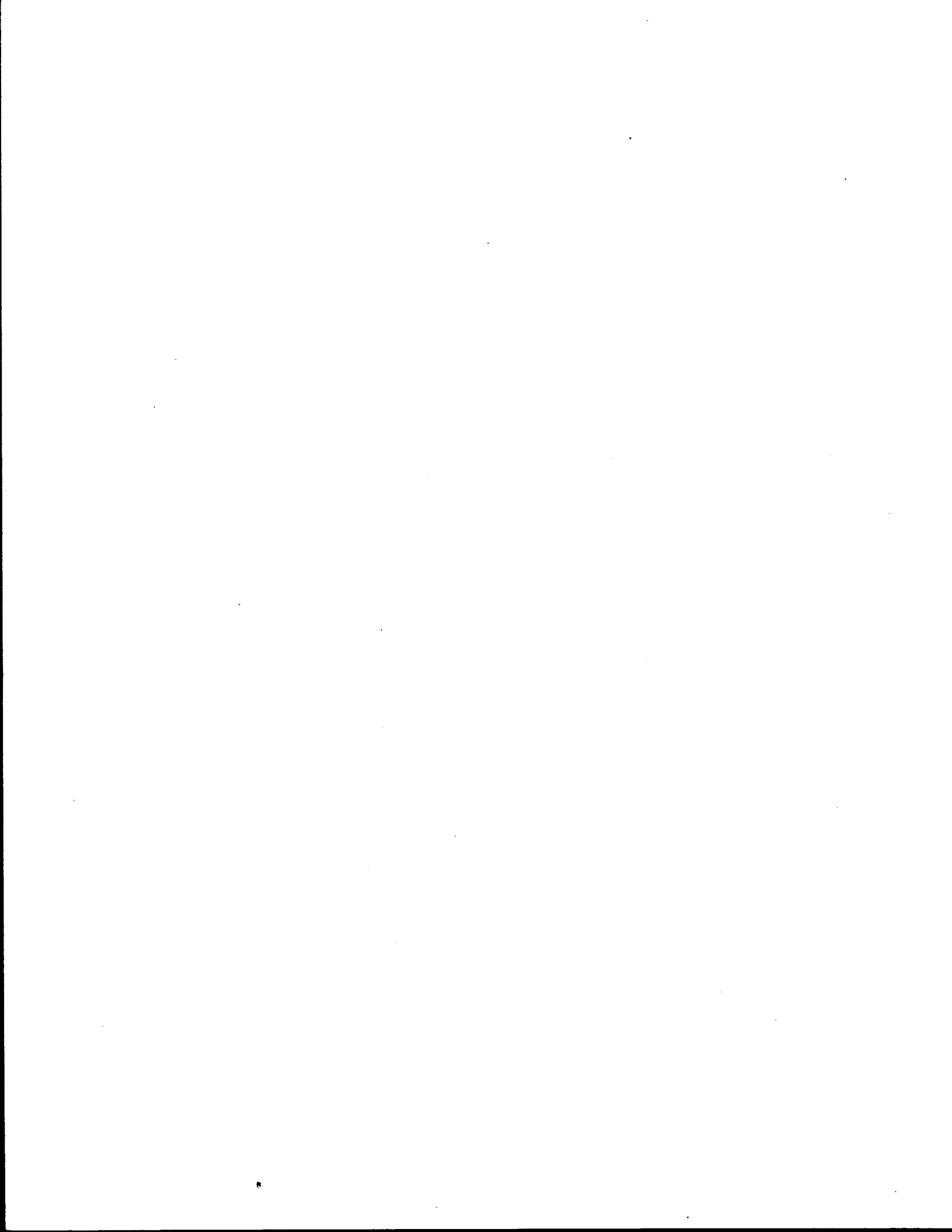
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TEXAS RANKING OF INTERCHANGE PROJECTS - TRIP

PC INTERCHANGE AND RR GRADE SEPARATION BENEFIT-COST PROGRAM

by

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

```
        °F                                      °F
       -40        32      98.6                  212
  -40   |    0   |40    80 |  120    160    200 |
   |----+----+----+----+----+----+----+----+----|
  -40    -20    0    20   |40    60    80    100
  °C                       37                  °C
```
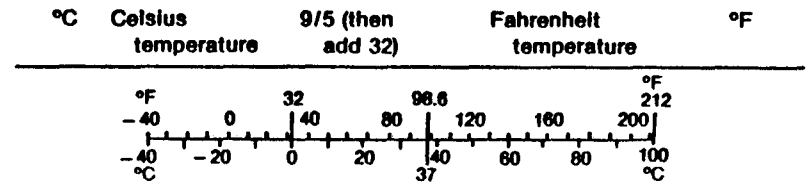
These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

ABSTRACT

This report documents a PC computer program that will analyze proposed interchange, railroad grade separation, and bypass projects. The Program is called TRIP, Texas Ranking of Interchange Projects. The evaluation includes calculations of motorist savings in user costs over a planning period. These user costs include delay costs, vehicle operating costs, and accident costs. The final output is a benefit-cost ratio.

TRIP is a menu driven program that includes a data input and editing process, data analysis, output display, and procedures to save both the input and output data. The menus allow for changes and modifications of the data at any stage, and a great deal of flexibility in changing the assumptions used to make the calculations.

The methods used to input data, analyze a problem, and output the results are described in the report. The user cost calculations are described, along with an example of the input and output.

PREFACE

The authors wish to thank Billy Rogers for his helpful comments, information, and suggestions during the course of the research project. Appreciation is also due to William F. McFarland and Margaret K. Chui for their assistance, efforts, and suggestions during the course of the research.

The contents of this report reflect the views of the authors and do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas State Department of Highways and Public Transportation. This report does not constitute a standard, a specification, or a regulation.

SUMMARY

This report is the documentation of a PC program to calculate the benefit-cost ratio of a proposed interchange or railroad grade separation. The program is called TRIP, Texas Ranking of Interchange Projects. The program also includes the capability of evaluating simple bypasses and partial bypasses. Bypasses were included to expand the capability of the program, and to provide a method to evaluate and implement the results of a related research project, Project 498 (1), which includes an analysis of several bypasses in Texas and gives methods to estimate the diversion rates when bypasses are built.

TRIP provides several menus to input the necessary data to run a problem and also provides menus to edit and make changes to the default assumptions at any time. A problem is broken up into routes, with required existing and proposed routes, and an optional alternate route. Each route can be broken up into 1 to 20 segments. Each segment would generally consist of a road segment and one intersection or interchange. If there is an existing or proposed interchange, the ramp type, ramp volume, ramp speed, and ramp distance can also be changed from the default standard design assumptions for that interchange.

The user costs are calculated for both the existing and proposed situations. From these costs a benefit-cost ratio is calculated. The user costs consist of delay costs, vehicle operating costs, and accident costs. TRIP provides considerable flexibility to change the speed, capacity, and unit cost assumptions used to make the calculations, and can be changed at any point after a problem is entered or read from a file.

The program also has the capability to save the input and output to a file for future use and examination and to send the information to a printer. The file created is a text file so that it can be used by a word processing package.
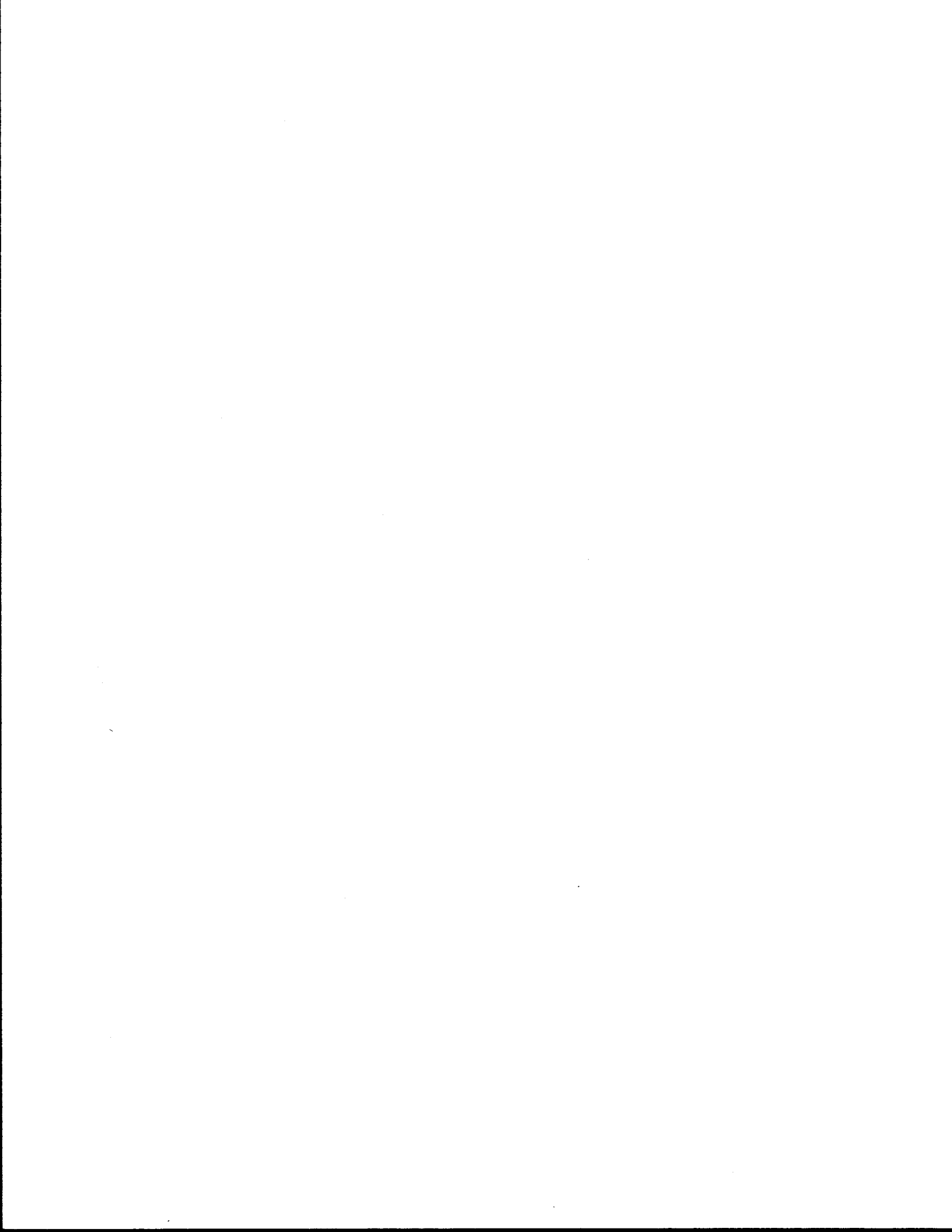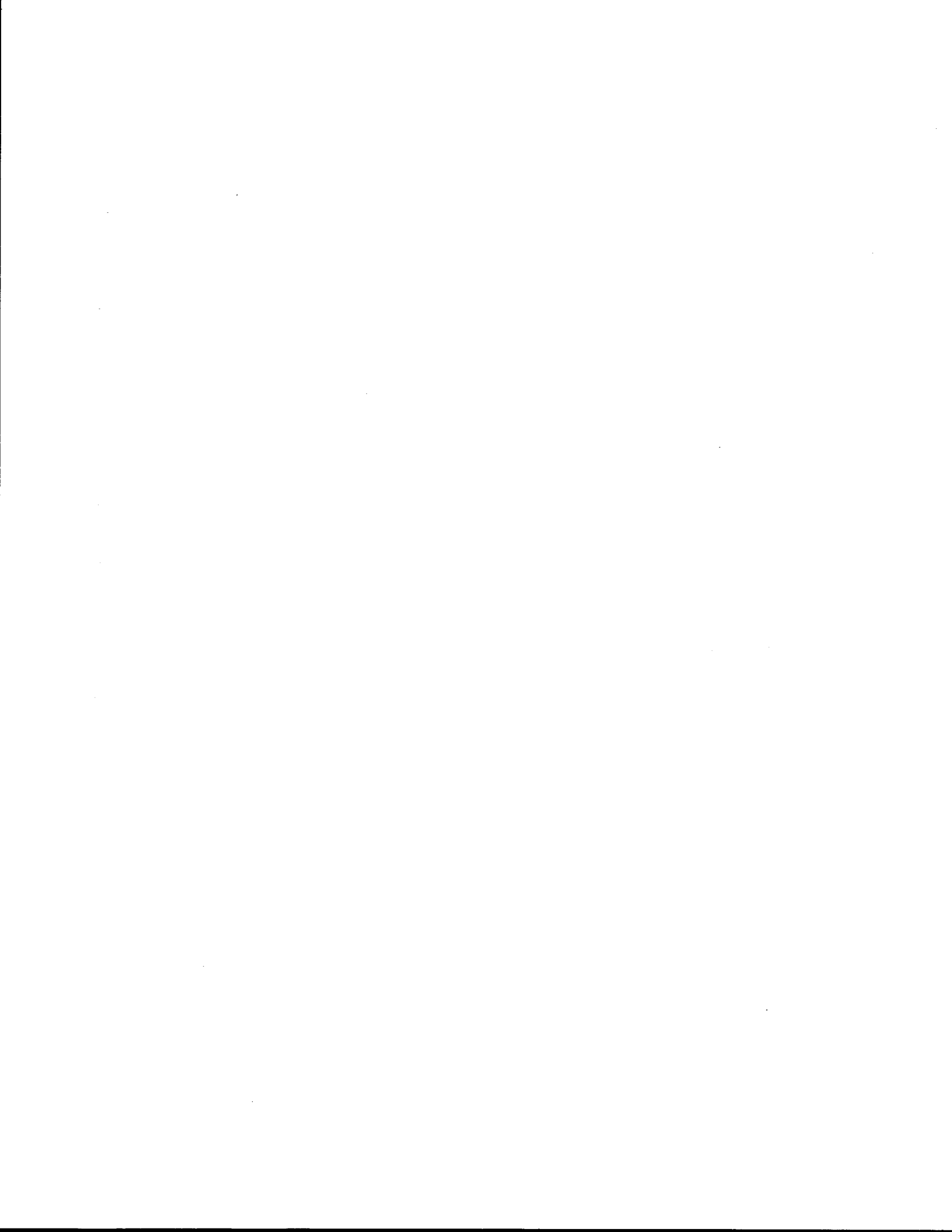
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INTRODUCTION

Some of the most important elements in highway networks are the intersections and interchanges. Even though they play a very important role in highway network, they are difficult to analyze, given the wide variety of operational and design characteristics. This is a result of the friction, weaving, changing speeds, and turning movements associated with intersections and interchanges. The problem becomes much greater when trying to rank and select some group of interchange projects when only limited funding is available.

Currently there are several computer programs to analyze the operational aspects of an intersection and diamond interchanges, including improvements to the signal phasing to increase the traffic flow within the intersection(s). These programs include PASSER-II (2), TRANSYT-7F (3), and NETSIM (4). However these programs require a detailed information on the configuration and flow of vehicles in the intersection, and are not of much practical use at the planning level, where little operational data are available.

The Texas Department of Highways and Public Transportation (SDHPT) has been using a computer program which calculates the delay savings of a simple diamond interchange with signalized, one-way frontage roads, when changed from a signalized intersection. The problem is that the program cannot calculate delay for other types of configurations, highway grade separations, or designs that improve operation for some traffic flows. There is also no way to compare an existing interchange with a proposed higher-design interchange. In addition, the program used a way of calculating delay that did not take into account, in a consistent fashion, the joint signal phasing of a pair of signals at a diamond interchange. TRIP was developed to address these areas, to develop a user-friendly computer program that could analyze a wide variety of intersection and interchange projects at the planning level, with little detailed operational data, and with sufficient flexibility to analyze "unusual" configurations.

A related problem is encountered with the evaluation of proposed highway-railroad grade separations. The need for grade separations is generally some combination of delay and safety concerns. There is currently no tool available to adequately analyze and

rank these types of projects. TRIP was also designed to analyze railroad grade separations at the planning level. It takes into account both the delay and safety improvements of a highway-railroad grade separation.

TRIP includes an analysis of the major motorist user costs associated with highway improvement projects, including delay costs, vehicle operating costs, and accident costs. The delay costs consist of delay traveling along a segment of highway, delay at a signed or signalized intersection or an at-grade RR crossing while a train is passing, and the delay of slowing down to cross over RR tracks. The vehicle operating costs consist of running costs traveling along a highway segment, the costs of slowing down and stopping at an intersection or RR grade crossing, the idling costs while waiting in a queue, and costs of slowing down to cross RR tracks. Accident costs consist of the accident rates and costs associated with an intersection, interchange, or RR grade crossing.

TRIP provides an easy-to-use and flexible method of inputting and editing the data. The minimal data required to run a problem is prompted from the user. That data, along with the other assumed data, can be changed at any time through a set of data menus. The input data set can then be saved and read directly into the program in subsequent applications. The output can be displayed on the screen, sent to a printer, or saved in a file. One important feature of the bypass analysis is the through traffic allocation. The program provides for a procedure to allocate the through traffic to an existing route, a proposed bypass, and an optional alternate route. The traffic is allocated based upon an iterative process that gives traffic to each route such that the motorist user costs are the same. This allocation procedure can be overridden and the user can input the traffic to use the bypass directly. Also the traffic can be reallocated at any time, for example when some input data item has been changed. This gives both the flexibility and control that should make it useful in a wide variety of applications.

The following sections in the report describe how to set up a problem, how to enter the data, how to use the edit menus, and how to analyze the problem. The delay and other user cost calculations are described in Appendix A. An example of the input and output are shown in Appendix B.

SETTING UP A PROBLEM

Since TRIP offers a great deal of flexibility in analyzing a problem, some care should be taken in setting up the structure of the problem and getting the input data ready before the program is started. There are four general categories of projects which TRIP can analyze, (1) simple bypass, (2) partial bypass, (3) interchange, and (4) highway-railroad grade separation. The simple bypass is a new location facility with an existing parallel route. The partial bypass is the situation where the new location bypass is being staged, and only a part of the bypass is being considered for this project. There can be an existing part of the bypass already in place. The interchange category is used when a proposed route is replacing an existing route. This would typically be when an intersection or interchange is being upgraded with a higher design structure. The railroad grade separation is used where an at-grade railroad grade crossing is being replaced with a grade separation.

The interchange category covers a wide variety of situations in which a proposed intersection or interchange is to be upgraded to higher facility type. The project doesn't have to be a signalized intersection upgraded to an interchange. There are several categories of intersections and interchanges, two-way stop, four-way stop, signalized intersection, simple diamond interchange, three-level diamond, cloverleaf, and directional. The existing and proposed highways can use any of these intersection/interchange categories. The standard configurations also allow for "unusual" situations, to the extent that each turning movement can be changed for differences in ramp type, ramp distance, ramp speed, and ramp volume.

To run a problem with TRIP, first determine both the existing and proposed routes. An optional alternate route can also be used if desired. For a bypass project, the existing route might be the route through town, and the proposed route could be the new location bypass. For an interchange project, the existing route might be an existing signalized intersection, and the proposed route could be a diamond interchange. For the interchange and RR grade separation categories of projects, the proposed route replaces the existing route when the improvement is simulated.

Each route must then be divided up into one or more segments. Each segment would typically contain at most, one intersection or interchange. This is generally to help in analyzing bypass projects, where there may be several intersections along a route, but it could also be used when a proposed interchange project is part of a project to widen a highway section or where more than one intersection or interchange is involved. Segments could also be used to divide up routes with significant changes in the design, such as changes in the number of lanes. Each route must contain from 1 to 20 segments, but they do not have to match up. For example an existing route through town may have 10 segments, while the bypass may need only 4.

Several items of information are required for each segment, including the average daily traffic volume (ADT), number of lanes, free flow speed, type of intersection/interchange, length, and for the minor crossing route (if any) the ADT, number of lanes, and free flow speed. For railroad grade separations, the number of trains per day, train speed, train length, and time to raise and lower gates are also required.

The traffic volume is handled at two levels. There is a through traffic (ADT) required for each route. It is also possible to specify additional local traffic for each route segment. This was designed principally for bypass projects. For interchange and RR grade separations, it would generally be sufficient to specify the through traffic as the ADT for each route and set the additional local traffic to 0. For bypasses, the through traffic represents traffic that can be allocated to the proposed bypass after it is built. The additional local traffic is that traffic that is not sensitive to the bypass and will use the route regardless. In this way the bypass may pull most or all of the through traffic to the new facility, but local traffic will remain on the existing or alternate routes.

There is a difference between the simple bypass and partial bypass in terms of the additional local traffic. The program will not allow local traffic to be assigned to a simple bypass because the facility does not exist for the current conditions. However, it is possible to assign local traffic to the proposed bypass in the partial bypass category because there may be an existing piece of the bypass already in use.

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The free flow speed is used as the intercept to calculate the running speed along a segment and to calculate the ramp speed for an interchange. The free flow speed is defined as the speed at level-of-service (LOS) A in the 1985 <u>Highway Capacity Manual</u> (<u>5</u>). For a segment with an intersection or interchange, it would be the midblock LOS A speed. This gives the basis for calculating much of the motorist user costs, so some care should be made in selecting a number. It would also be easy to run the program for some different values to see how the results change with different assumed free flow speeds.

In summary the following steps should be taken before running a problem with TRIP:

1. Select the existing route, the proposed route, and if desired, an alternate route.

2. Determine the through ADT for each of those routes. (The existing and proposed ADT would be the same if the proposed route will replace the existing route.)

3. Divide each route up into one or more segments. Each segment should contain at the most one intersection or interchange. Segments should also reflect significant changes in the route, such as changes in the number of lanes.

4. Assemble the necessary information on each route segment, including number of lanes, length, free flow speed, and additional local traffic. Information on the minor crossing road (if any) and train traffic (if any). The program uses the terminology major route for the route being analyzed, and minor route for the crossing route at an intersection or interchange.

GETTING STARTED

TRIP has been designed to work on an IBM PC/XT/AT or compatible microcomputer. It can be used with or without a math coprocessor, though the math chip does increase the speed of the analysis.

To begin, for a two-floppy disk system, copy the program onto another floppy disk to have a working disk. This can be accomplished by inserting the TRIP diskette into Drive A, and inserting a formatted diskette into Drive B. Then type in "COPY A:*.* B:".

For a hard disk system, make a directory for TRIP, by typing "MD C:\TRIP", then change directories by typing "CD C:\TRIP". Then copy the TRIP files by inserting the TRIP diskette into Drive A and then typing "COPY A:*.*".

To start TRIP, simply type "TRIP", and hit the <RETURN>. The Disclaimer Screen will appear as shown in Figure 1. Press any key and the Main Menu, shown in Figure 2, will appear. It is necessary to enter data or read a data set first, so you will need to type a "1" then hit the <RETURN>. The Data Entry Menu, shown in Figure 3, will then appear. If you want to enter data for a problem type "1" and hit the <RETURN>. You will be prompted for the following information:

1.   General Problem Information
      A.   Problem Description
      B.   Current Year
      C.   Total Construction Cost, in millions of dollars
      D.   Category of Construction Project
            1.   Simple New Location Bypass
            2.   Partial New Location Bypass
            3.   Interchange or Highway Grade Separation
            4.   Railroad Grade Separation
      E.   Alternate Parallel Route to be included in analysis, 1-Yes, 2-No
      F.   Area Type
            1.   Rural
            2.   Urban

```
          TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
               TEXAS RANKING OF INTERCHANGE PROJECTS - TRIP
         PC Interchange and RR Grade Separation Benefit-Cost Program
                              Version 1.1
                       (Costs Updated to May 1988)


     This program was developed under Texas Department of Highways and Public
     Transportation (SDHPT) study 2-8-87-1105, by the Texas Transportation
     Institute, Texas A&M University System.  It was designed for use by SDHPT
     personnel and other transportation professionals.  This program can be used to
     estimate the motorist user costs of proposed interchange projects, and
     proposed highway-railroad grade separations.  User comments are welcomed,
     contact Dr. Jeffery L. Memmott at (409) 845-9939.  No restrictions
     are made on copying or distributing this program.

     Please be advised that no warranty is made by the Texas Department of Highways
     and Public Transportation, the Federal Highway Administration, the Texas
     Transportation Institute, or the Texas A&M University System as to the
     accuracy, completeness, reliability, usability, or suitability of the computer
     program and its associated data and documentation.  No responsibility is
     assumed by the above parties for incorrect results or damages resulting from
     the use of the program package.

     Strike a key when ready . . .
```

Figure 1. Disclaimer Screen

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```
                         Main Menu

    1.  Enter Data or Read Input Data Set.

    2.  Edit Problem Assumptions.

    3.  Edit Overall Route Assumptions.

    4.  Edit Segment Data and Assumptions.

    5.  Edit Hourly Volume Distributions.

    7.  Allocate Traffic to Proposed New Location Bypass.

    8.  Analyze Problem.

    9.  Display Results.

    10. Save Input Data Set.

    11. Exit TRIP.

Which Item do you Select?
```

Figure 2. Main Menu Screen

```
                                    Data Input Menu


            1.  Enter Data from Console

            2.  Read Input Data File

            3.  Return to Main Menu



Which Item do you Select?
```

Figure 3. Data Input Menu Screen

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The Problem Data Edit Menu, Figure 4, will then be displayed, where the entered problem data, along with several other assumed values, can be changed. Type "16" and hit the <RETURN> to continue entering data.

2.   Route Information for Existing, Alternate (if any), then Proposed

     A.   Route Description

     B.   Total Through Traffic (ADT) along Route, in thousands, current and future.

     C.   Number of Segments the Route will have for the analysis

The Route Data Edit Menu, Figure 5, will then be displayed, where the data entered for the route can be changed. Type "5" and hit the <RETURN> to continue entering data.

     D.   Route Segment Information on each segment for that route

          a.   Segment Description

          b.   Type of Intersection, Interchange, or Crossing

               1.   None

               2.   Two-Way Stop

               3.   Four-Way Stop

               4.   Signalized Intersection

               5.   Simple Diamond

               6.   Cloverleaf

               7.   Three-Level Diamond

               8.   Directional

               9.   Railroad At-Grade Crossing

               10.   Railroad Grade Separation

          c.   If a Signalized Intersection or Diamond Interchange, Type of Intersection

               2.   4X4 Lane Configuration

               3.   4X6 Lane Configuration

               4.   6X6 Lane Configuration

          d.   Additional Local Traffic using Major Route, in thousands (set to zero unless being used for bypass project)

10

PROBLEM Data Edit Menu

1. Problem Description: Diamond Interchange Test
2. Current Year: 1988
3. Discount Rate (%): 8.0
4. Analysis Period (Years): 20
5. Type of Traffic Growth Rate (1-Const Grwth, 2-Strght Ln): 1
6. Car Value of Time per Person ($/hr): 8.58
7. Truck Value of Time per Person ($/hr): 20.39
8. Car Occupancy Rate: 1.30
9. Truck Occupancy Rate: 1.00
10. Percent Trucks: 3.0
11. Total Construction Cost (Millions of $):   5.00
12. Const. Cat. (1-Simple Bypass, 2-Partial Bypass,
       3-Interchange, 4-RR Grade Separation): 3
13. Alternate Parallel Route in Analysis (1-No, 2-Yes): 1
14. Operating Cost and Accident Cost Update Factor: 1.00
15. Area Type (1-Rural, 2-Urban): 2
16. Continue Entering Data.
17. Break out of the Data Entry Sequence.

Which Item do you wish to edit, 16 to continue, or 17 to break?

Figure 4. Problem Data Edit Menu Screen

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```
                EXISTING  Route Data Edit Menu


    1.  Route Description: EXISTING ROUTE

    2.  Current Year Average Daily THROUGH
        Traffic before Improvement (Thous.):    20.00

    3.  20 Year Future Average Daily THROUGH
        Traffic before Improvement (Thous.):    39.80

    4.  Current Year Average Daily THROUGH
        Traffic after Improvement (Thous.):      0.00

    5.  20 Year Future Average Daily THROUGH
        Traffic after Improvement (Thous.):      0.00

    6.  Number of Route Segments:  1

    7.  Return to Main Menu.

Which Item do you wish to edit, or 7 to exit?
```

Figure 5. Route Data Edit Menu Screen

e. Number of Major Route Lanes, Inbound Direction

f. Number of Major Route Lanes, Outbound Direction

g. Segment Length along Major Route, in miles

h. Major Route Facility Type

   1. Undivided

   2. Divided

   3. Freeway

i. Free Flow Speed along Major Route in miles per hour

For Railroad Grade Crossings:

j. Number of Trains Crossing per Day

k. Average Train Speed in miles per hour

l. Average Train Length in miles

m. Time for Gates to Close and Open in minutes

n. Percent Reduction in Vehicle Speed Crossing Tracks, Recommended:

   30. Smooth Crossing Surface

   40. Typical Crossing Surface

   50. Humped and Rough Crossing Surface

   60. Very Humped and Rough Crossing Surface

For Intersections and Interchanges:

o. Daily Traffic on Minor Route in thousands, current and future.

p. Number of Minor Route Lanes, Inbound Direction

q. Number of Minor Route Lanes, Outbound Direction

r. Minor Route Facility Type

   1. Undivided

   2. Divided

   3. Freeway

s. Free Flow Speed on Minor Route, in miles per hour

The Segment Data Edit Menu, Figure 6, will then be displayed, where the entered problem data, along with several other assumed values can be changed. To look at the assumed ramp information, if the segment contains an interchange, type "20" and hit the <RETURN>. The Ramp Data Edit Menu, Figure 7, will be displayed. To return to the Segment Data Edit Menu, type "9" and hit the <RETURN>. To continue entering data, type "22" and hit the <RETURN>.

If data for a bypass is being entered, at the end, after the data have been entered, the program will automatically allocate the through traffic on the existing route and alternate (if any) to the proposed route, after the improvement, using a sophisticated iteration technique, described in Appendix A. That automatic allocation can be overridden by going to the Route Edit Menus, Item "3" on the Main Menu, to assign traffic volumes to each route after the improvement. Care should be taken, however, that the same total volume is assigned to the routes. The program will not run if the total is not the same for the current conditions and the improved conditions. The allocation procedure can be run at any time using Item "7" on the Main Menu.

When the data entry is complete, the main menu will again be displayed on the screen. At this point, the problem can be analyzed by selecting "8" in the Main Menu. The output will be displayed on the screen when complete. The output can be viewed again, sent to a printer, or saved in a file by selecting "9" in the Main Menu. The input data set can be saved for future use by selecting "10" in the Main Menu. To exit the program, select "11".

```
              PROPOSED  Route, SEGMENT  1 Data Edit Menu     .
   1.  Segment Description: PROPOSED SEGMENT
   2.  Type of Int, 1-None, 2-2 Wy Stp, 3-4 Wy Stp, 4-Signl, 5-Smpl Dimnd,
       6-Clovrlf, 7-3 Lvl Dimnd, 8-Dirctnal, 9-RR Cross, 10-RR Grade Sep :  5     .
   3.  Major Rt Add Daily Loc Traf (Thous), Curr Yr:   2.00, 20 Yr Fut:   4.00
   4.  Number of Major Route Lanes, Inbound Direction:   2
   5.  Number of Major Route Lanes, Outbound Direction:  2
   6.  Segment Length (miles):  0.50
   7.  Free Flow Speed on Major Route (mph): 60.
   8.  Percent Trucks on Major Route:   3.0
   9.  Major Route Facility Type, 1-Undiv, 2-Div, 3-Frwy : 3
   10. Capacity per Lane on Major Route (vphpl): 1948
   11. Daily Traf on Minor Rt (Thous.), Curr Yr:  10.00, 20 Yr Fut:  19.50
   12. Number of Minor Route Lanes, Inbound Direction:   2
   13. Number of Minor Route Lanes, Outbound Direction:  2
   14. Percent Traffic with stop or Signal, Major Rt:  20, Minor Rt: 100
   15. Free Flow Speed on Minor Route (mph): 40.
   16. Percent Trucks on Minor Route:   3.0
   17. Minor Route Facility Type, 1-Undiv, 2-Div, 3-Frwy : 1
   18. Capacity per Lane on Minor Route (vphpl):  633
   19. Type of At-Grd Signl Inter, 1-none, 2-4X4, 3-4X6, 4-6X6 : 2
   20. Edit Ramp Types and Volumes.
   21. Delete Segment from data file.
   22. Return to Main Menu.
Which Item do you wish to edit, or 22 to exit?
```

Figure 6. Route Segment Data Edit Menu Screen

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PROPOSED Route, SEGMENT 1 Ramp and Volume Menu

	Type of Ramp	Ramp Volume (% ADT)	Ramp Speed (MPH)	Savings in Dist Traveled (Miles)	Interrupted Flow, End of Ramp (Y/N)
1. Maj. R, Inb, Rgt-Trn	DIAGONAL	5.0	39.0	0.02	Y
2. Maj. R, Inb, Lft-Trn	DIAGONAL	5.0	39.0	-0.05	Y
3. Maj. R, Out, Rgt-Trn	DIAGONAL	5.0	39.0	0.02	Y
4. Maj. R, Out, Lft-Trn	DIAGONAL	5.0	39.0	-0.05	Y
5. Min Rt, Inb, Rgt-Trn	DIAGONAL	5.0	26.0	0.02	Y
6. Min Rt, Inb, Lft-Trn	DIAGONAL	5.0	26.0	-0.05	Y
7. Min Rt, Out, Rgt-Trn	DIAGONAL	5.0	26.0	0.02	Y
8. Min Rt, Out, Lft-Trn	DIAGONAL	5.0	26.0	-0.05	Y

9. Return to Segment Edit Menu.

Which Ramp do you wish to edit, or 9 to exit?

Figure 7. Ramp and Volume Menu Screen

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USE OF THE MENUS

The menus are structured in such a way that the problem data can easily be accessed and changed as needed. They also offer a variety of options to display and save both the input and output data. The menus, and there use, are discussed below.

MAIN MENU

The Main Menu gives the user 11 choices, as shown previously in Figure 2. The user must select one of these numbers to continue. The choices are explained below.

1. Enter Data or Read Input Data Set.

    This option must be done first when starting the program. When this item is chosen, the Data Input Menu is displayed, giving the choice of entering the input data or reading an input data file. (See Data Entry Menu, below.)

2. Edit Problem Assumptions.

    This option allows the user to edit the problem assumptions, such as the project type, construction cost, and the economic assumptions. When this item is chosen, the Problem Data Edit Menu is displayed, giving the data items that can be changed. (See Problem Data Edit Menu, below.)

3. Edit Overall Route Assumptions.

    This option allows the user to edit the overall route assumptions, such as the through traffic volumes for the current and improved conditions, and the number of segments in the route. When this item is chosen, the Route Data Edit Menu is displayed, giving the route data items that can be changed. (See Route Data Edit Menu, below.)

4. Edit Segment Data and Assumptions.

    This option allows the user to edit the segment data for a particular route. These data include intersection/interchange type, number of lanes, free flow speed, length, and additional local traffic. For railroad crossings, it includes number of trains, speed, and length. When this item is chosen, the

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Segment Data Edit Menu is displayed, giving the route data items that can be changed. (See Segment Data Edit Menu, below.) The Segment Data Edit Menu also allows access to the Ramp and Volume Menu to edit the ramp assumptions for interchanges. (See Ramp and Volume Menu, below.)

5. <u>Edit Hourly Volume Distributions.</u>

This option allows the user to edit the assumed hourly traffic distribution. There is a separate default distribution for urban and rural areas. When this item is chosen, the Hourly Traffic Distribution Menu is displayed, giving the percent ADT, by hour, for a 24-hour period. (See Hourly Traffic Distribution Menu, below.)

6. <u>Edit Hourly Train Distributions.</u>

This option allows the user to change the assumed uniform arrivals of trains during a 24-hour period. If this item is chosen, the Hourly Train Traffic Distribution Menu is displayed, giving the percent of the daily trains arriving each hour. The objective is to allow for simulation of the interaction of the peaking patterns of vehicles with train arrivals. (See Hourly Train Traffic Distribution Menu, below.)

7. <u>Allocate Traffic to Proposed New Location.</u>

This option allows the user to allocate traffic to a proposed new location bypass. The allocation is based on the motorist costs of traveling each route. If this item is chosen, the Traffic Allocation Menu is displayed, giving the option of continuing. The allocation will not be allowed if the project is not a bypass project. (See the Traffic Allocation Menu, below.)

8. <u>Analyze Problem.</u>

This option allows the user to analyze the problem and see the output. A message will be displayed saying the problem is being analyzed. The time required to analyze a problem can vary greatly, depending on the complexity of the problem and the type of machine the problem is being run on. It can vary from a several seconds to a few minutes. There is no way the program can get into an infinite loop, so please wait for the analysis to

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be completed. After the analysis is complete, the traffic volumes over the analysis period will be displayed. If the volumes over time are too high or too low, the percent growth in ADT in the Problem Data Edit Menu should be changed. The next output screen shows the benefit calculations over time for delay savings, vehicle operating cost savings, and accident cost savings. Totals are also shown, along with the benefit-cost ratio. The output can be viewed again by selecting Item 9, Display Results, in the Main Menu.

9. Display Results.

This option allows the user to display the results of a problem that has been analyzed. If this item is chosen, the Output Options Menu is displayed, and the user has the option of displaying the output on the screen, sending it to a printer, or saving it in a file. (See Output Options Menu, below.)

10. Save Input Data Set.

This option allows the user to save the input data into a file for future use. When this item is chosen, the Save Input Data Menu is displayed, giving the option of saving the data, and if so, the name of the file. (See Save Input Data Menu, below.)

11. Exit TRIP.

This option allows the user to exit the program. If a data set has been input or changed since the last save, a warning message will be given before exiting, giving the user the chance to save the data set by displaying the Save Input Data Menu.

DATA INPUT MENU

The choices are explained below.

1. Enter Data from Console.

This option allows the user to enter the data for a new problem. The user will be prompted for the necessary information before returning to the main

menu. The data items the program will prompt the user for are listed in the previous section, "Getting Started." If the problem is a bypass project, then traffic will also be automatically allocated to the proposed bypass. This can be overridden by entering the improved condition traffic in the Route Data Edit Menu, Item 3, of the Main Menu.

2. Read Input Data File.

This option allows the user to read in an input data file previously saved. The user is prompted for the name of the file. The name of the file, as well as the directory it is in, should be noted before running the program, since there is no file list or directory command available to look at the file names. After the file is read, the user is returned to the main menu.

3. Return to Main Menu.

This option allows the user to return to the main menu without starting the data entry process or reading a file. This is especially helpful when inputting or reading in a new data set, when there is already a data set in the program. This option allows the user to return to the main menu and save the data before it is replaced by a new data set.

PROBLEM DATA EDIT MENU

The choices are explained below.

1. Problem Description.

This item can be used to put a problem description in the input and output. It can be up to 30 characters long.

2. Current Year.

The current year is used to set the time frame for the analysis. The project is assumed to be built and opened in the next year after the current year. The traffic volumes are also assumed to be for the current year, so if they do not match either, set the current year to the year of the traffic volumes, or update the traffic volumes to the current year.

3. <u>Discount Rate (%).</u>

The discount rate is used to discount the flow of future benefits over the analysis period to present value dollars, so they can then be compared to the construction cost to give a benefit-cost ratio. The default value is 8 percent, taken from a TTI study (6).

4. <u>Analysis Period (Years).</u>

The analysis period is the period of time benefits are assumed to flow from the proposed project. The default value is 20 years, taken from a TTI study (6).

5. <u>Type of Traffic Growth Rate.</u>

The type of traffic growth rate has two options, a constant growth rate and a straight line growth. This is used to determine how the traffic grows between the current year ADT and the twenty year future ADT. The default value is the constant growth rate.

6. <u>Car Value of Time per Person ($/hr).</u>

This item is the dollar value of passenger car time per person. The default is $8.58 per hour, which is updated to May 1988 from a TTI study (7). This number should be updated periodically, using an appropriate price index such as the Consumer Price Index (CPI).

7. <u>Truck Value of Time per Person ($/hr).</u>

This item is the dollar value of truck time per person. The default value is $20.39 per hour, which is updated to May 1988 from a TTI study (7). This number should be updated periodically using an appropriate price index, such as the Producer Price Index (PPI).

8. <u>Car Occupancy Rate.</u>

This item is the average number of passenger car occupants per vehicle. The default number is 1.3, which is taken from a TTI study (6).

9. <u>Truck Occupancy Rate.</u>

This item is the average number of truck occupants per vehicle. The default number is 1.0, which is taken from a TTI study (6).

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10. Percent Trucks.

This item is the percent of trucks, not counting pickups, in the traffic stream. This value is used for all routes, though it may be changed for any individual route segment. The default is 11 percent for rural areas and 3 percent for urban areas.

11. Total Construction Cost (Millions of $).

This item is the total construction and right-of-way costs for the proposed project, in millions of dollars.

12. Construction Category (1-Simple Bypass, 2-Partial Bypass, 3-Interchange, 4-RR Grade Separation).

This item is the general category of construction the project falls into. The category selected determines, to an extent, the data items that are prompted when entering data and some of the default values for individual routes and segments. A simple bypass is assumed to be on new location, and the proposed route will not replace the existing route. A partial bypass may have a portion already built and open, but the project itself is on new location, and the proposed route will not replace the existing route. For both the interchange category and the RR grade separation, the proposed route is assumed to replace the existing route.

13. Alternate Parallel Route in Analysis (1-Yes, 2-No).

This item is used to indicate if there is an alternate route to be included in the analysis. Normally this would be used for a bypass project, where the bypass would pull traffic off the existing route and an alternate parallel route. It could be used in the other categories if the proposed grade separation will pull traffic off an alternate parallel route.

14. Operating Cost and Accident Cost Update Factor.

This item is used to update the vehicle operating cost calculations and the accident cost calculations. The default is 1.00. Periodically this should be increased to reflect increases in vehicle and accident costs, using an

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appropriate price index, such as the CPI or the fuel cost component of the CPI.

15. Area Type (1-Rural, 2-Urban).

This item indicates the general area the project is located in. The area affects some of the assumed default numbers and is used in the program. It will also affect the calculated speed for a given traffic volume on non-freeway highway types.

16. Return to Main Menu.

This item is used to return to the Main Menu.

ROUTE DATA EDIT MENU

The choices are explained below.

1. Route Description.

This item can be used to put a route description in the input and output. It can be up to 30 characters long.

2. Current Year Average Daily THROUGH Traffic before improvement (Thous.).

This item gives the current year average daily through traffic in thousands on this route in the current conditions, before the improvement is made. For a grade separation project, this would normally be the total ADT volume. For a bypass project, this represents the ADT on the route available for allocation to the bypass route. Any additional traffic would go to the additional local traffic in the Segment Data Edit Menu.

3. Twenty-Year Future Average Daily THROUGH Traffic before improvement (Thous.).

This item gives the twenty-year forecasted average daily through traffic in thousands on this route in the current conditions, if the improvement is not made.

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4. <u>Current Year Average Daily THROUGH Traffic after improvement (Thous.).</u>
This item gives the current year average daily through traffic in thousands on this route for the improved conditions.

5. <u>Twenty-Year Future Average Daily THROUGH Traffic after improvement (Thous.).</u>
This item gives the twenty-year forecasted average daily through traffic in thousands on this route for the improved conditions.

6. <u>Number of Route Segments.</u>
This item gives the number of segments the route is to be divided up into. For a grade separation project, this would normally be 1. For a bypass project, each route can be divided up into a maximum of 20 segments, depending on the level of detail required for the analysis and the conditions of the routes. Normally segments are defined by breaks at signalized intersections or changes in the number of through lanes. The reason for those breaks is that for each segment, the intersection or interchange delay, along with the motorist costs of traveling the segment, are calculated. It is therefore of benefit to break the routes into segments if possible.

7. <u>Return to Main Menu.</u>
This item is used to return to the Main Menu.

SEGMENT DATA EDIT MENU

The choices are explained below.

1. <u>Segment Description.</u>
This item can be used to put a segment description in the input and output. It can be up to 30 characters long.

2. <u>Type of Intersection/Interchange (1-None, 2-Two Way Stop, 3-Four Way Stop, 4-Signalized Intersection, 5-Simple Diamond, 6-Cloverleaf, 7-Three Level Diamond, 8-Directional, 9-Railroad At-Grade Crossing, 10-Railroad Grade Separation).</u>

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This item designates the type of intersection or interchange in the segment. This item is used to set the default values on the percent of traffic going through the intersection, and the ramp type, volume, and speed assumptions.

3. Additional Local Traffic Using Major Route (Thous.).

This item gives the additional daily traffic on the segment not accounted for in the through traffic for the route. There are two volumes in this item, the current year volume and the twenty year forecasted volume. This local traffic option is normally used in the bypass analysis to designate the traffic that cannot be allocated to the new location bypass.

4. Number of Major Route Lanes, Inbound Direction.

This item gives the number of through lanes on the major route in the inbound direction. It is not important in the analysis which direction is designated inbound and which is designated outbound, since the program assumes a 50-50 directional split.

5. Number of Major Route Lanes, Outbound Direction.

This item gives the number of through lanes on the major route in the outbound direction.

6. Segment Length (miles).

This item gives the length of the segment in miles. The allocation procedure for allocating traffic to a proposed bypass is very sensitive to this item.

7. Free Flow Speed on Major Route (mph).

This item gives the free flow speed on the major route. The free flow speed is the midblock LOS A speed along the segment.

8. Percent Trucks on Major Route.

This item gives the percent trucks, not counting pickups, on the major route for this segment. The default is the percent trucks in the Problem Data Edit Menu.

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9. Major Route Facility Type, 1-Undivided, 2-Divided, 3-Freeway.

This item gives the facility type for the major route. This is used in calculating the average travel speed for a given traffic volume.

10. Capacity per Lane on Major Route (vphpl).

This item gives the capacity per hour per lane on the major route. This is used in calculating the average travel speed for a given traffic volume. It is not used in the intersection delay equations. The defaults are 2000 for freeways, 1900 for rural multilane, 1400 for rural two-lane, 780 for urban divided, and 600 for urban undivided. These are taken from a TTI study on delay (8). The capacity is then adjusted by the percent trucks, by multiplying the above numbers by (1 - .0085 x percent trucks).

If an intersection or interchange, then the following choices are given:

11. Daily Traffic on Minor Route (Thous.).

This item gives the average daily traffic, in thousands, on the minor route (cross street). There are two volumes included in this item, the current year volume and the twenty year forecasted volume.

12. Number of Minor Route Lanes, Inbound Direction.

This item gives the number of lanes on the minor route (cross street) in the inbound direction. As with the major route, it doesn't matter in the analysis which direction is designated inbound and which direction is designated outbound.

13. Number of Minor Route Lanes, Outbound Direction.

This item gives the number of lanes on the minor route (cross street) in the outbound direction.

14. Percent Major Route Daily Traffic with Stop or Signal.

This item gives the percent of the major route daily traffic going through an at-grade stop or signal. This value is important in evaluating interchanges, because much of the benefit results from pulling part or all of the traffic out of an at-grade intersection. The defaults are 100 percent for a four-way

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stop, signalized intersection, or a railroad grade crossing; 20 percent for a simple diamond; 10 percent for a three-level diamond; and 0 for the others.

15. Percent Minor Route Daily Traffic with Stop or Signal.

This item gives the percent of the minor route (cross street) traffic going through an at-grade stop or signal. The defaults are 100 percent for a two-way stop, four-way stop, signalized intersection, and a simple diamond interchange; 10 percent for a three-level diamond; and 0 for the others.

16. Percent Trucks on Minor Route.

This item gives the percent trucks, not including pickups, for the minor route (cross street). The default is the percent trucks in the Problem Data Edit Menu.

17. Minor Route Facility Type, 1-Undivided, 2-Divided, 3-Freeway.

This item gives the facility type for the minor route (cross street).

18. Capacity per Lane on Minor Route (vphpl).

This item gives the capacity per hour per lane on the minor route (cross street). The default values are calculated the same as the capacity on the major route, Item 10 above.

19. Type of At-Grade Signalized Intersection, 1-none, 2-4X4 configuration, 3-4X6 configuration, 4-6X6 configuration.

This item gives the at-grade signalized configuration (number of through lanes for each route). The category is used to determine which intersection delay equation to use. The number of through lanes in Items 4, 5, 12, and 13 because interchanges may have a different number of lanes at the signals than they have on the main lanes.

20. Edit Ramp Types and Volumes.

This option allows the user to modify the ramp type, speed, and volumes for situations where the assumed values are not appropriate. This would be particularly useful with an unusual interchange configuration. (See Ramp and Volume Menu, below.)

If a railroad grade crossing or grade separation, then the following choices are given:

11. **Number of Trains Crossing per Day.**

    This item gives the average number of trains passing the grade crossing each day.

12. **Average Train Speed (mph).**

    This item gives the average train speed, in mph, while passing the crossing.

13. **Average Train Length (miles).**

    This item gives the average train length, in miles, of the trains passing the crossing.

14. **Time for Gates to Close and Open (min.).**

    This item gives the time, in minutes, for the gates to close and open while the crossing is empty. It is the time the vehicles are prevented from crossing the tracks before and after the train passes the crossing.

15. **Percent Reduction in Vehicle Speed Crossing Tracks.**

    This item gives the percent reduction in speed to cross the tracks. This is during the time when the crossing is open and traffic can cross the tracks without interruption. Depending on the roughness and humped nature of the crossing, vehicle speeds can be significantly reduced. The recommended reductions, taken from a national study on railroad crossings (9), gives 30 percent reduction for a smooth crossing surface, 40 percent reduction for a typical crossing surface, a 50 percent reduction for a humped and rough crossing surface, and a 60 percent reduction for a very humped and rough crossing surface.

16. **Percent Major Route Daily Traffic Crossing Tracks.**

    This item gives the percent of traffic crossing the tracks. Normally this would be 100 percent for an at-grade crossing, and 0 for a grade separation, though it could be changed for unusual situations.

Then for all types, the following choices are given:

21. <u>Delete Segment from data file.</u>

This item allows the user to delete a segment from the data file. There is a warning message flashed before the segment is deleted. After the segment is deleted, all higher numbered segments are renumbered. The program will not allow the deletion when there is only one segment defined.

22. <u>Return to Main Menu.</u>

This item is used to return to the Main Menu.

RAMP AND VOLUME MENU

The choices are explained below.

1. <u>Major Route, Inbound, Right Turn.</u>

This item gives information on the right-turn movement, inbound direction, on the major route.

2. <u>Major Route, Inbound, Left Turn.</u>

This item gives information on the left-turn movement, inbound direction, on the major route.

3. <u>Major Route, Outbound, Right Turn.</u>

This item gives information on the right-turn movement, outbound direction, on the major route.

4. <u>Major Route, Outbound, Left Turn.</u>

This item gives information on the left-turn movement, outbound direction, on the major route.

5. <u>Minor Route, Inbound, Right Turn.</u>

This item gives information on the right-turn movement, inbound direction, on the minor route.

6. <u>Minor Route, Inbound, Left Turn.</u>

This item gives information on the left-turn movement, inbound direction, on the minor route.

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7. Minor Route, Outbound, Right Turn.

This item gives information on the right-turn movement, outbound direction, on the minor route.

8. Minor Route, Outbound, Left Turn.

This item gives information on the left-turn movement, outbound direction, on the minor route.

9. Return to Segment Edit Menu.

This option is used to return to the Segment Data Edit Menu.

Then for the item to edit, the following choices are given:

1. Type of Ramp   (1-None, 2-Diagonal, 3-Loop, 4-Directional, 5-Semi-directional).

This item gives the type of ramp for the specified turning movement. If the ramp type is changed from the standard configuration for that interchange, then the user is asked whether or not to use the default values for that ramp type for the other ramp parameters.

2. Ramp Volume (% of ADT).

This item gives the percent of ADT in both directions using that ramp. The default in every case is 5 percent.

3. Ramp Speed (mph).

This item gives the average speed the vehicles using the ramp will travel. It does not include slowing down or stopping at an at-grade intersection. The defaults are 65 percent of the free flow speed for a diagonal ramp, 50 percent of the free flow speed for a loop ramp, 80 percent of the free flow speed for a directional ramp, and 75 percent of the free flow speed for a semidirectional ramp.

4. Savings in Distance Traveled (miles).

This item gives the savings in distance traveled using the ramp versus going through a standard intersection. The defaults are .02 for a right-turn diagonal ramp, -.05 for a left-turn diagonal ramp, -.25 for a loop ramp, and .15 for a directional ramp.

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5. <u>Interrupted Flow at End of Ramp (Y-Yes, N-No).</u>

This item gives a yes or no switch on whether or not the flow at the end of the ramp is interrupted. This relates directly to the percent traffic going through a stop or signal, Items 14 and 15 in the Segment Data Edit Menu. When this item is changed, those Segment Data Edit Menu values are also changed if possible. The defaults are yes for the diagonal ramps, and the left-turning ramps of a three-level diamond. The other interchange ramps are no.

HOURLY TRAFFIC DISTRIBUTION MENU

The choices are explained below.

1. <u>% ADT during Hour 1.</u>

This item gives the percent of the daily traffic volume in both directions on the major route for hour 1.

2. <u>% ADT during Hour 2.</u>

This item gives the percent of the daily traffic volume in both directions on the major route for hour 2.

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.   .   .

24. <u>% ADT during Hour 24.</u>

This item gives the percent of the daily traffic volume in both directions on the major route for hour 24.

25. <u>Return to Main Menu.</u>

This option will return the user to the Main Menu.

HOURLY TRAIN TRAFFIC DISTRIBUTION MENU

The choices are explained below.

1. **% of Daily Trains during Hour 1.**

   This item gives the percent of the number of trains each day that pass during hour 1.

2. **% of Daily Trains during Hour 2.**

   This item gives the percent of the number of trains each day that pass during hour 2.

   .   .   .

   .   .   .

   .   .   .

24. **% of Daily Trains during Hour 24.**

   This item gives the percent of the number of trains each day that pass during hour 24.

25. **Return to Main Menu.**

   This option will return the user to the Main Menu.

TRAFFIC ALLOCATION MENU

The choices are explained below.

1. **Calculate Traffic Allocation for Proposed New Location Bypass, based on equal costs per motorist on each route.**

   This option will allocate through traffic to a proposed bypass route from an existing route and alternate route (if any).

2. **Return to Main Menu.**

   This option allows the user to return to the Main Menu without allocating the traffic.

OUTPUT OPTIONS MENU

The choices are explained below.

1. Show output on screen.

   This option will display the output on the screen of the last problem that has been analyzed during the current session.

2. Send output to printer.

   This option allows the user to send the summary input and output to a printer (Port LPT1).

3. Save output on disk file.

   This option allows the user to save the summary input and output information onto a disk file. The user is prompted for the file name to save the data set. The data could then be used in a word processing package.

4. Return to Main Menu.

   This option allows the user to return to the Main Menu.

SAVE INPUT DATA MENU

The choices are explained below.

1. Save Input Data to a File.

   This option allows the user to save the input data set on a disk file. The file could then be read directly into the program in the future, without going through the data entry process.

2. Return to Main Menu.

   This option allows the user to return to the Main Menu without saving the input data set.

CONCLUSIONS AND RECOMMENDATIONS

The TRIP computer program has been developed to assist SDHPT in evaluating proposed interchange, railroad grade separation, and bypass projects. The program does not require a large amount of detailed information · to run, though additional information can be used to revise the assumed parameters and relationships in the program. The program is designed to be used at the planning level, not at the design or operational level. The program provides a quick and easy method of evaluating the relative importance of proposed projects using a consistent standard, the benefit-cost ratio. This could then be incorporated into a more comprehensive procedure for ranking and selecting proposed projects for future funding.

TRIP has been designed to be easy to use, yet comprehensive enough to handle a wide variety of project characteristics. For interchanges, each ramp can be customized for a particular problem. The ramp type, ramp speed, ramp volume, and ramp distance can all be varied by the user. For bypasses, the traffic can be divided up into through traffic, which can be allocated to the proposed bypass, and local traffic, which is not sensitive to the bypass. This gives a great deal of flexibility in evaluating a project with some "unusual" characteristics.

It is recommended that TRIP go through an implementation process. The program needs to be field tested, so any problems not found in the development process can be corrected. In addition there should be some training of SDHPT personnel that will be using the program. While the program is designed to be easy to use, a person unfamiliar with some of the concepts and terminology of benefit-cost analysis or interchange design may encounter some problems in using TRIP, initially.

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APPENDIX A - Calculation of Delay Savings and Other Motorist Savings
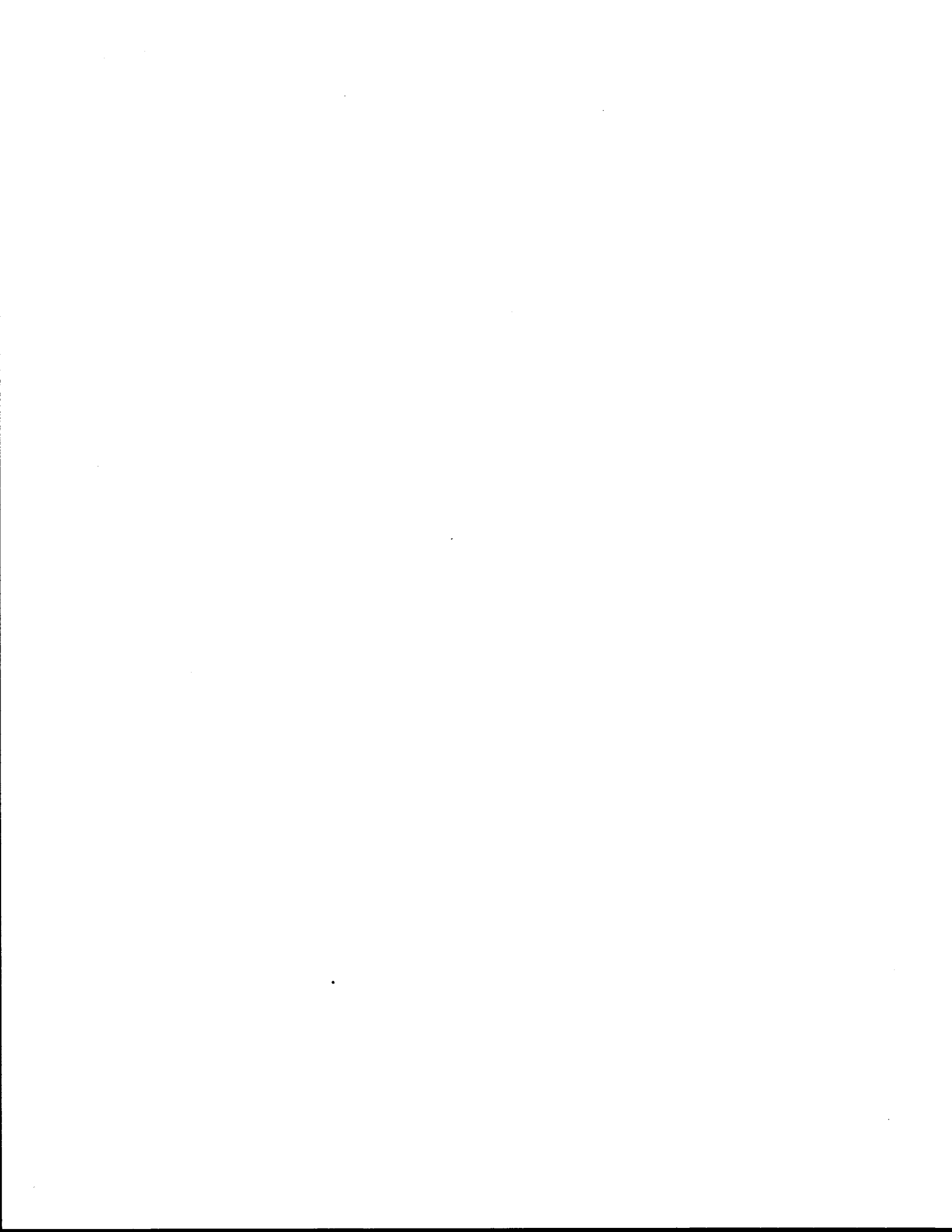
CALCULATION OF GRADE SEPARATION DELAY EQUATIONS

Transportation engineers and planners are often required to rank intersection-to-interchange improvement projects based on a minimal amount of input. The objective behind a grade separation is to enhance total overall traffic movement and/or to prioritize traffic movement on one functional class of roadway over another functional class of roadway. Grade separations improve the overall traffic movement at the junction of the roadways by increasing operational efficiency in the following areas: (1) increasing the amount of traffic the roadway junction can accommodate, (2) lowering the overall delay, and (3) decreasing certain types of accidents.

Currently, no guidelines exist for warranting a grade separation at a roadway intersection. The possible operational improvement the grade separation will have on the intersection has not been evaluated. One measure of operational improvement is the delay savings and increased capacity of the interchange versus the intersection. Delay can be used for a relative comparison of the improvement and it can also be used in an economic analysis by assigning a value to this delay time. This is the approach taken in this study, to incorporate the delay savings into a model to estimate the benefit-cost ratio of a proposed interchange project.

The study did not attempt to acquire data for estimating delay for every possible variety of intersection and interchange—a difficult if not impossible task. The purpose was to identify major characteristics so that one type of improvement may be compared to another.

A major portion of potential benefits can be attributed to delay reductions. At an interchange, traffic consists of two components—the grade separated vehicles and the vehicles operating at-grade and passing through the system. Separate procedures are necessary for evaluating the at-grade and grade separated portion of the interchanges. This section deals only with the at-grade signalized portion of interchanges. For purposes of this section, freeway saturation ≤ 1800 vphpl will contribute a negligible amount to the system delay.

After evaluating a variety of alternatives, the TRANSYT-7F computer model (3) was selected for developing relationships between alternative at-grade configurations. TRANSYT-7F is capable of evaluating at-grade intersections, simple diamond interchanges, and three-level diamond interchanges.

To simplify the evaluation, all types of intersections were high type with separate left-turn and right-turn bays. Figures 8-10 show the geometric layout of the various types of at-grade, signalized intersections. Saturation was set at 1700 vph for left-turns and 1750 vph for through and right-turning traffic. Right-turning traffic was phased with its corresponding through movement. Phasing at the high type intersection consisted of four phases with leading left turns. The simple diamond interchange operated on three phases with an offset between the two intersections. The three-level diamond run on a coordinated two-phase pattern. Minimum cycle lengths of 30 to 40 seconds were used with clearance intervals of 3 seconds. Another simplifying assumption made was that the cross road volume distribution was 1 to 1. Right- and left-turning movements were either heavy (20%) or light (10%) on each approach.

TRANSYT-7F is a macroscopic deterministic traffic model. For planning purposes, a certain amount of underlying assumptions are necessary for the TRANSYT-7F model. Variables such as geometrics, phasing, clearance, intervals, saturation, traffic volumes, and traffic distribution will all impact the analysis. There is an infinite amount of combinations. The important points are that the comparison is for planning purposes and should be a equitable as possible for evaluation of the operational upgrades from intersection to simple diamond interchange to three-level diamond interchange.

Traffic volumes and distributions are infinite and site specific. To reiterate, the purpose of this study was to guide planners in evaluating grade separation projects, so an analysis of most volume and distribution scenarios would be impossible.

Figure 11 presents the total system delay calculated by TRANSYT-7F at the signalized intersection, based on hourly volume, turning movement percentages, and the other assumptions made with the geometrics, phasing, and clearance intervals. The curves were obtained by starting with a low initial traffic volume and incrementally increasing the volume in each succeeding computer simulation until over saturation
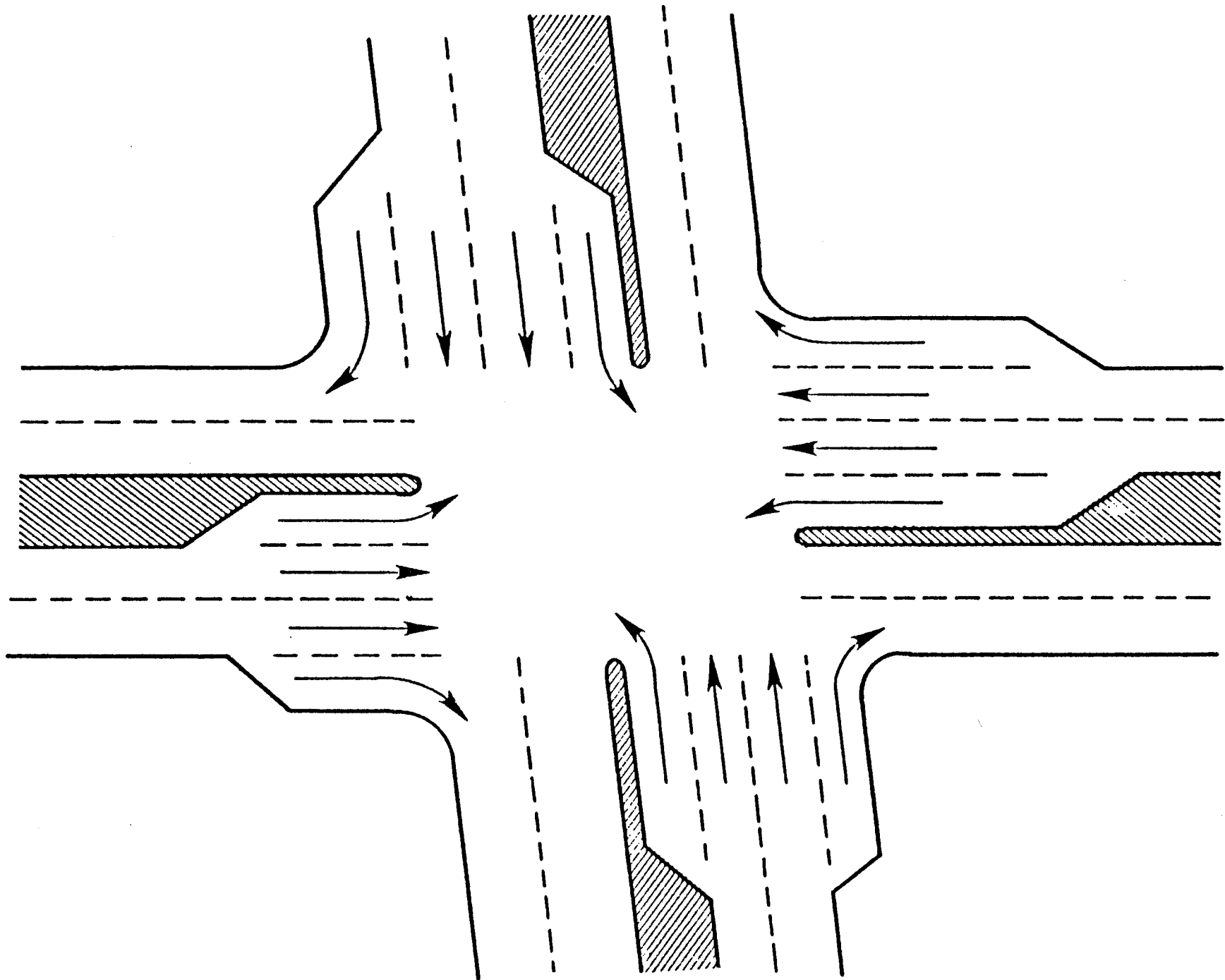
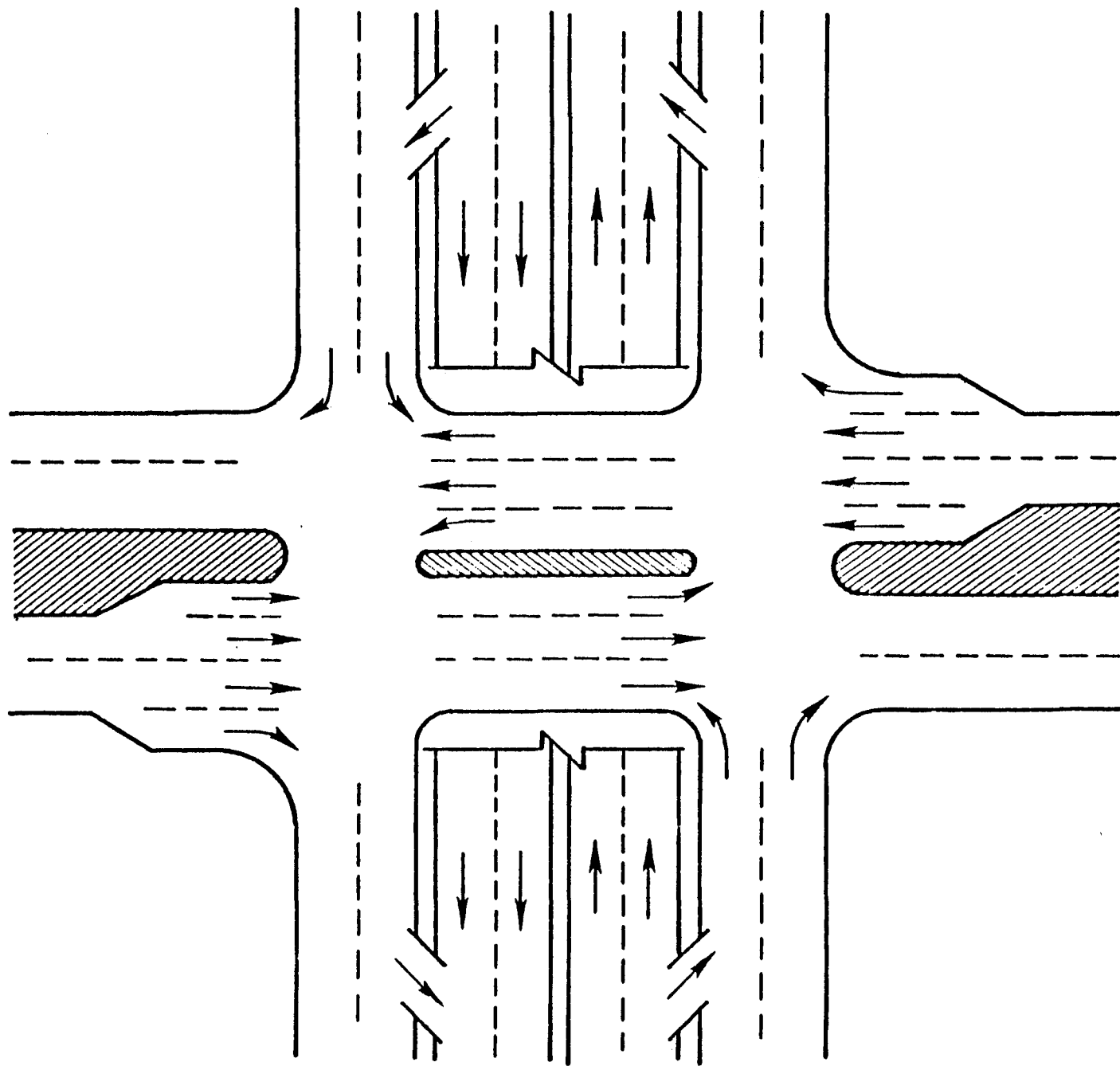Figure 8. Intersection Geometrics Used in T7F Simulation.

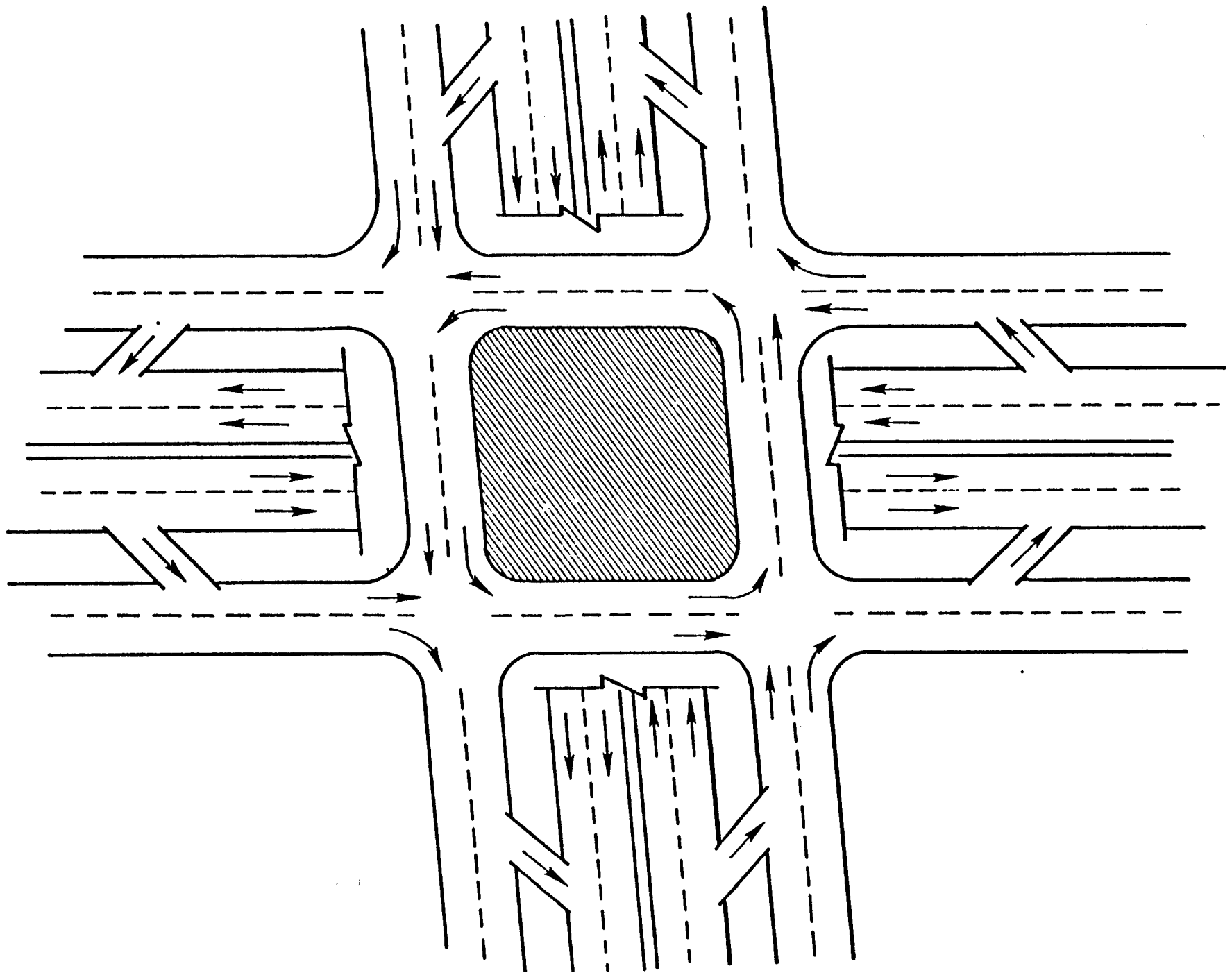Figure 9. Simple Diamond Geometrics Used in T7F Simulation.

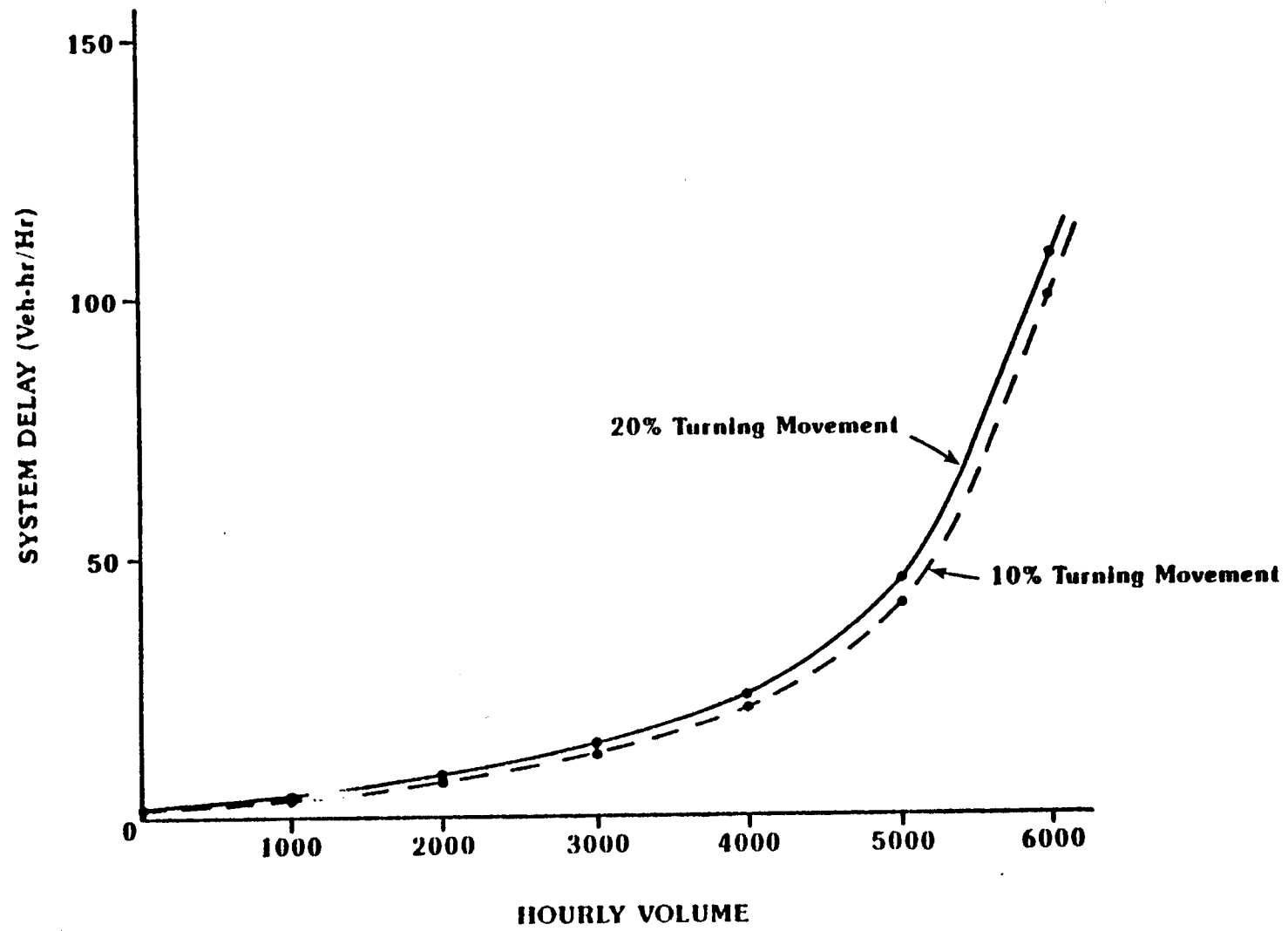Figure 10. 3 Level Diamond Used in T7F Simulation.

Figure 11. System Delay for High Type Intersection.

occurred. The plots in Figure 11 are asymptotical in appearance, much like the underlying TRANSYT-7F delay calculation. At 6,000 vph the average delay per vehicle is approximately 60 seconds, making the overall system delay 100 vehicle hours. This corresponds to a level-of-service F, as given by the Highway Capacity Manual (5).

A simple diamond in essence removes two through movements from the at-grade intersection and replaces on signal with two coordinated signals. When interpreting the delay calculations of TRANSYT-7F, the overall delay of the two signalized diamond interchange system will be compared to the one signal intersection "system." The same methodology is used when comparing the system delay of the four signaled, three-level diamond to the simple diamond and the intersection. So, the system delay on the ordinate represents a summation of all of the intersection(s) delay within the system. This was done to provide an equitable operational comparison of the different grade separation levels.

Figure 12 is a plot of the simple diamond interchange simulation. Again, the same asymptotical relationship is evident. The abscissa is marked with three different scales. The top scale reflects the total number of vehicles in the interchange system. From this total, two of the through movements have been removed by the grade separation, leaving the accompanying turning movements to negotiate the at-grade signals. The bottom two scales reflect the actual number of vehicles operating at-grade. Notice that the two curves are very similar in shape to the intersection curves once the abscissa is rescaled or compressed. The upper limit for the simple diamond interchange appears to be approximately 6,000 vph under the assumed variables.

Referring back to Figures 8-10, the initial assumptions were that each movement would have its own lane to travel through the "system." On the simple diamond interchange any frontage road traffic has been neglected and/or could be assigned to its own lane, provided that the frontage road traffic was equal to or less than the accompanying right-turning movement volumes. Both frontage road traffic and U-turning traffic was negated in order to provide a consistent comparison throughout. Frontage road and U-turning volumes are rarely known at the planning stage.
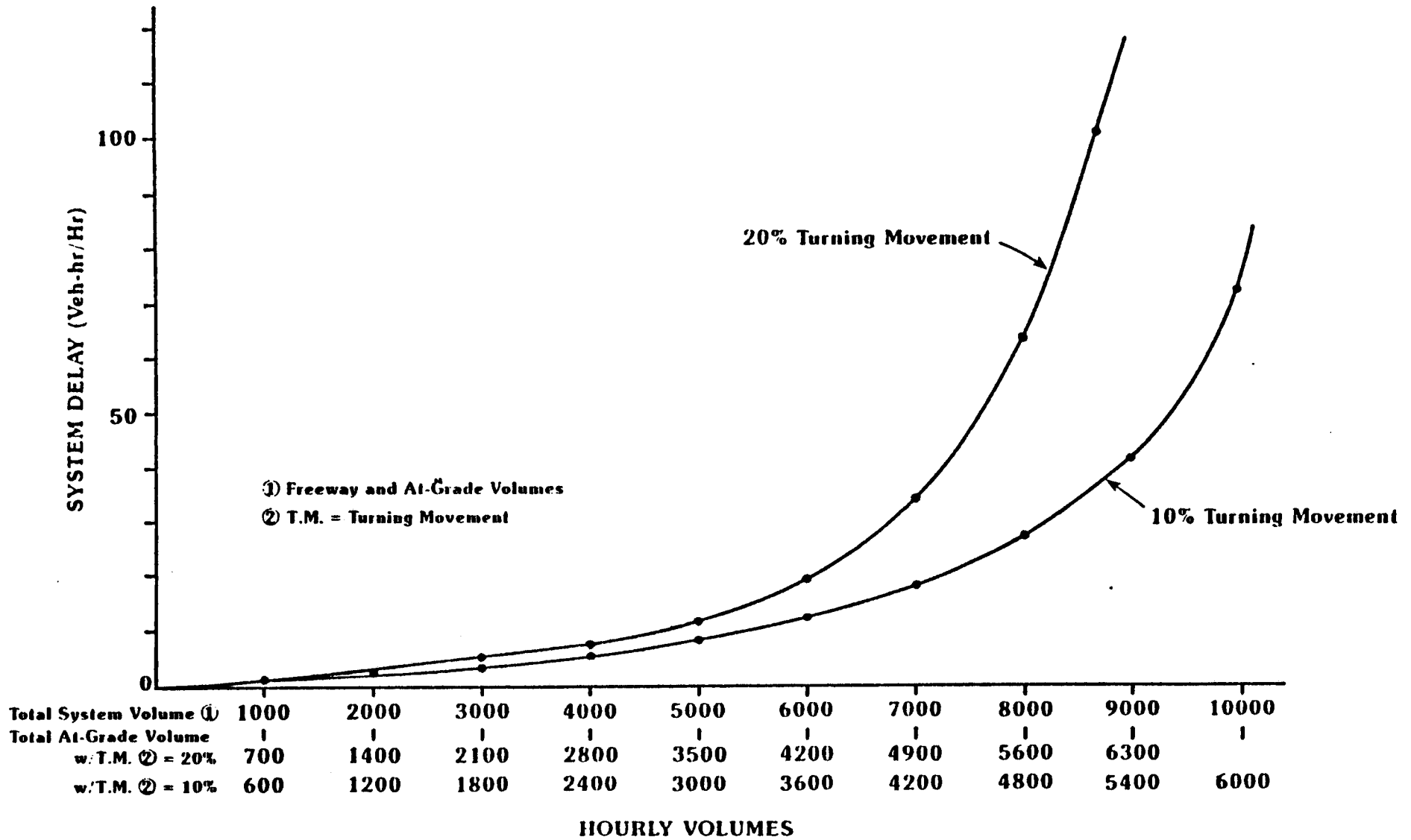
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Figure 12. System Delay for Simple Diamond Interchange.

Figure 13 demonstrates that the same asymptotical relationship exists in the three-level diamond interchange. The top abscissa scale is the total number of automobiles in the three-level diamond system. Four through movements have been grade separated or removed from the at-grade intersection. The remaining turning movements must negotiate the at-grade signals. The two lower abscissa scales reflect the residual of the through movement, and is a combination of the right turns plus the left turns, with two through lanes in each direction (as shown in Figure 10), the total system capacity for this roadway junction = 4 directions x 2 lanes/direction x 2000 vph/lane = 16,000 vph, which is the "theoretical" upper limit.

A three-level diamond interchange would probably have three or more lanes on each approach. Figure 10 represents the geometrics assumed for this analysis only. Each turning movement had a separate lane as it negotiated a signal controlled intersection. Frontage road traffic was not included in the system delay summation. Frontage road traffic does not enter into the analysis as long as it remains in its own assigned lane and is less than or comparable to an accompanying right-turning movement. With 40 percent (left + right) of the through movement exiting the freeway, the exit ramp has reached its capacity [(.40 x 2 lanes x 2000 vph/lane) = 1600 vph] and will act as a constraint on the at-grade capacity of the system. Once the two lower abscissa scales are compressed, a delay relationship very similar to the intersection relationship is formed. The upper limit appears to approach 6,000 vph for the three-level diamond under the assumed variables.

A family of curves has been developed for the three different geometric scenarios. Figure 14 shows the volume of traffic each roadway junction can accommodate relative to the other. Each roadway junction type has an upper and lower limit which is actually set by the severity of the left-turning movement demand.

Figure 14 is the summation of the range of intersection delays within each "system." This is neglecting any delay on the free moving through lanes. By definition, the freeway delay should also be included with the overall system delay. However, with at least 20 percent of the total traffic (10% right turns and 10% left turns) negotiating the
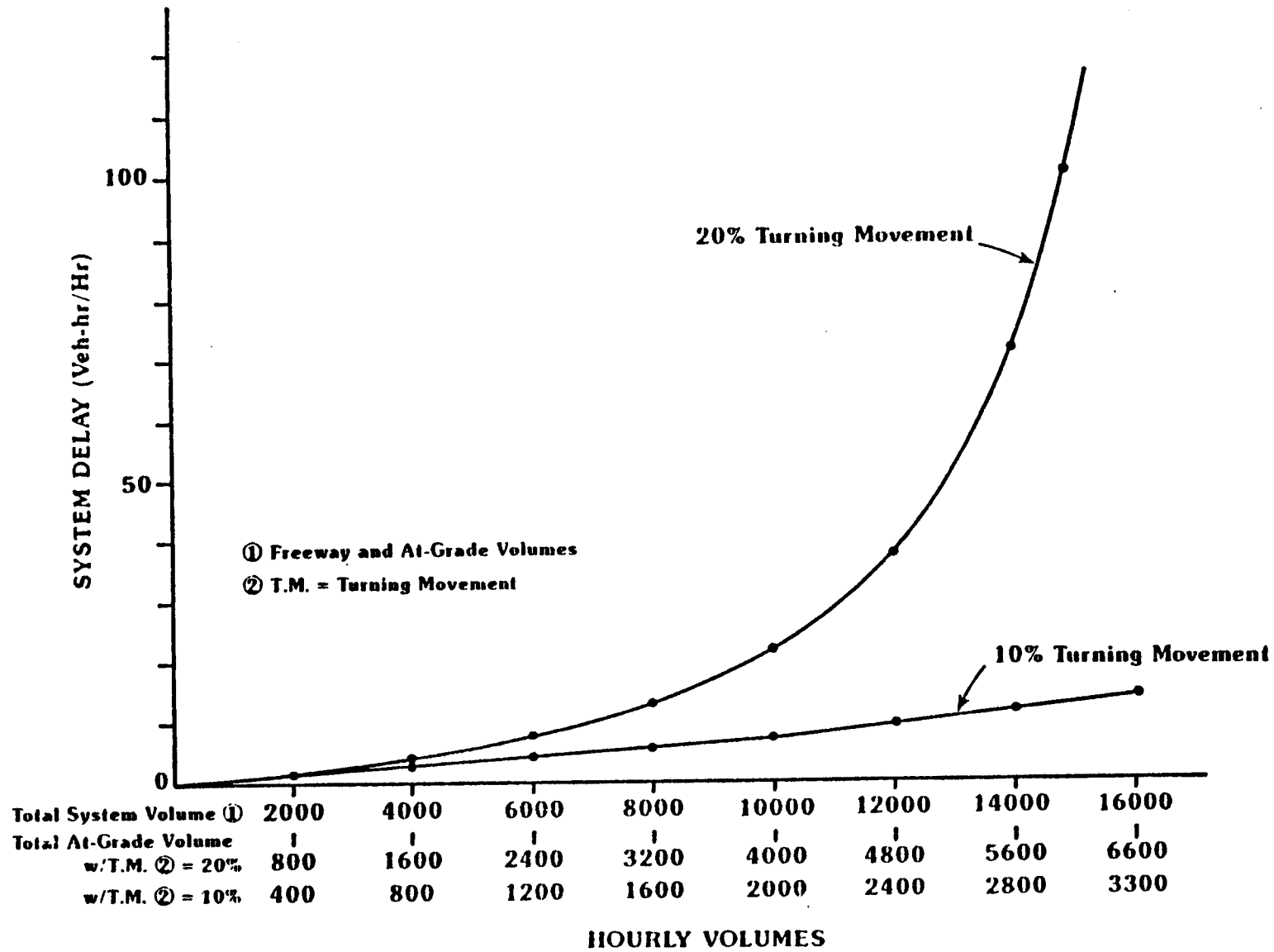
46

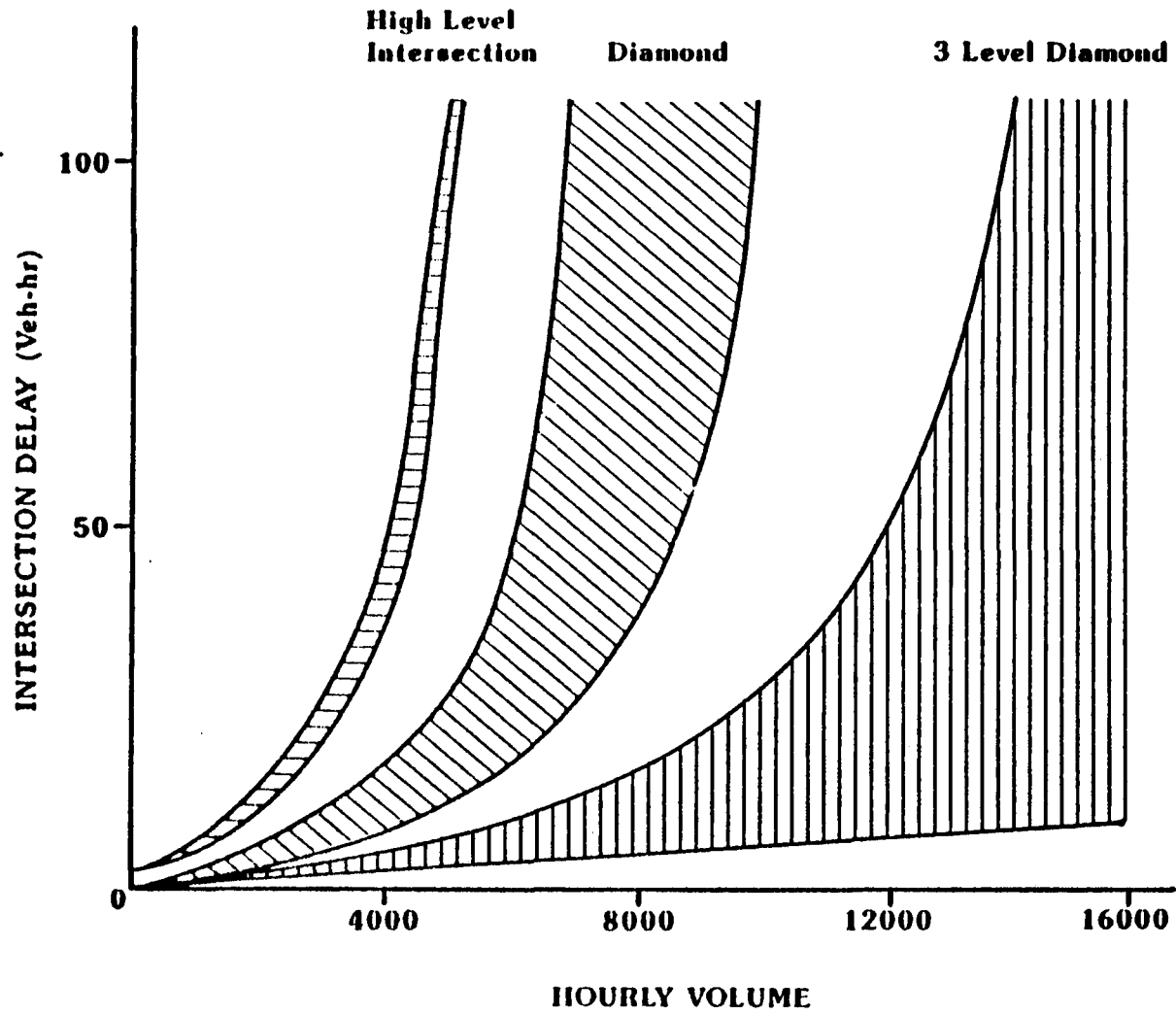Figure 13. System Delay for 3 Level Diamond Interchange.

Figure 14. At-Grade Delay Versus Capacity.

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at-grade portion of the interchange, this leaves 1800 vphpl on the freeway lanes on the three-level diamond. The freeway delay has been omitted from these calculations and are included in TRIP, using a speed/volume analysis. The freeway lanes on the diamond interchange are operating at 1,000 vph per lane when the at-grade delay reaches 60 seconds per vehicle.

The underlying asymptotical relationship as demonstrated in Figures 11, 12, and 13 is that the approximate capacity of the at-grade portions of the roadway junctions is 6,000 vph (with these assumed geometrics). What appears to be occurring is that any efficiencies gained by losing a phase and removing two through volumes are counter-balanced by increasing the number of coordinated traffic signals.

The delay relationships described above can be approximated by using an equation to estimate the delay for different hourly traffic volumes. The similarity between the intersection, simple diamond, and three-level diamond at-grade delay curves can be used to an advantage. This similarity in shape means that equations can be developed for a given number of through lanes that will apply to each design. Using the SAS curve fitting routine, equations were derived to approximate the delay.

For a 4x4 high type intersection (4 through lanes by 4 through lanes), the at-grade delay equation is:

$$Delay = 1.1778*exp(.00072452*vph)$$
where

Delay = vehicle hours of delay, vph = at-grade vehicles/hour.

For a 4x6 high type intersection, the at-grade delay equation is:

$$Delay = 1.1855*exp(.00065674*vph)$$

For a 6x6 high type intersection, the at-grade delay equation is:

$$Delay = 1.2662*exp(.00056726*vph)$$

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STOP SIGN DELAY EQUATIONS

The delay equations for the stop sign controlled intersections were generated by the NETSIM computer simulation model (4). NETSIM is a microscopic stochastic model, as opposed to the macroscopic, deterministic computations of the TRANSYT-7F computer model.

The four-way stop controlled intersection was modeled under a number of variations—1x1, 2x1, and 2x2 lane configurations, various directional splits (70/30, 60/40, and 50/50), different turning percentages (5% to 20%), and various levels of traffic volume. The model was not sensitive to the various parameters, except traffic volume, which gave the greatest impact on the intersection delay. None of the other parameters made significant impacts on the overall delay.

A regression was performed on the data and the following relationship was determined for a four-way stop controlled intersection:

$$Delay = 0.3993*exp(.00511955*vph)$$

where

Delay = vehicle hours of delay

vph = total vehicles/hour.

R^2 was 0.855 and the relationship becomes asymtotical at approximately 800+ vehicles per hour.

The delay equation for a two-way stop controlled intersection was based on the delay accumulated at one-stop controlled approach. The same parameters were varied, as in the four-way stop sign analysis, and the outcome was similar. The delay equation for the two-way stop is:

$$Delay = 0.2629*exp(.00209176*vph)$$

The maximum number of approach vehicles should be limited to 1500 vph and/or an upper limit of 150 vph on the stop controlled approach.

CALCULATION OF MOTORIST COSTS

Calculations are made on an hourly basis for each direction on both the major and minor routes for each route segment. The process is repeated over a 24-hour period for both the current and if improved situations. The costs are summed, and the difference between the current and improved conditions becomes the motorist benefits. The analysis is repeated for every year of the analysis period.

The intersection or interchange delay is calculated using the delay equations presented in the previous sections in this Appendix. The actual delay used in the calculations modifies the lower and upper parts of the curve so that unreasonable delays are not used. For the upper limit, the equation is cut off at 1.2 times the simulated capacity. For any additional traffic, the same delay per vehicle is used. This follows the reaction of motorists to LOS F conditions where alternate routes are used or the trip is taken during less congested times of the day. The lower end of the curve is adjusted so that for very low traffic volumes, the delay goes to zero as traffic goes to zero. While this may not be precisely true due to limitations in the signal timing mechanism, it gives consistent and reasonable numbers; as the traffic goes up, the delay goes up.

There are also operating costs calculated for motorists slowing down and stopping at intersections, and idling costs while waiting for the signal to turn and the queue to dissipate.

Costs are also calculated for vehicles traveling over the segment route. The most important variable is the average running speed. The average running speed is calculated based upon speed-volume relationships estimated from the 1985 Highway Capacity Manual LOS data (5). The equations above capacity and the urban arterial are taken from a TTI study on delay (8). The equations are given below:

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If the volume/capacity (VC) ratio is ≤ 1, then

    Speed = (FFSPD - CSPD) * $(1-VC^2)^{0.5}$ + CSPD

    where

        Speed = average running speed over segment, excluding intersections

        FFSPD = free flow speed, from input data

        MSPD = minimum speed at LOS F, assumed to be 10 in urban, 15 in rural

        VC = volume to capacity ratio, capacity taken from input data

        CSPD = capacity speed at LOS E, assumed to be 30 in urban, 45 in rural

If the VC ratio is > 1 and ≤ 2, then

    Speed = CSPD - CSPD * $[1-(2-VC)^2]^{0.5}$

If the VC ratio is > 2, then

    Speed = MSPD

If the route is an urban arterial, then

    Speed = FFSPD * (1 - 0.01875 * VC)

The delay is then simply calculated as the distance divided by the speed.

    The operating cost equations, used for the segment and intersection calculations, were estimated from Zaniewski (10), updated to May 1988, and are given below:

    Idling Costs, Passenger Car = $0.94/hour

    Idling Costs, Truck = $0.97/hour

    log(PCYC) = 1.2206 + .14948 * Speed + .01028 * $Speed^2$

where PCYC = passenger car cycling cost from Speed to 0 ($/1000 cycles)

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$$\log(TCYC) = -9.8845 + 3.3657 * Speed + .09396 * Speed^2$$

where TCYC = truck cycling cost from Speed to 0 ($/1000 cycles)

$$\log(PCYC1) = .9869 + .0324 * Speed - .0001 * Speed^2$$

where PCYC1 = passenger car cycling cost for a 10-mph speed change ($/1000 cycles)

$$\log(TCYC1) = 3.0784 + .0562 * Speed - .0004 * Speed^2$$

where TCYC1 = truck cycling cost for a 10-mph speed change ($/1000 cycles)

$$\log(PVOC) = 5.6370 - .02750 * Speed + .00033 * Speed^2$$

where PVOC = passenger car running costs per 1000 vehicle miles

$$\log(TVOC) = 6.7904 - .03464 * Speed + .00041 * Speed^2$$

where TVOC = truck running costs per 1000 vehicle miles.

Accident costs are calculated by multiplying the accident rate times the cost per accident. Accident rates for intersections, interchanges, and railroad grade crossings were estimated from Texas accident tapes from 1981 to 1986. It was not possible to distinguish among interchange configurations due to the way the data are coded and the small number of accidents at interchanges. Costs per accident were taken from a TTI study on accident costs by Rollins and McFarland (11). The accident rates and costs are shown in Table 1.

Table 1. Accident Rates and Costs in Texas

	PDO Accidents	Injury Accidents	Fatal Accidents
Accident Rates per Intersection per 1000 vehicle lane miles			
Urban			
RR Grade Crossing	0.0257	0.0156	.0005728
At Grade Stop	0.9393	0.5165	.0102303
At Grade Signal	0.4648	0.2145	.0020001
Interchange	0.0879	0.0518	.0014806
Rural			
RR Grade Crossing	0.0063	0.0036	.0004956
At Grade Stop	0.8374	0.5484	.0306748
At Grade Signal	0.8655	0.3598	.0075463
Interchange	0.0694	0.0406	.0046282
Cost per Accident (updated to May 1988)			
Urban			
RR Grade Crossing	2,006	22,420	899,042
Intersection	1,239	12,980	886,770
Interchange	1,180	12,272	856,326
Rural			
RR Grade Crossing	2,832	18,408	861,282
Intersection	1,711	22,066	990,492
Interchange	1,829	20,532	1,068,136
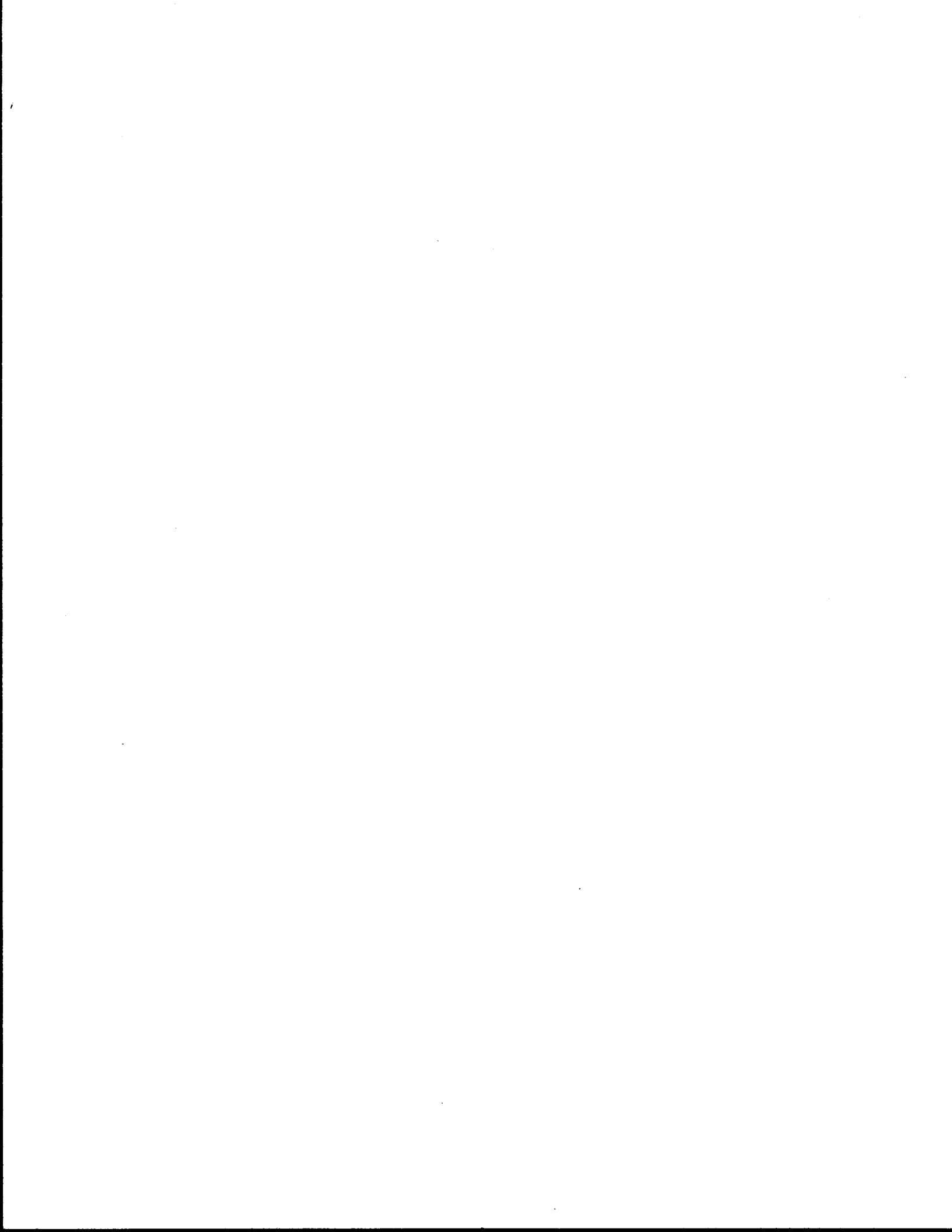
APPENDIX B - Example Input and Output for TRIP
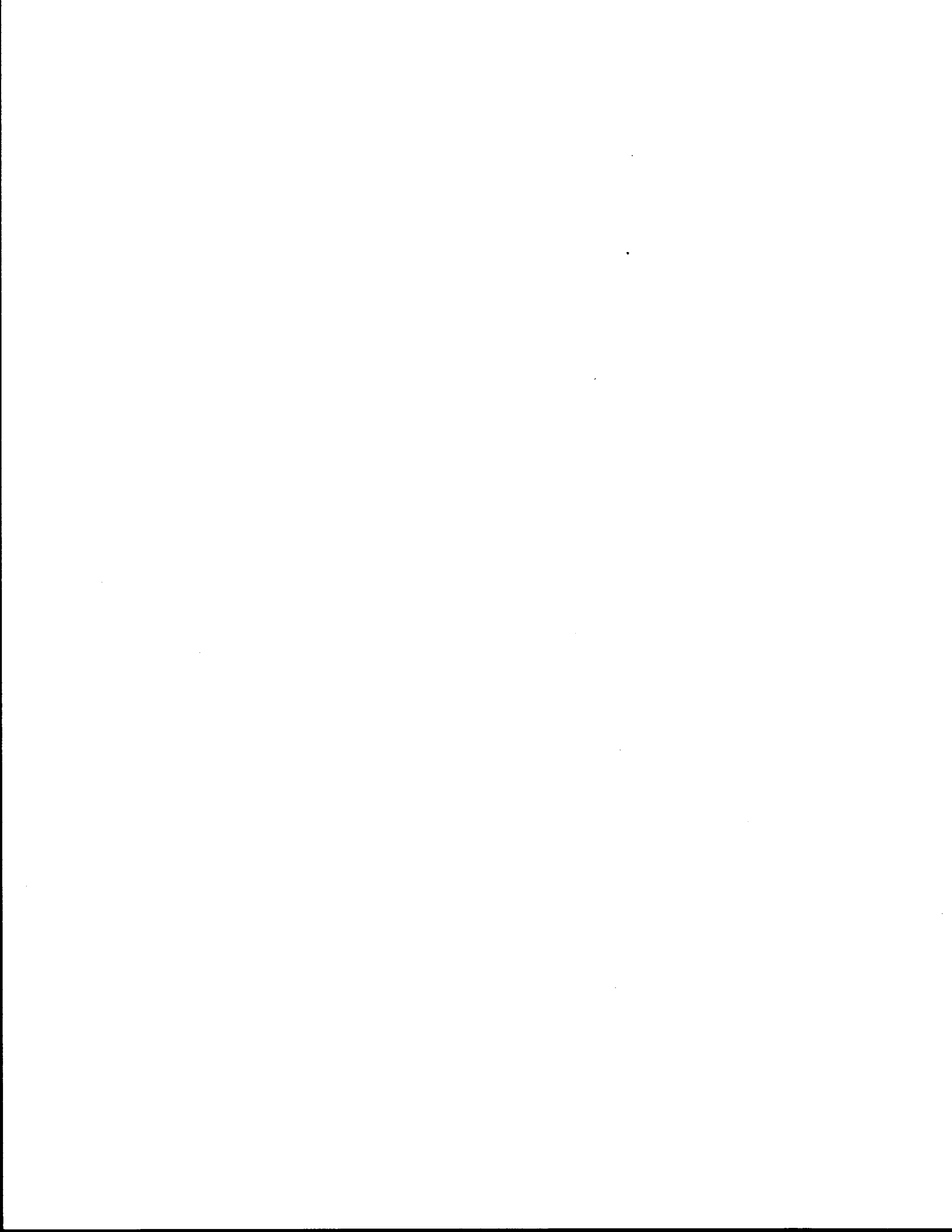
TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

TEXAS RANKING OF INTERCHANGE PROJECTS - TRIP
PC INTERCHANGE AND RR GRADE SEPARATION BENEFIT-COST PROGRAM
Version 1.0
(Costs Updated to May 1988)

PROBLEM Assumptions

1. Problem Description: Diamond Interchange Test
2. Current Year: 1988
3. Discount Rate (%): 8.0
4. Analysis Period (Years): 20
5. Type of Traffic Growth Rate (1-Const Grwth, 2-Strght Ln): 1
6. Car Value of Time per Person ($/hr): 8.58
7. Truck Value of Time per Person ($/hr): 20.39
8. Car Occupancy Rate: 1.30
9. Truck Occupancy Rate: 1.00
10. Percent Trucks: 3.0
11. Total Construction Cost (Millions of $):   5.00
12. Const. Cat. (1-Simple Bypass, 2-Partial Bypass,
    3-Interchange, 4-RR Grade Separation): 3
13. Alternate Parallel Route in Analysis (1-No, 2-Yes): 1
14. Operating Cost and Accident Cost Update Factor: 1.00
15. Area Type (1-Rural, 2-Urban): 2

EXISTING Route

1. Route Description: EXISTING ROUTE

2. Current Year Average Daily THROUGH
    Traffic before Improvement (Thous.):   20.00

3. 20 Year Future Average Daily THROUGH
    Traffic before Improvement (Thous.):   39.80

4. Current Year Average Daily THROUGH
    Traffic after Improvement (Thous.):   0.00

5. 20 Year Future Average Daily THROUGH
    Traffic after Improvement (Thous.):   0.00

6. Number of Route Segments: 1

EXISTING Route, SEGMENT 1

1.   Segment Description: EXISTING SEGMENT
2.   Type of Int, 1-None, 2-2 Wy Stp, 3-4 Wy Stp, 4-Signl, 5-Smpl Dimnd,
     6-Clovrlf, 7-3 Lvl Dimnd, 8-Dirctnal, 9-RR Cross, 10-RR Grade Sep : 4
3.   Major Rt Add Daily Loc Traf (Thous), Curr Yr: 2.00, 20 Yr Fut: 3.98
4.   Number of Major Route Lanes, Inbound Direction: 2
5.   Number of Major Route Lanes, Outbound Direction: 2
6.   Segment Length (miles): 0.50
7.   Free Flow Speed on Major Route (mph): 40.
8.   Percent Trucks on Major Route: 3.0
9.   Major Route Facility Type, 1-Undiv, 2-Div, 3-Frwy : 2
10. Capacity per Lane on Major Route (vphpl): 730
11. Daily Traf on Minor Rt (Thous.), Curr Yr: 10.00, 20 Yr Fut: 19.90
12. Number of Minor Route Lanes, Inbound Direction: 2
13. Number of Minor Route Lanes, Outbound Direction: 2
14. Percent Major Route Daily Traffic with stop or Signal: 100
15. Percent Minor Route Daily Traffic with stop or Signal: 100
16. Percent Trucks on Minor Route: 3.0
17. Minor Route Facility Type, 1-Undiv, 2-Div, 3-Frwy : 1
18. Capacity per Lane on Minor Route (vphpl): 633
19. Type of At-Grd Signl Inter, 1-none, 2-4X4, 3-4X6, 4-6X6 : 2

EXISTING Route, SEGMENT 1 Ramp and Volume Data

	Type of Ramp	Ramp Volume (% ADT)	Ramp Speed (MPH)	Savings in Dist Traveled (Miles)	Interrupted Flow, End of Ramp (Y/N)
1. Maj. R, Inb, Rgt-Trn	NONE	0.0	0.0	0.00	Y
2. Maj. R, Inb, Lft-Trn	NONE	0.0	0.0	0.00	Y
3. Maj. R, Out, Rgt-Trn	NONE	0.0	0.0	0.00	Y
4. Maj. R, Out, Lft-Trn	NONE	0.0	0.0	0.00	Y
5. Min Rt, Inb, Rgt-Trn	NONE	0.0	0.0	0.00	Y
6. Min Rt, Inb, Lft-Trn	NONE	0.0	0.0	0.00	Y
7. Min Rt, Out, Rgt-Trn	NONE	0.0	0.0	0.00	Y
8. Min Rt, Out, Lft-Trn	NONE	0.0	0.0	0.00	Y

PROPOSED   Route

1. Route Description: PROPOSED ROUTE

2. Current Year Average Daily THROUGH
    Traffic before Improvement (Thous.):   0.00

3. 20 Year Future Average Daily THROUGH
    Traffic before Improvement (Thous.):   0.00

4. Current Year Average Daily THROUGH
    Traffic after Improvement (Thous.):   20.00

5. 20 Year Future Average Daily THROUGH
    Traffic after Improvement (Thous.):   39.80

6. Number of Route Segments: 1

PROPOSED   Route, SEGMENT 1

1. Segment Description: PROPOSED SEGMENT
2. Type of Int, 1-None, 2-2 Wy Stp, 3-4 Wy Stp, 4-Signl, 5-Smpl Dimnd,
    6-Clovrlf, 7-3 Lvl Dimnd, 8-Dirctnal, 9-RR Cross, 10-RR Grade Sep : 5
3. Major Rt Add Daily Loc Traf (Thous), Curr Yr: 2.00, 20 Yr Fut: 4.00
4. Number of Major Route Lanes, Inbound Direction: 2
5. Number of Major Route Lanes, Outbound Direction: 2
6. Segment Length (miles): 0.50
7. Free Flow Speed on Major Route (mph): 60.
8. Percent Trucks on Major Route: 3.0
9. Major Route Facility Type, 1-Undiv, 2-Div, 3-Frwy : 3
10. Capacity per Lane on Major Route (vphpl): 1948
11. Daily Traf on Minor Rt (Thous.), Curr Yr: 10.00, 20 Yr Fut: 19.50
12. Number of Minor Route Lanes, Inbound Direction: 2
13. Number of Minor Route Lanes, Outbound Direction: 2
14. Percent Major Route Daily Traffic with stop or Signal: 20
15. Percent Minor Route Daily Traffic with stop or Signal: 100
16. Percent Trucks on Minor Route: 3.0
17. Minor Route Facility Type, 1-Undiv, 2-Div, 3-Frwy : 1
18. Capacity per Lane on Minor Route (vphpl): 633
19. Type of At-Grd Signl Inter, 1-none, 2-4X4, 3-4X6, 4-6X6 : 2

PROPOSED   Route, SEGMENT 1 Ramp and Volume Data

	Type of Ramp	Ramp Volume (% ADT)	Ramp Speed (MPH)	Savings in Dist Traveled (Miles)	Interrupted Flow, End of Ramp (Y/N)
1. Maj. R, Inb, Rgt-Trn	DIAGONAL	5.0	39.0	0.02	Y
2. Maj. R, Inb, Lft-Trn	DIAGONAL	5.0	39.0	-0.05	Y
3. Maj. R, Out, Rgt-Trn	DIAGONAL	5.0	39.0	0.02	Y
4. Maj. R, Out, Lft-Trn	DIAGONAL	5.0	39.0	-0.05	Y
5. Min Rt, Inb, Rgt-Trn	DIAGONAL	5.0	26.0	0.02	Y
6. Min Rt, Inb, Lft-Trn	DIAGONAL	5.0	26.0	-0.05	Y
7. Min Rt, Out, Rgt-Trn	DIAGONAL	5.0	26.0	0.02	Y
8. Min Rt, Out, Lft-Trn	DIAGONAL	5.0	26.0	-0.05	Y

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Diamond Interchange Test   Daily Through Traffic (Thous.)

Year	Current Conditions			After Improvement Conditions		
	Existing	Alternate	Proposed	Existing	Alternate	Proposed
1988	20.00	0.00	0.00	0.00	0.00	20.00
1989	20.70	0.00	0.00	0.00	0.00	20.70
1990	21.42	0.00	0.00	0.00	0.00	21.42
1991	22.17	0.00	0.00	0.00	0.00	22.17
1992	22.95	0.00	0.00	0.00	0.00	22.95
1993	23.75	0.00	0.00	0.00	0.00	23.75
1994	24.59	0.00	0.00	0.00	0.00	24.59
1995	25.45	0.00	0.00	0.00	0.00	25.45
1996	26.34	0.00	0.00	0.00	0.00	26.34
1997	27.26	0.00	0.00	0.00	0.00	27.26
1998	28.21	0.00	0.00	0.00	0.00	28.21
1999	29.20	0.00	0.00	0.00	0.00	29.20
2000	30.22	0.00	0.00	0.00	0.00	30.22
2001	31.28	0.00	0.00	0.00	0.00	31.28
2002	32.38	0.00	0.00	0.00	0.00	32.38
2003	33.51	0.00	0.00	0.00	0.00	33.51
2004	34.68	0.00	0.00	0.00	0.00	34.68
2005	35.90	0.00	0.00	0.00	0.00	35.90
2006	37.15	0.00	0.00	0.00	0.00	37.15
2007	38.45	0.00	0.00	0.00	0.00	38.45
2008	39.80	0.00	0.00	0.00	0.00	39.80

Diamond Interchange Test   Summary of Discounted Benefits (Thous. $)

Year	Delay Savings	Red Veh Op Cost	Red Acc Cost	Total Benefits
1988	0.00	0.00	0.00	0.00
1989	696.52	45.82	23.97	766.32
1990	674.45	47.14	22.97	744.57
1991	653.83	48.41	22.01	724.26
1992	634.61	49.63	21.10	705.34
1993	616.76	50.81	20.22	687.78
1994	600.33	51.95	19.38	671.65
1995	585.64	53.09	18.57	657.30
1996	572.26	54.21	17.79	644.26
1997	559.78	55.26	17.05	632.09
1998	548.59	56.30	16.34	621.23
1999	538.65	57.32	15.66	611.63
2000	530.26	58.34	15.01	603.61
2001	523.58	59.40	14.38	597.37
2002	518.25	60.46	13.78	592.50
2003	514.54	61.56	13.21	589.31
2004	512.23	62.40	12.66	587.28
2005	511.14	62.87	12.13	586.14
2006	511.49	63.37	11.63	586.49
2007	513.63	63.83	11.14	588.60
2008	517.74	64.39	10.68	592.82
Total	11334.28	1126.57	329.70	12790.54

Total Discounted User Benefits (Millions $) :   12.79
Total Construction Cost (Millions $) :   5.00
Benefit-Cost Ratio :   2.56