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Final Report

A TOOL FOR EVALUATING ACCESS CONTROL ON HIGH-SPEED URBAN ARTERIALS

PART II: USER'S GUIDE

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Indiana Department of Transportation

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16. Abstract

A highway system serves two needs: mobility and accessibility. Access control techniques are used to restrict access to the highway and improve vehicle flow. The objective of this research was to develop a comprehensive procedure to evaluate access control alternatives. The procedure includes the design and quantitative evaluation of alternatives to select the best one. Evaluation of each alternative includes prediction of turning volumes, delays, crash rates, and economic effectiveness. Several existing models predict traffic delays for signalized intersections and for minor streams at unsignalized intersections. Models are needed to predict delays of arterial streams caused by minor streams at unsignalized intersections. To address this missing component, models were developed to predict the delays caused to arterial streams by the following maneuvers: merging onto the arterial, diverging from the arterial, and left turn from the arterial. Models to predict crash rates for multi-lane arterial segments in Indiana based on geometric and access control characteristics were also developed. Models were developed to predict total, property-damage-only, and fatal/injury crashes. For the economic evaluation of each alternative, delays and stops are converted to operating costs for representative periods, and the crash rates are converted to crash costs. The agency costs can also be estimated. After the economic evaluation of each access control alternative, the best alternative can be selected.

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This guide describes the procedure to evaluate access control alternatives. In addition, computer tools that could facilitate the evaluation process are also discussed. The analyst carrying out the arterial access control analysis is expected to have a basic background in transportation planning and should also be familiar with TRANPLAN transportation planning software.

1. PROCEDURE FRAMEWORK

The procedure for evaluating access control alternatives involves several steps whereby the alternatives are designed, evaluated, and compared to select the best one. Figure 1 shows the overall procedure for access control evaluation. The user first collects input data and he/she designs the various alternatives to be evaluated. The road network is modeled using TRANPLAN transportation planning software to predict the turning volumes for each alternative. Based on the turning volumes, the common impact area for all the alternatives is determined, and the analysis of each alternative limited to the impact area begins. The analysis continues with estimating operating costs and crash costs, and estimating the economic effectiveness of each alternative. Finally, the best access control alternative is selected.

The analysis of each alternative is based on the operating costs and crash costs during the project lifetime. The project lifetime may be selected based on the service lives of different project components listed in Figure 50-2B of the INDOT *Road Design Manual* (1994). The components of the alternatives should be compared to determine which components are not common to all alternatives. The common service life for all alternatives that should be selected is the longest service life for a component that is not included in all access control alternatives. The user of the method has the flexibility to determine the discount rate to be used. The *Road Design Manual* suggests a value of four percent.

During the project lifetime, the operating costs and crash costs may vary during each year. Since the calculation of these costs for each year may become cumbersome, the project lifetime may be represented by a few typical years. For example, the first and last year of the project lifetime could be selected as representative years, and linear interpolation could be used to find the operating costs and crash costs for other years. Another option would be to use the middle year as a representative year and assume that the annual costs are constant.

The calculation of user costs for a given representative year includes operating costs and crash costs.

(1) To calculate annual operating costs, a representative day may be selected. Each representative day may be represented by several typical hours such as a morning hour, an afternoon hour, and an hour representing the remainder of the day. The operating costs for these typical hours are calculated. The hourly operating costs can then be converted to daily operating costs and annual operating costs.

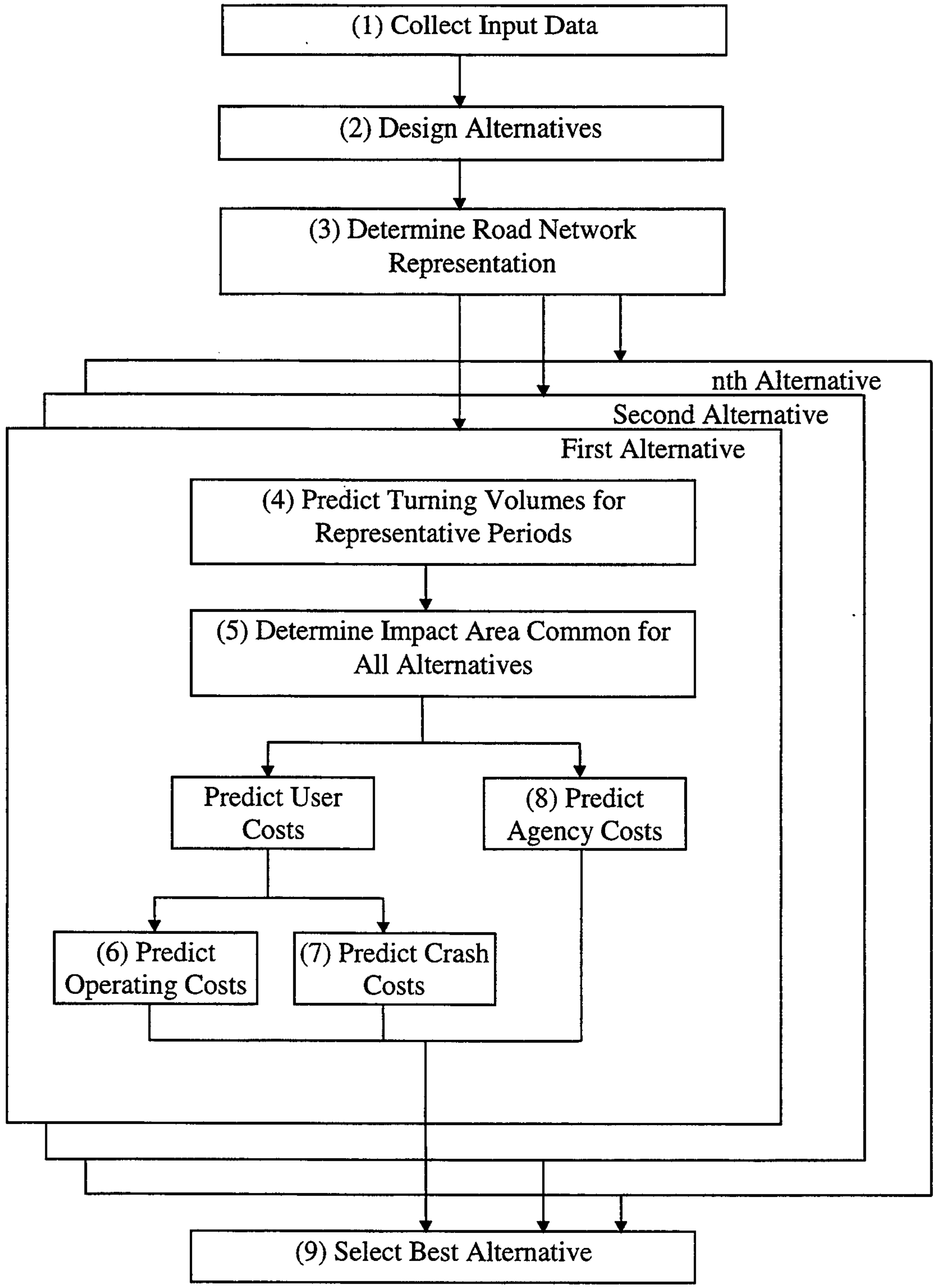

Figure 1 Procedure to evaluate access control alternatives

(2) Crash costs are estimated by first calculating the annual number of crashes by severity type using regression equations. The annual number of crashes is converted to crash costs by using default values for the costs of crashes by severity type.

2. DESCRIPTION OF MODULES

Module *(1)*: Collect Input Data

Input Data for Planning Models

For determination of link volumes and turning volumes at intersections, TRANPLAN transportation planning software is recommended. TRANPLAN requires three basic types of input data that must be provided by the user:

Zonal land-use characteristics and trip generation rates. This refers to the socioeconomic characteristics of each zone, such as the number of households, number of vehicles owned by each household, types of residential and commercial activities, floor space, number of employees, etc. It also includes the number and types of trips (home-based work, home-based other, etc.) that are generated by each type of land-use. The characteristics of the area being modeled determine largely the trip generation rates of that area.

Some MPOs have carried out studies to determine the rates of trip generation for each land use, and therefore trip generation rates obtained through such local studies may be used. However, if these are not available, the Institute of Transportation Engineers' Handbook on Trip Generation should be consulted to provide the appropriate rates.

Trip generation rates are applied to land-use data to obtain the amount of trips made in each zone.

Friction factors. These are numeric values that represent the relative change in the attractiveness of making a particular type of trip (such as home-based work) in response to incremental changes in the travel "impedance," such as time, distance, and cost.

Like trip generation rates, friction factors are also influenced by the characteristics of the area being modeled.

Highway network characteristics. This input file makes use of a schematic representation of a highway network in terms of nodes and links. Nodes define a given point or physical location within the study area, such as intersections or dead-ends. Each node is assigned a unique number that identifies that node. Links define a section of roadway between two nodes and characteristics such as length and number of lanes that are associated with that link.

Input Data for Delay and Crash Models

For the delay models, the turning volumes obtained from TRANPLAN are used as input. Other input data used by the delay models include arterial speeds and turning speeds. The input data for the delay models is described in greater detail in the discussion of Module (6).

For the crash models, the required input for segments includes AADT and segment length. For arterial segments, additional input data regarding access density and cross section characteristics are needed. For signalized intersections, data regarding approach volumes and approach characteristics are needed. The input data for the safety models is described in greater detail in the discussion of Module (7).

Module *(2):* Design Alternatives

The user of the method designs the access control alternatives to be evaluated and compared.

Module *(3):* Determine Road Network Representation and Traffic Analysis Zones

The road network is a collection of nodes and links between nodes that represent, in a simplified way, the actual system of streets. The road network representation should be sufficiently detailed to model in TRANPLAN those traffic streams that are required in the succeeding steps. The streams required in the next steps include:

(a) turning movements at signalized and major unsignalized intersections, and
(b) volumes of vehicles turning left or right to exit or enter the arterial between the intersections.

Network nodes represent major intersections and access points between major intersections. It is recommended that major intersections in the impact area be represented by intersection nodes since the turning volumes at intersections are necessary input for the succeeding steps of the procedure.

Access points and minor intersections are assumed not to experience significant queues of vehicles. This assumption allows for grouping several access points together into one access node in the network representation. All access points between two intersections can be classified by its geometric design (presence of auxiliary lanes) and its class represented by one access node. This possibility simplifies the network representation remarkably.

Steps needed to use a travel demand model to estimate the impacts of proposed access control alternatives are discussed in this section and the following two sections. Because TRANPLAN is used by many MPOs in Indiana and is familiar to all MPOs, the steps will refer to TRANPLAN functions. However, it should be possible for users of other software to translate TRANPLAN functions into the equivalent procedures they would need to employ.

Traffic analysis zones in the area of concern

The size of traffic analysis zones in the area of concern and the way centroids are connected to the road network are critical issues in predicting traffic for access control alternatives. Most likely, the analyst is beginning with a set of TAZs that have been established for use in a regional travel demand model. Their boundaries were probably set in accordance with certain rules of thumb, such as:

- Be compatible with census block or block group boundaries.
- Avoid using main roads as boundaries.
- Maximize homogeneity of land use within a TAZ.
- Achieve a moderate number of TAZs -- not a lot of small TAZs and not a few large ones.

It is difficult to adhere to all of these guidelines for a regional model. In any case, it is quite possible that the TAZ size(s) will be too large to assess the impact of access control measures. One centroid -- even with several centroid connectors added -- may not properly represent the traffic generated by individual sites in the standard TAZ. If certain sites generate significant traffic, it will be easier to direct that traffic onto the appropriate network links if such sites have their own centroids and connectors. In TRANPLAN, adding centroids and connectors can be done rather easily using the HNIS graphics interface. The alternative is to modify the network file more directly using the "Add Node Data Record" and "Add Link Data Record" features in the BUILD HIGHWAY NETWORK function. It may be wise to remove some of the centroid connectors that were in place for the "standard" TAZ. This can be done in TRANPLAN using either HNIS or BUILD HIGHWAY NETWORK. These modifications to the TAZ structure are subject to the judgment of the analyst. The analyst must decide which sites to consider as new centroids -- normally the larger traffic generators along the arterial being studied. A suggestion to new users of this procedure is to add a single new centroid (and associated connectors) only for the largest traffic generator along the arterial, then continue with the next steps. This will give the analyst experience with adding a centroid, and allow the analyst to determine the impact of the additional TAZ with respect to the results of the standard TAZ structure.

As the analyst proceeds with this procedure, decisions must be made regarding how centroid connectors should be used to represent a heavily-used driveway or a group of driveways. The recommendation is to start with one centroid connector to represent a set of driveways between signalized intersections. If certain turn movements from certain driveways onto the arterial are a source of delay, then centroids should be added to show this traffic.

Road network representation in the area of concern

In the previous step, the source of traffic that affects the operation of the arterial was addressed. In this step, the analyst must insure that the street links that may carry a "significant" amount of traffic to the arterial are included in the travel demand model's link list. Street links that are not important in a regional model may offer detours around points of congestion or "shortcuts" around points of delay in the arterial's corridor. Network links for such streets must be added to the network model. Failure to do so will overload the links that are shown in the network and give a distorted picture of flow patterns under specified access control measures. As in the previous section, TRANPLAN users can employ either HNIS or BUILD HIGHWAY NETWORK to add the desired links.

<u>Road network changes to manage access</u>

The challenge here is to change the network representation of the impact area so as to accurately portray the way traffic movements will be restricted and redirected by access control measures. Several examples are given below.

a. Prohibit left turns. The node at which the left turn prohibition is applied can be implemented by TRANPLAN using the "Add Turn Prohibitor Record" feature in the BUILD HIGHWAY NETWORK function. Another way is through the use of a TRNDATA file as input to the LOAD HIGHWAY NETWORK or similar functions. TRANPLAN users can also use the ADD TURNP[rohibitors] editing function under the Network Update Menu in the HNIS graphics system. Virtually all travel demand software packages have similar features.
b. Add median barrier along arterial to prohibit left turns and through movements.
    - If the arterial is represented by a single two-way link, the "Add Turn Prohibitor Record" feature in TRANPLAN can again be used. Through movements across the arterial can be banned by specifying the exit node on the far side of the arterial as the "C" node in an A-B-C "turning" movement.
    - If the arterial is represented by a series of parallel one-way links and the median cut to be closed is shown as a separate link, this "median link" need only be deleted or deactivated.
c. Close driveway(s) that enter onto the arterial. Deleting or deactivating the link that represents the driveway is the first thing to do. However, the analyst must check to see if the link to be deleted or deactivated also represented other driveways that will still be allowed direct access to the arterial. In addition, the resulting network model must allow any traffic that used the deleted/deactivated driveway to have some other means to enter/exit the site served by the deleted/deactivated driveway. This network modification may involve the introduction of new centroids to distinguish between sites with continued direct access to the arterial and sites that no longer have direct access.
d. Add frontage and reverse frontage roads. This type of access control measure can be implemented in the network by adding the appropriate links, including centroid connectors. As in the "close driveway" case, new centroids may have to be introduced.
e. Add or retime signals. Incorporating signal timings into a travel demand model is usually a weak aspect of such models. In TRANPLAN, the MACRO HIGHWAY NETWORK UPDATE function allows changes to be made to free-flow link travel times without editing the original link list. However, such changes would be for the approach link at an intersection, not for delays at the intersection, which

usually depend on exit directions. "TURN PENALTIES" can be introduced in some of TRANPLAN's LOADING functions, but the analyst must calculate and enter penalty values for each turn movement that he/she feels reflects changes in signal timing. TRANPLAN has no provision for the direct entry of signal timings.

Module *(4)*: Predict Turning Volumes for Representative Periods

The turning volumes produced in TRANPLAN are an input to the traffic engineering analyses to estimate the operating costs, crash costs, and user costs, as well as economic effectiveness for each access control alternative (see Figure 1).

The results from TRANPLAN should be sufficient in scope to estimate the component costs for an entire typical day. The crash costs estimation requires annual average daily traffic to predict crash frequency at intersections and on road segments in the impact area. Thus, daily volumes in the area of concern are required, together with information as to how the daily volumes are related to the annual average daily traffic to allow conversion.

Calculation of operating costs (fuel consumption, lost time, etc.) must respect changes in traffic intensity over a day. Predicting the volumes for a 24-hour period on a typical day is desirable from the accuracy standpoint. However, the limited data (typically unknown hourly O-D matrices) and laborious calculations prompt for a smaller number of periods. It seems sufficient to divide an entire day into three periods:

Morning peak period
Afternoon peak period
Off-peak period

Each representative day is represented by these three periods. For each period, turning volumes are needed as input for the next stage of the analysis, i.e., estimation of operating costs. There are two alternative ways in which the analyst could determine turning volumes for the three periods:

(a) Run TRANPLAN once using only one set of input data (O-D matrices) and use appropriate adjustment factors to obtain the values for each period;

(b) Run TRANPLAN three times (once for morning peak period, once for afternoon peak period, and once for entire day).

The hourly volumes for the off-peak period can be determined by running TRANPLAN for a daily period to determine daily traffic volumes and then taking the difference between the daily volumes and the volumes observed during peak hours. Thus, the volumes for an off-peak hour can be calculated as

$$q_{op} = \frac{q_{day} - q_{am} \cdot N_{am} - q_{pm} \cdot N_{pm}}{24 - N_{am} - N_{pm}} \qquad (1)$$

where:

q_{op} = volume for off-peak hour (vph),
q_{day} = daily volume (vpd),
q_{am} = volume for morning peak hour (vph),
N_{am} = number of morning peak hours,
q_{pm} = volume for afternoon peak hour (vph),
N_{pm} = number of afternoon peak hours.

A daily traffic flow profile may be assumed to assist in the analysis. An example traffic flow profile for an intercity route is given in Figure 9-7 of the *Traffic and Transportation Engineering Handbook* (1982). Based on this profile for a weekday, a morning hour could be used to represent the period from 8 am to 1 pm. An afternoon hour could be used to represent the period from 1 pm to 7 pm, and an off-peak hour can be used to represent the remaining hours.

The TURNS FILE option in TRANPLAN's REPORT HIGHWAY LOAD function converts LOADING output into a table of turning movement flows for specified intersections. The table has four columns for each turning movement: From node, Through node, To node, and Flow rate. An excerpt of such a table is shown below.

From-node	Thru-node	To-node	Flow	Description
363	364	365	4666	LT from EB SR26 to NB Creasy Lane
363	364	741	1019	Through on EB SR26 at SB Creasy Lane
363	364	742	1281	RT from EB SR26 to SB Creasy Lane

Most travel demand software packages have a similar capability.

Module *(5)*: Determine Impact Area Common for All Alternatives

For the purposes of this study, an Impact Area is defined as the sub-network including the links and intersections whose traffic flows are significantly affected by changes in access control scenarios on an arterial of interest.

TRANPLAN permits the user to create a subarea within a regional study area. The "Extract Subarea Network" feature of the TRANPLAN travel demand software lets the user "carve out" an impact study area from the complete network. Section 6.4 of the Highway NIS User Manual (an appendix to the TRANPLAN user manual) describes how easily an impact study area can be defined while viewing a graphical display of the network. There are also separate software packages specifically designed to carry out "subarea focussing".

The question is, however, where to draw the cordon line that defines the limits of the impact area. Here is a case in which an analyst need not make arbitrary judgments. Running travel demand software for a city of small or moderate size does not take exorbitant amounts of time. Running TRANPLAN on the full Lafayette network, for example, takes about two minutes. Consequently, saving computer time does not appear to be a strong reason for creating a subarea. Furthermore, setting up a cordon line around a subarea introduces the need to maintain some sort of relationship with the surrounding network. The subarea model needs a trip table, but almost all of the trips using the streets in the subarea have at least one trip end outside the subarea. The way in which the trip ends, external to the subarea, are aggregated into gateway volumes is a possible source of error. Trying to explicitly define an impact area takes time, and it has many more risks than benefits.

A reasonable recommendation is that the regional model with the TAZ and network modifications discussed in Step 3 is maintained to produce turning volumes for the entire network. The regional trip table need not be aggregated, but it will have to be rebuilt to reflect the additional TAZs created in Step 3. When any access control measure (ACM) is implemented and the network is further modified to reflect the ACM, the modified regional network can be implemented. The output for the full regional network can be examined to determine changes in network-wide performance measures, such as vehicle-hours traveled.

If it is desired, however, to identify an impact area for crash and operating costs estimation, the TRANPLAN output can be examined to find links with significant changes in flow. TRANPLAN has a utility called COMPNET that detects flow changes and whether a link has been added to (or deleted from) the network. If the links having "significant" changes in flow can be highlighted in a network display, and they form a contiguous pattern, the analyst can define the impact area accordingly. The turning volumes for the impact area are transferred to the further modules of the algorithm. It sgould be kept in mind, that the smaller is the impact area, the less labor is required for the remaining part of analysis.

Module *(6):* Predict Operating Costs

Each representative day may be represented by several typical hours: morning hour, afternoon hour, and an hour representing the remainder of the day. For each typical hour, turning volumes are needed as input. A daily traffic flow profile may be assumed to assist in the analysis.

The operating cost calculations are performed for each representative hour in several steps as shown in Figure 2. The following steps are needed for the calculation of hourly operating costs:

- estimate total and average delays at access points on arterial segments,
- correct the cruise speeds on arterial segments,
- perform calculation of operating cost (impact of access points not included),
- calculate extra operating costs caused by access points, and
- aggregate hourly operating costs for the network.

These hourly operating costs are then converted into daily operating costs and then annual operating costs. The following paragraphs discuss these steps in more detail.

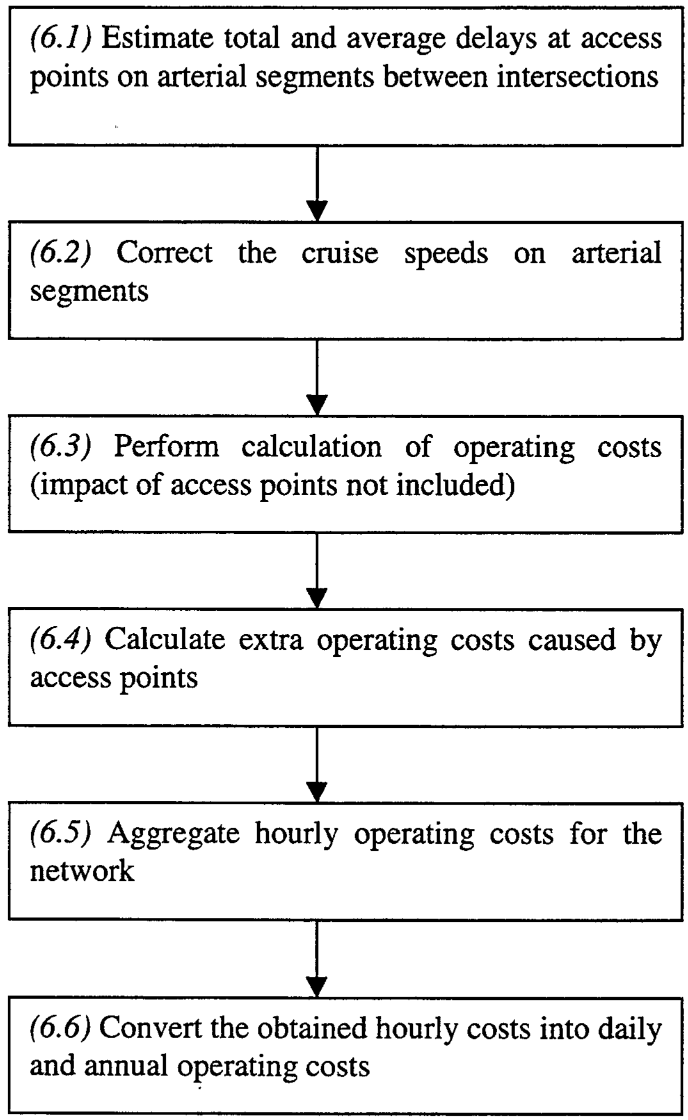

Figure 2 Procedure to estimate operating costs

Module *(6.1):* Estimate total and average delays on arterial segments between intersections

The delay models developed in this project can be used to estimate delays at access points between intersections, which include the delays of minor streams at access points and the delays caused to arterial streams by minor streams at access points. A Microsoft Excel spreadsheet is used for the calculation of delays and operating costs for access points. This spreadsheet is hereafter referred to as the *Access Delay* spreadsheet. The turning movements at access points between intersections need to be provided as input to the *Access Delay* spreadsheet.

Delays of the minor streams can be calculated for the following minor stream maneuvers:

- right turn onto the arterial,
- left turn from the arterial, and
- left turn onto the arterial.

The delays of arterial streams caused by the following maneuvers are also calculated:

- merging by right turn onto the arterial,
- merging by left turn onto the arterial,
- right turn from the arterial, and
- left turn from the arterial.

The crossing maneuver is not considered for several reasons. First, crossing maneuvers from access points on an arterial typically are infrequent. Second, the crossing vehicle occupies a given traffic lane for a short period of time. Finally, the critical gap for the crossing maneuver is longer than for the merging maneuver. Thus the crossing maneuver can be expected to have less impact than the other maneuvers.

The capacities of minor movements can be calculated using Equation (10-1) in the *Highway Capacity Manual* (1994):

$$c = \frac{3600}{t_f} \cdot \exp\left(-\frac{V_c \cdot \left(t_g - \frac{t_f}{2} \right)}{3600} \right) \tag{2}$$

where:

c = capacity of minor stream (vph),
V_c = conflicting volume (vph),
t_g = critical gap (sec),
t_f = follow-up time (sec).

Once the capacity of each maneuver is calculated, the average delay for each maneuver can be calculated assuming no queuing at access points:

$$d = \frac{3600}{c} \tag{3}$$

where:

d = average delay experienced by one vehicle in minor stream (sec/veh),
c = capacity calculated from *Highway Capacity Manual* (vph).

The total delay for each minor stream maneuver can then be calculated by multiplying the average delay by the number of maneuvers of a given type. The total delay experienced by all minor streams for a given segment can then be calculated by adding the total delay experienced by each minor stream. The total delay experienced by all minor streams for a given segment is provided as output in the *Access Delay* spreadsheet.

It is assumed in the calculations that the minor streams do not experience queuing. If there is an access point on the segment where minor streams experience queuing, the access point should be represented as an intersection in the network.

The delays for the arterial streams caused by minor streams at access points are also calculated using the *Access Delay* spreadsheet. Delays caused by the following minor streams are calculated:

- merging by right turn,
- merging by left turn,
- diverging by right turn, and
- left turn from the arterial.

For the case of a left turn from the arterial, the diverging model is used to calculate the delay caused to through vehicles when an exclusive left-turn lane is present. When an exclusive left-turn lane is not present and the through and left-turning vehicles share a lane, the left-turn model is used to calculate the delay caused to through vehicles.

The merging model is used to estimate the total delay of through vehicles caused by vehicles turning right and left onto the arterial. The *Access Delay* spreadsheet performs these calculations. The following input data for each link are needed for the merging model:

- merging speed,
- merging distance,
- merging volume,
- arterial speed, and
- arterial traffic distribution by lane.

The merging distances can be estimated for given merging and arterial speeds using Figure II-16 in AASHTO (1994). The merging speed, merging distance, and merging volume are different for the right-turn and left-turn maneuvers. Default values are provided for the following model parameters:

- saturation flow rate (0.5 veh/sec),
- lag time (4 sec),
- critical gap for merging (5.5 sec from *Highway Capacity Manual*),
- critical space gap for lane changing (4 sec × arterial speed),
- likelihood that a driver wants to change lanes (0.5), and
- proportion of traffic in each lane (equal distribution).

The uses of these parameters in the calculations are described in Part I of the report. The parameter values can be modified by the user as needed.

The diverging model can be used to estimate the total delay of through vehicles caused by vehicles turning right from the arterial. The following input data for each link are needed for the right-turn diverging model:

- right-turn diverging speed,
- right-turn diverging distance,
- right-turn diverging volume,
- arterial speed, and
- arterial traffic distribution by lane.

The diverging distances can be estimated for given diverging and arterial speeds using Figure II-17 in AASHTO (1994). Default values are provided for the following parameters:

- saturation flow rate (0.5 veh/sec),
- critical space gap for lane changing (4 sec × arterial speed),
- reaction time for through-vehicle (1.5 sec),
- acceleration rate of through-vehicle (1.5 m/sec^2),
- maximum allowable deceleration rate (-4.9 m/sec^2),
- likelihood that a driver wants to change lanes (0.5), and
- proportion of traffic in each lane (equal distribution).

The uses of these parameters in the calculations are described in Part I of the report. The parameter values can be modified by the user as needed.

The presence of an exclusive left-turn lane determines which model is used to estimate the delay caused by vehicles turning left from the arterial. If an exclusive left-turn lane is present, the diverging model should be used to estimate the delay caused by left-turning vehicles. If an exclusive left-turn lane is not present, the left-turn model should be used to estimate the delay caused by left-turning vehicles. The *Access Delay* spreadsheet selects the correct model to apply based on the input data provided by the user regarding the presence of a left-turn lane.

If the diverging model is used for the left-turn maneuver, the calculations are similar to the procedure in the right-turn case. The following input data for each link are needed for the left-turn diverging model:

- left-turn diverging speed,
- left-turn diverging distance,
- left-turn diverging volume, arterial speed, and
- arterial traffic distribution by lane.

The estimation of the left-turn diverging speed requires careful consideration and may depend on the length of the left-turn lane. For a long left-turn lane, the diverging speed may be equal to the arterial speed. For a short left-turn lane, the diverging speed is less than the arterial speed. The diverging distances can again be estimated using Figure II-17 in AASHTO (1994).

When an exclusive left-turn lane is not present, the left-turning vehicle may block through vehicles. In this case, the left-turn model is used to estimate the delay caused to through vehicles by vehicles turning left from the arterial. These calculations are again performed by a spreadsheet. The following input data are needed:

- arterial speed,
- blockage time of left-turning vehicle, and
- sight distance when the left-turning vehicle is first observed by the through-vehicle.

The following default parameter values are provided:

- speed reduction when through-vehicle approaches left-turning vehicle (15 km/hr),
- critical space gap for lane change (4 sec × arterial speed),
- likelihood that a driver wants to change lanes (1.0), and
- saturation flow rate (0.5 veh/sec).

The uses of these parameters in the calculations are described in Part I of the report. The parameter values can be modified by the user as needed.

The final output from the *Access Delay* spreadsheet includes the total delay experienced by minor streams on each segment and the total delay of arterial streams caused by minor streams on each segment.

Module *(6.2)*: Correct the cruise speeds on arterial segments

Once the delays caused by minor streams are estimated, the initial cruise speeds provided by the user can then be adjusted to account for the reduction in travel time associated with the delays caused by minor streams. The initial cruise speeds used to calculate the delays at access points are adjusted for each link before estimating delays at intersections. The *Access Delay* spreadsheet performs these calculations. To revise the cruise speed, the average delay for each through vehicle needs to be estimated as

$$d_{t,i} = \frac{D_{t,i}}{Q_{t,i}} \tag{4}$$

where:
$d_{t,i}$ = average delay experienced by one arterial vehicle on link i (sec/veh),
$D_{t,i}$ = total delay caused by minor streams on link i (sec/hr),
$Q_{t,i}$ = total volume on link i (vph).

The revised cruise speed for each link can then be estimated:

$$V_i' = V_i^0 \cdot \left(\frac{1}{1 + \frac{d_{t,i} \cdot V_i^0}{3600 \cdot L_i}} \right) \tag{5}$$

where:
V_i^0 = initial cruise speed on link i (km/hr),
V_i' = revised cruise speed on link i (km/hr),
L_i = length of link i (km).

These revised cruise speeds are provided as input to the TRANSYT-7F software to determine operating costs for the network, not including the impact of access points.

Module *(6.3)*: Perform calculation of operating cost (impact of access points not included)

The TRANSYT-7F software can be used to optimize signal timings and to calculate delays, stops, and operating costs for the network, not including access points. To estimate delays and operating costs associated with intersections, the turning volumes for intersections need to be provided as input. The corrected cruise speed for each link is also used as input to TRANSYT-7F. The value of the operating costs for the network is one of the measures of effectiveness provided in the TRANSYT-7F output. The operating costs calculated by TRANSYT-7F, when using default cost values, are given in 1987 dollars. The effects of inflation can be incorporated in two alternate ways:

(1) To apply inflation uniformly to all cost components, use default unit cost values and multiply the operating costs given by TRANSYT-7F by the appropriate inflation factor to convert costs to the first year of the project lifetime, or

(2) To apply inflation differently to the various cost components, use an inflation factor of 1 and select individual unit cost values based on the first year of the project lifetime.

Thus, the operating costs, not including the effects of access points, can be estimated by using the TRANSYT-7F software.

One possible software package that could be used to manage the data for intersections is SYNCHRO3, which provides a graphical interface that can be used to enter network and traffic data. SYNCHRO3 can convert the input data to TRANSYT-7F formats, and TRANSYT-7F can be run directly from SYNCHRO3. SYNCHRO3 may be used to optimize phases at signalized intersections and to prepare data for TRANSYT-7F. Alternatively, the TRANSYT-7F data editor can be used to enter the input data.

Software other than TRANSYT-7F can be used to estimate the delays and stops at intersections. The delays, stops, and travel times should then be converted to operating costs using the TRANSYT-7F models (Wallace et al., 1991). The operating cost model in Wallace et al. (1991) includes fuel consumption, cost of travel time, cost of delay, stops, and total travel. The equations for fuel consumption and operating costs from Wallace et al. (1991) are as follows:

$$F = K_{1FC} \cdot TT + K_{2FC} \cdot D + K_{3FC} \cdot S \tag{6}$$

$$K_{1FC} = A_{11FC} + A_{12FC} \cdot V + A_{13FC} \cdot V^2 \tag{7}$$

$$K_{2FC} = A_{21FC} + A_{22FC} \cdot V + A_{23FC} \cdot V^2 \tag{8}$$

$$K_{3FC} = A_{31FC} + A_{32FC} \cdot V + A_{33FC} \cdot V^2 \tag{9}$$

$$C = [(K_{1OC} \cdot TT + K_{2OC} \cdot S + DC \cdot D)/1000 + FC \cdot F + O \cdot TC \cdot (TT/V + D)] \cdot I \tag{10}$$

$$K_{1OC} = A_{11OC} + A_{12OC} \cdot V + A_{13OC} \cdot V^2 + A_{14OC} \cdot V^3 \tag{11}$$

$$K_{2OC} = A_{21OC} + A_{22OC} \cdot V + A_{23OC} \cdot V^2 + A_{24OC} \cdot V^3 \tag{12}$$

where:

F = fuel consumption (lit),
TT = total travel (veh-km),
D = total delay (veh-hr),
S = total stops (vph),
V = cruise speed (km/hr),
A_{ijFC} = model coefficients for fuel consumption model,
DC = unit cost of vehicle delay ($/1000 veh-hr),
FC = cost of fuel consumption ($/lit),
O = vehicle occupancy (persons/veh),
TC = unit cost of passenger time ($/pers-hr),
I = inflation factor to convert costs from base year of 1987,
A_{ijOC} = model coefficients for operating cost model.

Wallace et al. (1991) also provide default values for model parameters and unit costs. The default values after conversion to metric units are listed in Table 1. The default unit cost values are in 1987 dollars. The user can specify other values for the other parameters if needed.

The effects of inflation can be incorporated in two alternate ways:

(1) To apply inflation uniformly to all cost components, use default unit cost values and select the appropriate inflation factor to convert costs to the first year of the project lifetime, or

(2) To apply inflation differently to the various cost components, use an inflation factor of 1 and select individual unit cost values based on the first year of the project lifetime.

Module *(6.4)*: Calculate extra operating costs caused by access points

The extra operating costs caused by access points can then be calculated based on the equations given by Wallace et al. (1991). The total delay caused to arterial vehicles by all minor streams and the total delay of minor streams are needed as input. The equations to calculate the additional operating costs caused by access points are given by

$$F_a = K_{2,FC} \cdot D_a \tag{13}$$

$$F_m = K_{2,FC} \cdot D_m \tag{14}$$

$$C_{ma} = \left(F_a \cdot FC + \frac{DC \cdot D_a}{1000} \right) \cdot I + \left(F_m \cdot FC + \frac{DC \cdot D_m}{1000} + O \cdot TC \cdot D_m \right) \cdot I \tag{15}$$

$$K_{2FC} = A_{21FC} + A_{22FC} \cdot V + A_{23FC} \cdot V^2 \tag{16}$$

where:

F_a = additional fuel consumption for arterial vehicles caused by access points (lit),
F_m = additional fuel consumption of minor stream vehicles (lit),
D_a = total delay to arterial vehicles caused by all minor stream maneuvers (veh-hr),
D_m = total delay of minor streams at access points (veh-hr),
C_{ma} = additional operating cost due to access points,
A_{ijFC} = model coefficients for fuel consumption model,
V = cruise speed (km/hr),
FC = cost of fuel consumption ($/lit),
DC = unit cost of vehicle delay ($/1000 veh-hr),
TC = unit cost of passenger time ($/pers-hr),
I = inflation factor to convert costs from base year of 1987,
O = vehicle occupancy (persons/veh).

The default parameter values based on the values given by Wallace et al. (1991) after conversion to metric units are listed in Table 1. The effects of inflation should be incorporated to convert costs from 1987 to the first year of the project lifetime by changing either unit cost values or the inflation factor.

Table 1 Converted default parameters for TRANSYT-7F models (adapted from Wallace et al. 1991)

Parameter	Value
A_{11FC}	0.177079
A_{12FC}	-0.0023227
A_{13FC}	1.3683×10^{-5}
A_{21FC}	2.77244
A_{22FC}	0
A_{23FC}	0
A_{31FC}	0
A_{32FC}	0
A_{33FC}	8.9757×10^{-6}
A_{11OC}	78.815
A_{12OC}	0.10972
A_{13OC}	0.0029497
A_{14OC}	2.5000×10^{-5}
A_{21OC}	-0.59937
A_{22OC}	0.18821
A_{23OC}	0.012623
A_{24OC}	6.7176×10^{-5}
DC	145.1
FC	0.33
TC	1.3039
I	1
O	1.20

Module *(6.5)*: Aggregate hourly operating costs for the network

The extra operating costs caused by access points are added to the operating costs obtained from running TRANSYT-7F to obtain the total hourly operating cost. The final result of this step is the hourly operating costs for each representative hour under a given access control alternative.

Module *(6.6)*: Convert the obtained hourly costs into daily and annual operating costs

The hourly operating costs for the three typical hours can be converted to daily operating costs as follows:

$$C_{day} = N_{am} \cdot C_{am} + N_{pm} \cdot C_{pm} + \left(24 - N_{am} - N_{pm}\right) \cdot C_{op} \tag{17}$$

where:

C_{day} = daily operating cost,

C_{am} = operating cost for morning peak hour,

C_{pm} = operating cost for afternoon peak hour,
N_{am} = number of morning peak hours,
N_{pm} = number of afternoon peak hours,
C_{op} = operating cost for off-peak hour.

Once daily operating costs have been estimated, they can be converted to annual operating costs by multiplying the daily operating cost by the number of days per year:

$$C_{yr} = 365 \cdot C_{day} \tag{18}$$

where C_{yr} is the annual operating cost.

Thus, the final result of this step is the annual operating costs under a given access control alternative for a representative year.

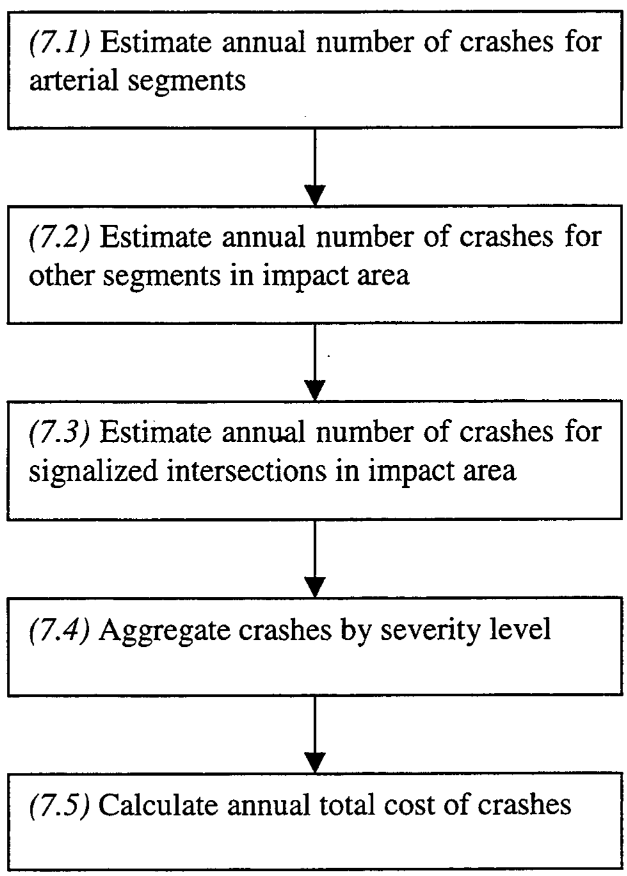

Figure 3 Procedure to estimate crash costs

Module *(7):* Predict Crash Costs

In addition to operating costs, the crash costs also need to be estimated and are calculated for each representative year. Crash rates for each representative year for each alternative are estimated for intersections and for segments between intersections. The crash rates are then aggregated for the entire network and converted to crash costs by using the unit costs of crashes by severity type. The crash rate calculations are performed in a spreadsheet hereafter referred to as the *Safety* spreadsheet. Figure 3 summarizes the steps for predicting crash costs. Crash rates are predicted for multi-lane arterial segments, other segments in the impact area, and signalized intersections. These results are then aggregated to obtain the total number of crashes for a representative year under a given access control alternative. The number of crashes is then converted to crash costs by using the unit costs of crashes by severity level. The final result of this step is the annual cost of crashes for each representative year.

Module *(7.1):* Estimate number of crashes for arterial segments

Crash rates for multi-lane arterial segments can be calculated using the regression models in Equations 19 and 20. For each segment, the required input includes:

- segment length,
- number of years,
- AADT,
- access density,
- proportion of access points that are signalized,
- presence of outside shoulder,
- presence of two-way left-turn lane, and
- presence of a median with no openings between signals.

The AADT data can be obtained by running TRANPLAN for a daily period. The number of crashes by severity type can then be calculated using the *Safety* spreadsheet. The equations to calculate the annual number of crashes on multi-lane arterial segments are as follows:

$$\begin{aligned} PDO = 0.374 \cdot LEN \cdot AADT \cdot \exp(&0.0261 \cdot \mathrm{ACCESS} - 0.669 \cdot \mathrm{SHLDR} \\ &+ 2.627 \cdot \mathrm{PS} - 0.686 \cdot \mathrm{TWLTL} - 0.684 \cdot \mathrm{NOMEDO}) \end{aligned} \tag{19}$$

$$\begin{aligned} FATINJ = 0.127 \cdot LEN \cdot AADT \cdot \exp(&0.0325 \cdot \mathrm{ACCESS} - 0.525 \cdot \mathrm{SHLDR} \\ &+ 2.280 \cdot \mathrm{PS} - 0.865 \cdot \mathrm{TWLTL} - 0.493 \cdot \mathrm{NOMEDO}) \end{aligned} \tag{20}$$

where:

PDO	= number of pdo crashes on the segment in representative year,
FATINJ	= number of fatal and injury crashes on the segment in representative year,
LEN	= length of the segment (km),
AADT	= Annual Average Daily Traffic (thousands of vehicles),

ACCESS = access density (per km),
SHLDR = dummy variable to indicate presence of outside shoulder (1 if outside shoulder is present, 0 otherwise),
PS = proportion of access points that are signalized,
TWLTL = dummy variable to indicate presence of two-way left-turn lane on segment (1 if two-way left-turn lane is present, 0 otherwise),
NOMEDO = dummy variable to indicate segment with median (excluding two-way left-turn lane) with no openings between signalized intersections (1 if segment has median with no openings between signals, 0 otherwise).

The access density is calculated as the total number of access points divided by the segment length. The total number of access points includes both signalized and unsignalized access points. For unsignalized intersections, a T-intersection is considered as one access point, while an all-way intersection is considered as two access points. All signalized intersections are considered as two access points since traffic may have to stop at the signal in either direction on the segment. Access points within 30 meters of the segment endpoints are not considered. The proportion of signalized access points is calculated as the number of signalized access points divided by the total number of access points. This value is defined to be zero for a segment with no access points. The result of this step is the number of crashes per year by severity type for arterial segments.

Module *(7.2)*: Estimate annual number of crashes for other segments in impact area

The annual number of crashes for other segments in the impact area can be estimated by using the basic calibrated models developed by Eranky et al. (1997). Separate models were developed for urban multi-lane and urban two-lane segments. The required input data for these models include segment length and AADT. The number of crashes by severity type on urban multi-lane segments are given by the following equations:

$$PDO = 0.23031 \cdot LEN \cdot AADT^{1.1009} \tag{21}$$

$$FATINJ = 0.0076528 \cdot LEN \cdot AADT^{1.665} \tag{22}$$

The annual number of crashes for urban two-lane segments by severity type can be calculated using the following equations:

$$PDO = 0.088600 \cdot LEN \cdot AADT^{1.415} \tag{23}$$

$$FATINJ = 0.062552 \cdot LEN \cdot AADT^{1.2236} \tag{24}$$

where:
PDO = number of pdo crashes on the segment in representative year,
FATINJ = number of fatal and injury crashes on the segment in representative year,

LEN	= length of the segment (km),
AADT	= Annual Average Daily Traffic (thousands of vehicles).

The result of this step is the annual number of crashes by severity type for each representative year for segments not on the arterial but in the impact area.

Module *(7.3):* Estimate annual number of crashes for signalized intersections in impact area

Crash rates for signalized intersections at the endpoints of arterial segments or outside the arterial but in the impact area can also be estimated. Regression models for signalized intersections were recently developed by Jonathan Weiss at Purdue University. The equations for the annual number of crashes by severity type are as follows:

$$PDO = 1.1050\times10^{-4} \cdot APPVOL1^{0.65010} \cdot APPVOL2^{0.52946} \cdot exp(-0.37831 \cdot LFTPROB - 0.11651 \cdot NUMDIV) \tag{25}$$

$$FATINJ = 4.4571\times10^{-4} \cdot APPVOL1^{0.38638} \cdot APPVOL2^{0.37357} \cdot exp(0.36144 \cdot NUMAPP) \tag{26}$$

where:

PDO	= number of pdo crashes at the signalized intersection in representative year,
FATINJ	= number of fatal and injury crashes at the signalized intersection in representative year,
APPVOL1	= average volume on N-S approaches (vehicles),
APPVOL2	= average volume on E-W approaches (vehicles),
NUMAPP	= number of intersection approaches (2,3, or 4),
LFTPROB	= number of left-turning movements forbidden on all approaches (0,1,2,3, or 4),
NUMDIV	= number of approaches on which traffic is divided by median.

The final result of this step is the number of crashes by severity type at each signalized intersection for each representative year.

Module *(7.4):* Aggregate crashes by severity level

The crash rates for the segments and intersections are then aggregated by severity type over the network for each representative year. Thus, the crash rates for arterial segments, other segments in the impact area, and signalized intersections are added for each representative year under a given access control alternative. The final result of this step is the number of crashes by severity type for each representative year under a given access control alternative.

Module *(7.5)*: Calculate annual total cost of crashes

The annual total cost of crashes can be calculated by using the predicted number of crashes by severity level and the unit costs of crashes by severity level. The annual total cost of property-damage-only crashes can be found by multiplying the annual number of property-damage-only crashes by the unit cost of a property-damage-only crash. The annual total cost of fatal/injury crashes can be found by multiplying the annual number of fatal/injury crashes by the unit cost of a fatal/injury crash. Figure 50-2A of the INDOT *Road Design Manual* (1994) contains values for the unit costs of crashes by severity type. The annual total cost of crashes for a given year and a given access control alternative is then found by adding the annual total cost of property-damage-only crashes and the annual total cost of fatal/injury crashes. The final result of this step is the annual total cost of crashes for each representative year under a given access control alternative.

Module *(8)*: Predict Agency Costs

In addition to user costs, the agency costs also need to be estimated. The agency costs for a given alternative include the construction and maintenance costs of the alternative. These costs can be converted to present worth.

Module *(9)*: Select Best Alternative

Once each access control alternative has been evaluated for user costs and agency costs, the alternatives can be compared to select the best one. An incremental approach can be used in which pairwise comparisons are made between alternatives. In this method, the projects are ranked in order of increasing agency costs. Pairwise comparisons of alternatives are then made, beginning with the alternative with the lowest agency costs. The incremental net present value between two projects can be calculated as

$$NPV_{ij} = \left(PWUC_i - PWUC_j\right) - \left(PWAC_j - PWAC_i\right) \tag{27}$$

where:

NPV_{ij}	= incremental net present value between Alternatives i and j, where j is the alternative with the higher agency costs, and i is the current best alternative,
$PWUC_i$	= present worth of user costs for Alternative i,
$PWUC_j$	= present worth of user costs for Alternative j,
$PWAC_i$	= present worth of agency costs for Alternative i,
$PWAC_j$	= present worth of agency costs for Alternative j.

If the incremental net present value is greater than zero, the Alternative j is selected as the new current best alternative. After all comparisons are made, the final current best alternative is selected as the best access control alternative.

3. IMPLEMENTATION TOOLS

Several software tools can be used in the access control evaluation process. These tools include existing software packages and spreadsheets developed as a part of this research. These tools can facilitate the access control evaluation process. The existing software packages that can be used include TRANPLAN, SYNCHRO3, and TRANSYT-7F. Several spreadsheets developed in this research project assist in the calculations, including the *Access Delay*, *Safety*, and *Cost* spreadsheets. The *Access Delay* spreadsheet calculates delays and costs due to access points between intersections on the arterial. The *Safety* spreadsheet calculates crash rates and crash costs. The *Cost* spreadsheet (1) calculates daily and annual operating costs and (2) converts user and agency costs to present worth.

TRANPLAN

The application of computer software to the access control evaluation process involves several steps as shown in Figure 4. First, input data is provided to the TRANPLAN software. Then TRANPLAN is used to obtain turning volumes. TRANPLAN forecasts the impacts of alternative land-use scenarios and transportation network schemes on the performance of the highway system. The TRANPLAN Users Manual is a part of the URBANSYS Version 8.0 User's Manual (1995) distributed by the Urban Analysis Group of Danville, California. Other programs in the TRANPLAN include the Network Information System (NIS), which is a flexible interactive graphics tool for displaying and editing spatial data; TP MENU, a shell which allows the user to flexibly combine TRANPLAN; NIS and supplementary software; and Database Capable Interface (DBC), a support for data sets maintained in selected database and GIS formats.

According to the URBANSYS User's Manual, TRANPLAN is structured as a dynamic tool. There are over 40 modules in TRANPLAN, referred to as "functions," each of which has specific capabilities. It is important to note that due to different users' needs and requirements, it is not possible to define a single correct methodology that can be applied to all transportation planning models. The comprehensive and modular structure and inherent flexibility of TRANPLAN makes it possible for the user to select the appropriate modules of TRANPLAN (as well as the appropriate options and functions within each module) to suit his/her purposes. This is especially relevant in this project, considering that the main objective of using TRANPLAN (i.e., determining turning volumes) is such that only very few of the TRANPLAN functions are needed, and very few options within the needed functions are required. In this respect, this *User's Guide* has been designed, for the sake of simplicity, to incorporate only the few needed functions and options.

The 40+ TRANPLAN functions that cover the entire transportation planning process are grouped into eight categories:

1. *Distribution/Modal Choice Models*: These models describe the forecasting processes which simulate travel behavior, such as the Gravity Model, Fratar Model, and the Modal Choice Model, as well as many calibration techniques.

2. *Networks*: This group of functions is used to build new highway networks or to update existing ones by addition, deletion, or replacement of a link or node, or modification of a link or node characteristic.

3. *Paths*: These functions are used to build minimum zone-to-zone paths for highway networks.

4. *Loading*: These functions are used for loading trips on highway networks. Several loading methods are available in addition to special post-processor techniques for analysis of sub-areas and selected links.

5. *Matrix Utilities*: These describe the functions that are used to create and modify information that is in matrix form, i.e., trip tables, travel impedance, etc.

6. *Reporting*: These functions are used solely for generating reports. Many other functions in TRANPLAN also produce reports, but they are not included in this section because their reports are secondary operations.

7. *Plotting*: These functions produce plots for the pictorial representation of network characteristics.

8. *Trip Generation*: This set of functions is used to produce trip generation values.

Each of the above categories is represented by at least one of the functions that are needed for this specific application of TRANPLAN, i.e., determination of turning volumes.

A description of the general structured format for the TRANPLAN functions is provided on Page 1-4 of the TRANPLAN User's Manual. Also, the syntax conventions that apply to the construction of TRANPLAN control files and program execution are found on the same page of the manual.

The size limits for various features of the network (such as the maximum number of links), for each type of operating system, are provided on page 2 of the URBANSYS User's Manual.

The output from TRANPLAN is used in various ways. First, the link volumes are used by the *Safety* spreadsheet to estimate crash rates. The turning movements at access points are used by the *Access Delay* spreadsheet. The turning movements at intersections are used by TRANSYT-7F. The results from the *Access Delay* spreadsheet, TRANSYT-7F, and the *Safety* spreadsheet are used by the *Cost* spreadsheet.

Access Delay

The *Access Delay* spreadsheet calculates the delays and operating costs due to access points between intersections. The delays include the delays of minor streams and the delays of arterial streams caused by minor streams. The user can enter the movement volumes and other data for each segment. The output data regarding delays and operating costs due to access points are then provided.

SYNCHRO3 and TRANSYT-7F

In order to prepare data for TRANSYT-7F, SYNCHRO3 or the TRANSYT-7F editor may be used. SYNCHRO3 provides a graphical interface for data input, which enables graphic display of the traffic network. Intersections may be identified by node numbers and by the intersecting street names. Turning movements are identified based on the approach (northbound, eastbound, southbound, and westbound) and movement type (left turn, through, and right turn). SYNCHRO3 may also be used to optimize the sequences of phases for signalized intersections. After the input data are entered in SYNCHRO3 and phases are optimized, SYNCHRO3 can create a TRANSYT-7F input file, and TRANSYT-7F can be run directly from SYNCHRO3.

If SYNCHRO3 is not available or if signal phase sequences are not being optimized, the TRANSYT-7F editor may be used to enter input data prior to running TRANSYT-7F. Intersections in TRANSYT-7F are identified by node numbers. The movement volumes for each intersection can then be entered using the TRANSYT-7F editor. The turning movements are identified based on the approach (northbound, eastbound, southbound, and westbound) and movement type (left turn, through, and right turn). TRANSYT-7F numbers the turning movements. Table 2 summarizes the standard TRANSYT-7F movement numbering scheme.

Safety

The *Safety* spreadsheet is used to calculate crash rates for segments and signalized intersections. The spreadsheet is arranged by segments and signalized intersections. Each row corresponds to a different segment or signalized intersection. The output from the spreadsheet includes the number of crashes by severity type for each segment or signalized intersection. The output also includes the annual total cost of crashes for a given year.

Cost

The *Cost* spreadsheet performs two tasks:

1. Convert hourly operating costs to daily and annual operating costs,
2. Convert annual operating costs, annual crash costs, and annual agency costs to present worth.

Table 2 Standard TRANSYT-7F numbering scheme
(Wallace et al., 1991)

Movement No.	Approach	Movement
1	nb	Through
2	nb	Left
3	sb	Through
4	sb	Left
5	eb	Through
6	eb	Left
7	wb	Through
8	wb	Left
9	nb	Right
10	sb	Right
11	eb	Right
12	wb	Right

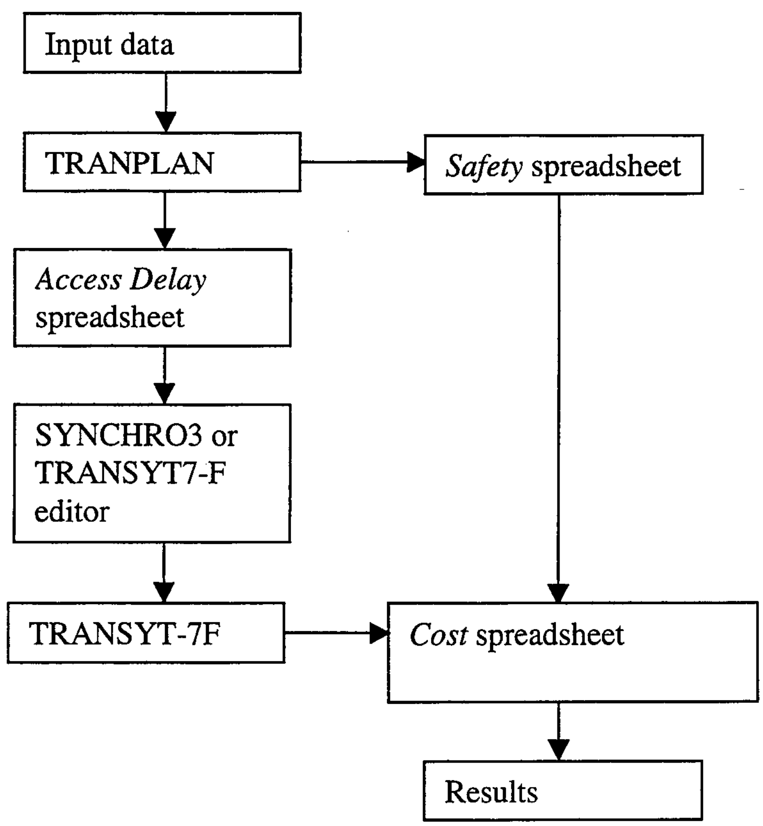

Figure 4 Use of software tools in access control evaluation

4. CONCLUSIONS

This study presents a comprehensive procedure for evaluation of access control alternatives to select the best one. The procedure comprises several steps, including the design and analysis of alternatives and the selection of the best alternative. Analysis of each alternative includes prediction of turning volumes, user costs, and economic effectiveness. The analysis is based on representative periods during the project lifetime.

This study provides a methodology through which network volumes can be predicted for various access control scenarios and thereby determine the impact area of access control measures for a given arterial. A framework is also provided for determining predicted turning volumes at any intersection on the arterial as an input to further analysis to evaluate the various access control alternatives.

Once the turning volumes and impact area have been determined, the user costs can be calculated. The user costs include operating costs and crash costs. The TRANSYT-7F software and spreadsheets developed especially for this procedure can be used to estimate delays and operating costs. Crash rates can be estimated using regression models for multi-lane arterial segments, other segments in the impact area, and signalized intersections. The crash rates can then be converted to crash costs. The user costs can be combined with the agency costs to determine the economic effectiveness of each alternative. After each alternative has been evaluated, the best access control alternative can be selected. Various computer tools can be used in the evaluation process, including TRANPLAN, SYNCHRO3, TRANSYT-7F, and spreadsheets.

5. EXAMPLE CALCULATIONS

This section introduces example prediction of turning volumes (Section 5.1) and example calculations of operating costs and crash costs (Section 5.2). The examples use sections of SR 26 in Lafayette, Indiana, between US 52 and Meijer Way. The purpose of these examples is to illustrate the use of the procedure for evaluating access control alternatives. The examples are not intended to provide any basis for access control decision on the studied sections since some data have been assumed and may not be correct.

5.1 Turning Volumes (Modules 1-5)

Module (1): Collect Input Data

The example calculations begin with a review of files normally used for a standard travel demand analysis in an urban area. The file "tranplan.in" contains TRANPLAN functions, options, and parameters for such an analysis. This file controls the flow of data and functions when TRANPLAN is run. The particular "tranplan.in" file used as the starting point for the example calculations looks for the following input files:

- "i07bla89.pa", which contains production and attraction totals, for each of three trip purposes, for zones 1-210 in the Lafayette area
- "hw33", which is the network file, beginning with a list of node coordinates, followed by the characteristics of each link in the network representation
- "lafaffac.dat", which contains a table of friction factors, one column for each trip purpose
- "lafaxxtr.dat", which lists the number of trips made through the study area for each pair of external stations
- "turn93.dat", which assigns penalties to specified turning movements in the network. Its format and contents are shown in Figure 5 below. The data in the file appear in groups of four fields. For example, the string "363 364 741 100" means that a turn from node 363 at node 364 to node 741 will incur an average delay of 1.00 minutes. If the fourth field in the string is blank or "0", the turn movement is prohibited. (In Figure 5, for example, see "989 412 411 ".) Other software packages have similar provisions.

```
T 363 364 741 100 363 364 365 175 363 364 742 175
T 363 364 363
T 365 364 742 175 365 364 363 175 365 364 741 100
T 365 364 365
T 741 364 365 100 741 364 742 175 741 364 363 175
T 741 364 741
T 742 364 363 175 742 364 741 175 742 364 365 175
T 742 364 742
T 989 412 411    1229 1217 1216 175 724 719 720
```

Figure 5 Format of TRANPLAN input file "turn93.dat"

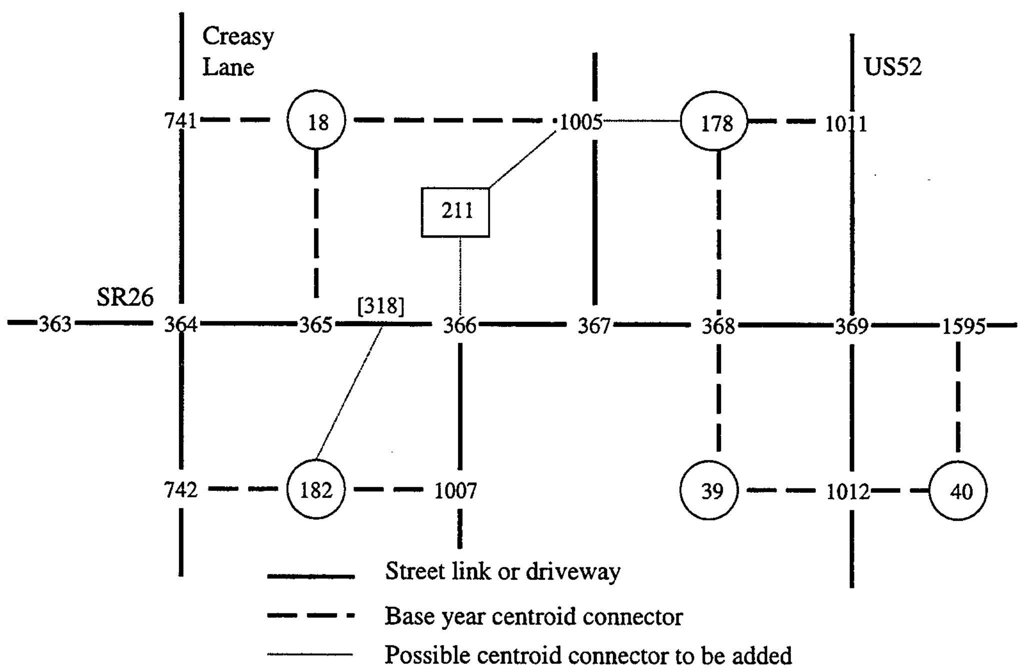

Figure 6 Section of SR 26 in Lafayette used for example prediction of turning volumes

AT FROM -----------TO-----------

-364-		363	365	741	742	SUM IN	TWOWAY
	363	---	2373	730	810	3913	7408
	365	3132	---	576	805	4513	8361
	741	211	447	---	5278	5936	11913
	742	152	1028	4671	---	5851	12744
	SUM OUT	3495	3848	5977	6893		

-365-		18	364	366	SUM IN	TWOWAY
	18	---	58	601	659	1131
	364	354	---	3494	3848	8360
	366	118	4454	---	4572	8667
	SUM OUT	472	4512	4095		

-366-		365	367	1007	SUM IN	TWOWAY
	365	---	3494	601	4095	8667
	367	4454	---	4441	8895	17028
	1007	118	4639	---	4757	9799
	SUM OUT	4572	8133	5042		

-367-		366	368	1006	SUM IN	TWOWAY
	366	---	7575	558	8133	17028
	368	8262	---	2290	10552	20788
	1006	633	2661	---	3294	6142
	SUM OUT	8895	10236	2848		

-368-		39	178	367	369	SUM IN	TWOWAY
	39	---	233	1962	0	2195	4784
	178	236	---	1552	835	2623	4117
	367	2353	1261	---	6622	10236	20788
	369	0	0	7038	---	7038	14495
	SUM OUT	2589	1494	10552	7457		

-369-		368	1011	1012	1595	SUM IN	TWOWAY
	368	---	378	1276	5804	7458	14496
	1011	443	---	3696	2810	6949	14494
	1012	239	2311	---	4293	6843	16417
	1595	6356	4856	4602	---	15814	28721
	SUM OUT	7038	7545	9574	12907		

Figure 7 Assigned Turn Volumes -- Base Case

The files that are most likely to be modified to analyze access control strategies are "hw33" and "turn93.dat". These files and their modifications will be discussed in Module (3). Before any changes are made, however, the "base case" model was run. The resulting turning movements for the arterial segments shown in Figure 6 are displayed in Figure 7. Figure 7 shows a series of turning movement matrices extracted from the TRANPLAN output file "tranplan.out". For example, the first matrix is for the intersection represented by node 364. There were 730 turns from node 363 at node 364 to node 741 during the hour of analysis. These turns were left turns. There were also 2373 turns from node 363 at node 364 to node 365, but these "turns" were actually through movements. Similar matrices follow in Figure 7 for intersection nodes 365-369.

Module (2): Design Alternatives

The user may consider turn prohibitions, road closures, frontage and/or reverse frontage roads and other access control measures. The next modules demonstrate how some of these strategies can be incorporated into an evaluation process.

Module (3): Determine Road Network Representation and Traffic Analysis Zones

Let us say that a planner believes that traffic flow along this corridor would be more accurately portrayed if a new centroid were to be added where "211" is shown in Figure 6. This can be done using the "Add Node Data Record" feature in TRANPLAN's BUILD HIGHWAY NETWORK function or by using HNIS. As a result, the centroid connectors (211,366) and (211,1005) must be added, if traffic from the "211" site will reach the network links in that fashion. TRANPLAN's BUILD HIGHWAY NETWORK function has an "Add Link Data Record" feature, or HNIS can be used to add the centroid connectors. In this case, the trip productions and attractions associated with centroid 18 will have to be shared with the new centroid "211". Editing the "i07bla89.pa" file described in Module (1) above can accomplish this. In addition, it is felt that traffic from centroid "182" has direct access to the arterial via one or more driveways between intersection nodes 365 and 366, so centroid connector (182,318) should be added. Likewise, the analyst thinks that adding centroid connector (178,1005) better represents the traffic movements in this area for the purposes of a corridor-level study. All of these changes will cause the network file (called "hw33" in this example) to be modified.

For the record, here is how the researcher carried out the modifications prescribed above:

1. Used HNIS to mark the location of new centroid "211". The centroid number was assigned automatically by TRANPLAN.
2. Used HNIS to add the centroid connectors associated with centroids 211, 178, and 182. The node number 318 was assigned to the access node between intersection nodes 365 and 366 automatically by TRANPLAN. When the user was prompted for link attributes, the researcher decided it would be easier to enter them outside of HNIS (to be described below).

3. Before exiting HNIS, saved the network output file as (in this case) "net94". HNIS saves network files in "internal unformatted" form, i.e., something unreadable by the user.
4. Used the TRANPLAN utility NETCARD to convert "net94" into a network input file "hw34" that can be read and edited.
5. Confirmed that centroid "211" and access node 311 now appear in the network input file. Also, found the lines in the link list for the new centroid connectors. These lines should contain few or no link attributes.
6. Edited the new centroid link list lines by copying sections of link list lines from centroids that were similar in character to the new centroids. Added estimates of delay for movements at node 318 in file "turn93.dat", with a stop sign controlling traffic entering the arterial from the driveway(s). Added access node 318 to the list of intersection nodes for which turning movement output is desired in input file "tranplan.in".
7. To keep the example simple, half of the productions and attractions listed in file "i07bla89.pa" for zone 18 were given to centroid 211.
8. Changed the number zones from 210 to 211 in the "tranplan.in" file.

TRANPLAN was run on this modified base case -- no real changes to the network had been made, only in how the existing network was being represented. The turning movement results for the modified base case are shown in Figure 8. First, note that centroid 211 is automatically included in the turning movement matrix for intersection node 366. More importantly, note that the flows in the Figure 8 matrices have changed -- often significantly -- from the corresponding Figure 7 values. These values should be carefully checked and further network modifications considered and tried before any access control measures are introduced into the model.

Figure 8 shows the desired turn movement flows in a matrix format that is similar to that of a trip table. TRANPLAN also produces a file "TRNDATA" (renamed "turnmvt93.out" in this example) that has the same data in *list* format. See Figure 9. This list format is easier to use as input to other programs in the access control evaluation procedures that follow. In fact, it is the required format.

Module (4): Predict Turning Volumes for Representative Periods.

From the numerous possible traffic problems and remedies in a corridor, such as that shown in Figure 6, let us concentrate in this example on left turns that cause traffic backups and crashes. Let us say that the centroid connectors (18,365), (182,318), (39,368), and (178,368) each represent one or more driveways that allow traffic to enter the arterial at unsignalized access nodes. At the access nodes 365, 318, and 368, it is proposed to install median barriers that would make left turns and through movements across the median impossible. In each case, there are less direct means of access to the arterial, usually at signalized intersections. This proposal will be evaluated by first generating a forecast of the flow pattern that is likely to result, then using that output in the modules 5-8 that follow. By repeating this procedure for several alternative proposals, the most desirable alternative can be selected in Module (9).

```
AT     FROM    -----------TO-----------

-318-            182     365     366 SUM IN TWOWAY

182     ---     408    1201    1609    3596
365     847     ---    3283    4130    8509
366    1140    3971     ---    5111    9595

SUM OUT    1987    4379    4484

-364-            363     365     741     742 SUM IN TWOWAY

363     ---    2520     365     537    3422    6833
365    3197     ---     600     612    4409    8595
741      31     825     ---    5018    5874   11237
742     183     841    4398     ---    5422   11589

SUM OUT    3411    4186    5363    6167

-365-             18     318     364 SUM IN TWOWAY

18      ---     122      86     208     443
318      56     ---    4323    4379    8508
364     179    4007     ---    4186    8595

SUM OUT     235    4129    4409

-366-            211     318     367    1007 SUM IN TWOWAY

211     ---     262     648     523    1433    2876
318     237     ---    4170      77    4484    9594
367     697    4838     ---    3589    9124   17343
1007     509      10    3401     ---    3920    8109

SUM OUT    1443    5110    8219    4189

-367-            366     368    1006 SUM IN TWOWAY

366     ---    7634     585    8219   17343
368    8476     ---    1550   10026   19836
1006     648    2176     ---    2824    4959
```

Figure 8 Assigned Turn Volumes -- Modified Base Case

182	318	365	0
182	318	366	1199
365	318	182	839
365	318	366	3186
366	318	182	0
366	318	365	3931
363	364	365	2510
363	364	741	370
363	364	742	544
365	364	363	3313
365	364	741	129
365	364	742	672
741	364	363	43
741	364	365	850
741	364	742	4929
742	364	363	162
742	364	365	665
742	364	741	4926
18	365	318	0
18	365	364	200
318	365	18	16
318	365	364	3914
364	365	18	0
364	365	318	4025
211	366	318	217
211	366	367	637
211	366	1007	569
318	366	211	239
318	366	367	4145
318	366	1007	0
367	366	211	683
367	366	318	3698
367	366	1007	4257
1007	366	211	510
1007	366	318	16
1007	366	367	3447
366	367	368	6655
366	367	1006	1574
368	367	366	7941
368	367	1006	928
1006	367	366	696
1006	367	368	2235

Figure 9 TRNDATA output for Median Barrier

The "median barrier" proposal can be invoked in TRANPLAN by revising the "turn93.dat" to prohibit turns and through movements that are used to cross the median at the nodes listed above. The resulting turning movements are shown in *list* format in Figure 9. All but two of the zero flows are for forbidden movements. The other two zero flows are explained by the existence of another route that is superior to using the given intersection. As mentioned above, the TRNDATA file is used later in the access control evaluation process.

Module (5): Determine Impact Area Common for All Alternatives

TRANPLAN offers a utility called "COMPNET" that compares two loaded highway networks, which are contained in the "LODHIST" output files. The user is prompted for the specific names given to the two LODHIST files, the magnitude of absolute difference in link flows that are considered "significant" by the user, and a name for the file that reports the differences. Using LODHIST files "basemod.out" and "medbar.out" for the Modified Base and Median Barrier cases, respectively, and a minimum absolute difference in link flows of 500 vehicles per hour, the "impact1.rpt" file in Figure 10 results. A majority of the links in Figure 10 are located in the corridor shown in Figure 6. However, two clusters of links also show up in the list. One cluster is in the area of Eisenhower Road to the northeast of the arterial being studied. The other cluster is along Teal Road, a mile or two to the southwest. These clusters of links with significant differences may indicate shifts in traffic because of turning restrictions imposed along the arterial being analyzed, but the network model should once again be checked for any quirks that may be present.

5.2 Operating and Crash Costs (Modules 6-8)

This example uses Modules 6-8 of the procedure to estimate operating costs and crash costs assuming that anticipated turning volumes for representative hours are known. The example assumes a 20-year project life beginning in 1999 and an impact area limited to the SR 26 arterial (see Figure 11).

The example shows detailed calculations of operating costs for one hour and of crash costs for one year based on the existing conditions. The input consists of field data and assumed values. The assumptions regarding the conversion of hourly costs to annual costs and the calculation of present worth costs are for illustrative purposes only. Although the calculations are based on the existing case, the framework described in this example could be applied to any access control scenario. This section is organized based on the steps described in Modules (6) through (8).

```
Link:   39 -  368 -- Flows: File 1   2210, File 2     0 -- Diff (1-2)   2210
Link:   39 - 1012 -- Flows: File 1   2169, File 2  4325 -- Diff (1-2)  -2156
Link:  178 -  368 -- Flows: File 1   2013, File 2   992 -- Diff (1-2)   1021
Link:  178 - 1011 -- Flows: File 1    258, File 2  1052 -- Diff (1-2)   -794
Link:  318 -  182 -- Flows: File 1   1987, File 2   839 -- Diff (1-2)   1148
Link:  366 -  318 -- Flows: File 1   5111, File 2  3931 -- Diff (1-2)   1180
Link:  366 - 1007 -- Flows: File 1   4189, File 2  4826 -- Diff (1-2)   -637
Link:  367 -  368 -- Flows: File 1   9810, File 2  8890 -- Diff (1-2)    920
Link:  368 -  178 -- Flows: File 1   1211, File 2     0 -- Diff (1-2)   1211
Link:  368 -  367 -- Flows: File 1  10026, File 2  8869 -- Diff (1-2)   1157
Link:  368 -  369 -- Flows: File 1   7330, File 2  6482 -- Diff (1-2)    848
Link:  369 -  368 -- Flows: File 1   7050, File 2  7877 -- Diff (1-2)   -827
Link:  369 - 1011 -- Flows: File 1   7420, File 2  8274 -- Diff (1-2)   -854
Link:  406 -  407 -- Flows: File 1   7487, File 2  8212 -- Diff (1-2)   -725
Link:  407 -  408 -- Flows: File 1   7216, File 2  7928 -- Diff (1-2)   -712
Link:  423 -  424 -- Flows: File 1   2116, File 2  1550 -- Diff (1-2)    566
Link:  423 -  955 -- Flows: File 1   2980, File 2  3666 -- Diff (1-2)   -686
Link:  424 -  425 -- Flows: File 1   2037, File 2  1464 -- Diff (1-2)    573
Link:  425 -  426 -- Flows: File 1   2989, File 2  2477 -- Diff (1-2)    512
Link:  426 -  427 -- Flows: File 1   2989, File 2  2477 -- Diff (1-2)    512
Link:  427 -  428 -- Flows: File 1   2989, File 2  2477 -- Diff (1-2)    512
Link:  428 -  429 -- Flows: File 1   2989, File 2  2477 -- Diff (1-2)    512
Link:  637 -  638 -- Flows: File 1   1795, File 2  1184 -- Diff (1-2)    611
Link:  638 -   43 -- Flows: File 1   1348, File 2   686 -- Diff (1-2)    662
Link:  744 -  549 -- Flows: File 1  11109, File 2 11668 -- Diff (1-2)   -559
Link:  955 -  404 -- Flows: File 1   5032, File 2  5716 -- Diff (1-2)   -684
Link: 1002 -  451 -- Flows: File 1   3325, File 2  2736 -- Diff (1-2)    589
Link: 1003 - 1002 -- Flows: File 1   3325, File 2  2736 -- Diff (1-2)    589
Link: 1004 - 1003 -- Flows: File 1   3325, File 2  2736 -- Diff (1-2)    589
Link: 1005 -  178 -- Flows: File 1    912, File 2  1922 -- Diff (1-2)  -1010
Link: 1005 - 1004 -- Flows: File 1   3325, File 2  2736 -- Diff (1-2)    589
Link: 1007 -  182 -- Flows: File 1      0, File 2  1063 -- Diff (1-2)  -1063
Link: 1011 -  369 -- Flows: File 1   6766, File 2  7681 -- Diff (1-2)   -915
Link: 1011 -  453 -- Flows: File 1   6858, File 2  7517 -- Diff (1-2)   -659
Link: 1012 -  369 -- Flows: File 1   7010, File 2  8767 -- Diff (1-2)  -1757
```

Figure 10 Difference in Flows, Modified Base vs. Median Barrier Case

Module *(6)*: Predict Operating Costs

This example describes in detail the calculation of hourly operating costs for an off-peak hour on SR 26 in 1999 based on the existing conditions. The example also demonstrates the process of converting hourly operating costs to daily operating costs and then to annual operating costs. The software tools used in this part of the example include the Arterial Analysis Package (AAP), PASSER II-90, TRANSYT-7F, *Access Delay* spreadsheet, and *Cost* spreadsheet. The AAP, PASSER II-90, and TRANSYT-7F are programs funded and recommended by FHWA. The two mentioned spreadsheets: *Access Delay* and *Cost* have been developed as a part of this research. The theoretical basis for these spreadsheets is given in the research part (Part I) of this report. The user's manual for the spreadsheets is attached in the Appendix to this guide.

Figure 11 shows the example section of the SR 26 highway. The section contains five segments between six signalized intersections. Three access nodes are used to represent nine access points. The SR 26 arterial contains two through-lanes in each direction and a median with exclusive left turn lanes.

The operating costs are calculated for the existing conditions. The geometry, control, and off-peak volume data were collected recently by Gary Shoup, a graduate student at Purdue University. The turning volumes at access nodes are assumed for this example. In a real analysis, all of the turning volumes should be measured or predicted using TRANPLAN or other tools of confirmed quality.

Module *(6.1)*: Estimate total and average delays on arterial segments between intersections

The delays incurred between major intersections are estimated in this step. Two types of delays are regarded: (1) delays experienced by arterial through vehicles and caused by the vehicles entering or exiting the arterial street; and (2) delays experienced by the vehicles that enter or exit the arterial street. The delay calculation was done for one hour using the *Access Delay* spreadsheet. The input and results obtained in this spreadsheet are given in the *Access_Delay_sr26.xls* file (on attached disk). This example illustrates the application of the *Access Delay* spreadsheet with turning volumes as input. The following steps were performed to calculate average delays on arterial segments between intersections:

1. Add turning volumes to *tpdata2* sheet.
2. Run *sortalt* macro.
3. Run *sortdata* macro.
4. Enter turning movement data for access nodes.
5. Enter segment data.
6. Override or accept the TRANSYT-7F default parameters.
7. Run *costcalc* macro.

The following paragraphs detail these seven steps.

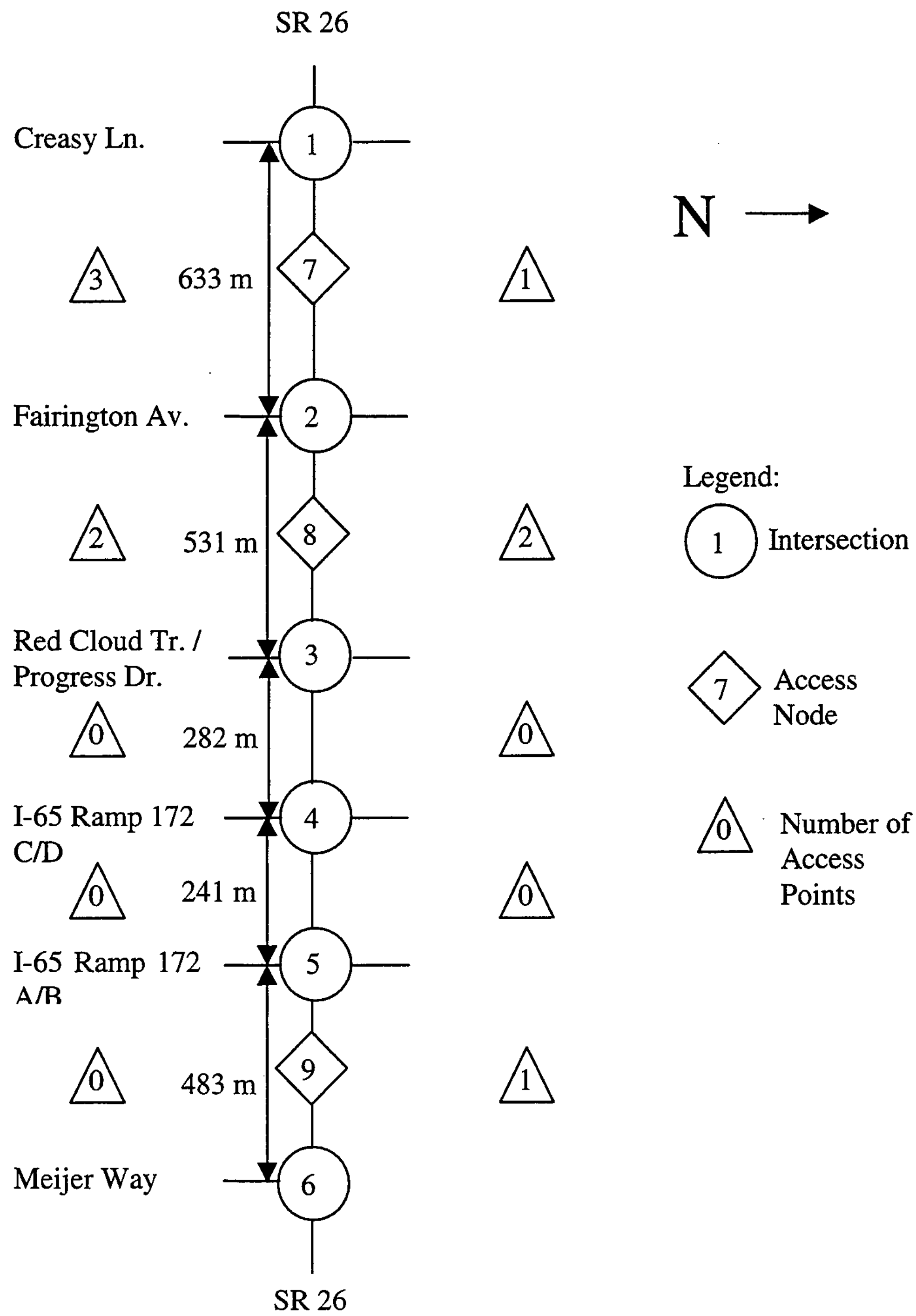

Figure 11 SR 26 network for analysis of operating costs

The turning movements were entered in the *tpdata2* worksheet in this case because these data were available separately. Since user-defined volumes were being entered, the *from* and *to* nodes of each turning movement did not need to be entered. However, the *from* and *to* nodes of each turning movement have been added to the example input data for illustrative purposes. After the data were entered, the *sortalt* macro was run to sort these movements by through node. Table 3 summarizes the input data entered in the *tpdata2* sheet after the *sortalt* macro was run.

After these data were sorted by the *sortalt* macro, the *sortdata* macro was run to prepare the data for delay calculations. Data were then entered in the *accesscalc* worksheet to calculate the delays due to access nodes. The arterial through movement data are summarized in Table 4.

Table 3 Input data in *tpdata2* worksheet for SR 26 example

From Node	*Through* Node	*To* Node	Volume	Approach	Movement	Node Type
71	7	2	60	nb	r	ae
71	7	1	6	nb	l	ae
72	7	1	60	sb	r	ae
72	7	2	15	sb	l	ae
1	7	72	25	eb	l	ae
1	7	2	960	eb	t	ae
1	7	71	50	eb	r	ae
2	7	71	26	wb	l	ae
2	7	1	962	wb	t	ae
2	7	72	40	wb	r	ae
81	8	2	17	nb	l	ae
81	8	3	70	nb	r	ae
82	8	3	20	sb	l	ae
82	8	2	83	sb	r	ae
2	8	82	30	eb	l	ae
2	8	3	1007	eb	t	ae
2	8	81	60	eb	r	ae
3	8	81	23	wb	l	ae
3	8	2	931	wb	t	ae
3	8	82	77	wb	r	ae
92	9	5	5	sb	r	ae
92	9	6	8	sb	l	ae
5	9	92	8	eb	l	ae
5	9	6	626	eb	t	ae
6	9	5	722	wb	t	ae

Table 4 Input data values for arterial through movements in *accesscalc* worksheet

Through Node	Volume	Approach	Movement	Traffic Direction From Intersection	Traffic Direction To Intersection	Arterial Speed (km/hr)	One-Way Number of Through Lanes
7	960	eb	t	1	2	72	2
7	962	wb	t	2	1	72	2
8	1007	eb	t	2	3	72	2
8	931	wb	t	3	2	72	2
9	626	eb	t	5	6	72	2
9	722	wb	t	6	5	72	2

Table 5 Input data values for right and left-turn movements in *accesscalc* worksheet

Through Node	Volume	Approach	Movement	Is LTL present? (y/n)	Sight Distance of Left-Turn Queue w_l (m)	Merging/ Diverging Speed (km/hr)	Merging/ Diverging Distance (m)
7	25	eb	l	y		20	80
7	50	eb	r			20	80
7	26	wb	l	y		20	80
7	40	wb	r			20	80
7	6	nb	l			20	180
7	60	nb	r			20	180
7	15	sb	l			20	180
7	60	sb	r			20	180
8	30	eb	l	y		20	80
8	60	eb	r			20	80
8	23	wb	l	y		20	80
8	77	wb	r			20	80
8	17	nb	l			20	180
8	70	nb	r			20	180
8	20	sb	l			20	180
8	83	sb	r			20	180
9	8	eb	l	y		20	80
9	8	sb	l			20	180
9	5	sb	r			20	180

Data were also entered for right and left-turn movements at access nodes. For the arterial left-turn, the data for the diverging model were entered because exclusive left-turn lanes were present. A turning speed of 20 km/hr was assumed for both the diverging and merging cases. The merging distance was estimated from Figure II-16 in AASHTO (1994), and the diverging distance was estimated using Figure II-17 in AASHTO. The data for right and left-turn movements are shown in Table 5.

After the data were entered in the *accesscalc* worksheet, some of the default values for the TRANSYT-7F unit costs were entered in the *transyt7f_params* worksheet to override the default values. This step was needed so that the TRANSYT-7F costs would be in 1999 dollars. It was assumed in this case that inflation applied differently to the unit costs of fuel and delay. Thus, the default inflation factor of one was used, and the individual unit costs were modified. A fuel cost of $0.29 per liter was assumed based on current prices. The unit cost of delay was assumed to be $206.88/1000 veh-hr based on the assumption of three percent inflation per year ($206.88 = 145.1 \times 1.03^{12}$). The unit cost of passenger time was assumed to be $1.86 /pers-hr based on three percent inflation per year. For auto occupancy, the default value of 1.20 was used.

The segment data were then entered in the *segment_data* worksheet. These data are summarized in Table 6. After these data were entered, the *costcalc* macro was run. The results for delays for each segment and direction are given in Table 7.

Table 6 Input data for *segment_data* worksheet for SR 26 example

Traffic Direction From Intersection	Traffic Direction To Intersection	Segment Length (km)	Cruise Speed (km/hr)
1	2	0.24	72
2	1	0.24	72
2	3	0.362	72
3	2	0.362	72
5	6	0.446	72
6	5	0.446	72

Table 7 Output data for delays between intersections for SR 26 example

Traffic Direction From Intersection	Traffic Direction To Intersection	Total Delay Of Minor Streams (sec)	Total Delay of Arterial Stream (sec)
1	2	1772.1	133.5
2	1	1139.1	121.6
2	3	2439.7	174.0
3	2	2231.9	179.1
5	6	242.1	4.9
6	5	30.3	4.9

Module *(6.2)*: Correct the cruise speeds on arterial segments

After the *costcalc* macro had been run, the cruise speeds for each segment and direction were given as output in the *segment_data* worksheet. The output data are summarized in Table 8.

Table 8 Results for corrected cruise speeds for SR 26 example

Traffic Direction From Intersection	Traffic Direction To Intersection	Revised Cruise Speed (km/hr)
1	2	71.2
2	1	71.3
2	3	71.4
3	2	71.3
5	6	72.0
6	5	72.0

Module *(6.3)*: Perform calculation of operating cost (impact of access points not included)

Once the cruise speeds had been calculated, the calculation of operating costs, not including access points, could be performed. This analysis was done using existing software packages including AAP, PASSER II-90, and TRANSYT-7F. The signal settings were also optimized. The following steps were performed in these calculations:

1. Network and traffic data were entered in AAP;
2. Data pertaining to left-turn treatments were entered using the PASSER II data editor;
3. The sequence of phases for each signal was optimized by running PASSER II;
4. The PASSER II phase sequences were loaded into the AAP data file;
5. Data regarding unit costs were entered using the TRANSYT-7F data editor;
6. TRANSYT-7F (Version 7) was run to optimize signal settings and to calculate operating costs.

The AAP package, Release 4.2, was used to enter the traffic and network data. The AAP software provides the option of using U.S. or metric units. The AAP data were entered using U.S. units because it was determined that the metric unit version did not adjust saturation flow rates properly. The traffic signals were designed in this example as fully actuated and coordinated. The lengths and speeds were entered for each segment and direction. The revised cruise speeds in Table 8 were used after conversion to U.S. units. The approach and traffic data were entered for each signalized intersection. These data are summarized in Table 9.

Table 9 Approach and traffic data for signalized intersections for SR 26 example

Intersection	Approach	Left-Turn Volume	Through Volume	Right-Turn Volume	Number o f Left-Turn Lanes	Number of Through Lanes	Number of Right-Turn Lanes
Creasy Ln.							
	nb	281	553	136	1	2	1
	sb	207	289	94	1	2	0
	eb	170	617	276	1	2	1
	wb	202	625	135	1	2	1
Fairington Av.							
	nb	42	0	58	1	0	1
	sb	10	0	10	1	0	1
	eb	10	941	10	1	2	1
	wb	19	912	0	1	2	1
Red Cloud Tr./Progress Dr.							
	nb	48	16	136	0	2	0
	sb	70	10	192	0	2	0
	eb	30	876	101	1	2	1
	wb	42	691	100	1	2	1
I-65 Ramp 172 C/D							
	sb	57	0	203	1	0	1
	eb	0	876	206	1	2	1
	wb	40	629	0	1	2	0
I-65 Ramp 172 A/B							
	nb	135	0	20	1	0	1
	eb	327	606	0	1	2	0
	wb	0	534	188	0	2	1
Meijer Way							
	nb	328	0	32	2	0	1
	eb	0	413	213	0	2	0
	wb	16	394	0	1	1	0

For the timing data in AAP, allowable phase sequences were specified in preparation for running PASSER II. These sequences were specified using the *Edit/Timing Plan* command in AAP. For the arterial approaches, leading left-turn with overlap was specified. Since PASSER II does not optimize cross street phase sequences, the cross street phase sequences were specified. In the *Edit/Run Instructions* input screen, optimization of phase sequence, splits, and offsets was requested; the cycle range selected was between 60 sec and 150 sec in increments of five sec. The *sr26ex.aap* file contains the input data for AAP.

After the AAP data were entered, the PASSER II data editor was used to specify left-turn treatments for the arterial approaches. The arterial left-turn treatments for each intersection are listed in Table 10. The *sr26p.pin* file contains the input that was used to run PASSER II to optimize the arterial phase sequences.

Table 10 Arterial left-turn treatments

Intersection	Arterial Left-Turn Treatment
Creasy Ln.	Protected only
Fairington Av.	Permitted only
Red Cloud Tr./Progress Dr.	Protected only
I-65 Ramp 172 C/D	Protected only
I-65 Ramp 172 A/B	Protected only
Meijer Way	Permitted only

PASSER II was then run to optimize the sequence of phases. The timing plan determined by PASSER II was then loaded into AAP. The loaded timing plan includes the sequence of phases, splits, and offsets determined by PASSER. The split and offset values were cleared because they were to be optimized using TRANSYT-7F. The split and offset values were cleared in the *Edit/Timing Plan* and *Edit/Progression Data* screens. The *sr26exb.aap* file contains the AAP data with the optimal sequence of phases as determined by PASSER loaded in the *Edit/Timing Plan* screen in AAP.

The data for TRANSYT-7F regarding unit cost values were then edited using the *Edit/TRANSYT-7F Data* command in AAP. The unit cost values were similar to those used in the *Access Delay* spreadsheet. The fuel cost was $0.29/lit. However, TRANSYT-7F requires input units of $/gal, so a fuel cost of $1.10/gal was used as input to TRANSYT-7F. The unit cost of vehicle delay was again assumed to be $206.88/1,000 veh-hr. The value for the unit cost of passenger time was assumed to be $1.8590/pers-hr based on three percent inflation per year.

These unit cost values were coded in TRANSYT-7F as follows. The fuel cost was coded in Field 15 of Card Type 10 with a value of 110. The unit cost values were specified by inserting a Card Type 8, which is the Model Coefficients Card used to override default values. Field 2 of Card Type 8 specifies the model for which the values are being overridden. A value of 2 in Field 2 specifies the operating cost model. All parameter values must be specified when Card Type 8 is used, including default values. If default values are used for all parameter and unit cost values, Card Type 8 is not needed. The values in Card Type 8 are coded as integers; thus, each parameter has an associated magnitude. For example, Fuel Cost has a magnitude in Card Type 8 of 4, thus $1.10 would be coded as 11000 ($=1.10*10^4$). The parameter values must be specified in U.S. units in TRANSYT-7F. Table 11 lists the parameter values that were coded in TRANSYT-7F Card Type 8. In addition, the default value of auto occupancy (1.20) was used. The coded value (120 based on a magnitude of 2) for auto occupancy is listed in Field 16 of Card Type 10. The default values were taken from Wallace et al. (1991).

Table 11 Parameter values coded in Card Type 8

Field	Parameter	Value	Magnitude	Coded Value
3	A_{11OC}	126.84*	1	1268
4	A_{12OC}	0.28417*	4	2842
5	A_{13OC}	0.012295*	5	1230
6	A_{14OC}	0.0001677*	7	1677
7	A_{21OC}	-0.59937*	4	-5994
8	A_{22OC}	0.30289*	4	3029
9	A_{23OC}	0.032693*	5	3269
10	A_{24OC}	0.00028*	7	2800
11	Unit cost of vehicle delay ($/1000 veh-hr)	206.88	2	20688
12	Fuel cost ($/gal)	1.10	4	11000
13	Unit cost of passenger time ($/pers-hr)	1.8590	4	18590
14	Inflation factor	1.0*	4	10000

* default values

Once the unit cost values were coded in TRANSYT-7F, the TRANSYT-7F software was used to optimize signal timings and to calculate operating costs excluding access points. The *sr26tr.tin* file contains the input data used for TRANSYT-7F. The output data is contained in the *sr26tr.tof* file. The summary measures of effectiveness are provided in this output file in the table giving the system-wide performance for all nodes as shown in Table 12. The results indicate operating costs for the off-peak hour not including the effects of access points of $1,461.

Table 12 TRANSYT-7F output for system-wide performance for SR 26 example

```
        SYSTEM-WIDE PERFORMANCE: ALL NODES
        ----------------------------------
                                              SYSTEM
PERFORMANCE MEASURES     UNITS              TOTALS
------------------------------------------------------
Total Travel             veh-mi/hr            2458
Total Travel Time        veh-hr/hr             127
Total Uniform Delay      veh-hr/hr              65
Total Random Delay       veh-hr/hr               6
Total Delay              veh-hr/hr              71
Average Delay            sec/veh              19.5
Passenger Delay          pax-hr/hr              85
Stops: Total             veh/hr               6377
       Percentage        %                      49
System Speed             mph                  19.3
Fuel Consumption         gal/hr                197
Operating Cost           $/hr                 1461
Average PROS             PROS                 31.6
Performance Index        DI                  112.3
------------------------------------------------------
```

Module ***(6.4):*** **Calculate extra operating costs caused by access points**

The extra operating costs caused by access points are provided as output by the *Access Delay* spreadsheet. The output is given in the *segment_data* worksheet. The results from this example indicate additional operating costs due to access points of $7.66. In this example, the effect of access points on delays appears to be minimal. This result is due to several factors. First, the volumes are relatively low because of the off-peak period. Due to the low arterial volumes, the delay of arterial streams due to minor streams is relatively low. Second, the arterial contains a small number of unsignalized access points. Most of the access is provided through frontage roads and signalized intersections.

The example indicates that the additional operating costs due to access points may be small in some cases. In other cases, the effect may be more pronounced. For example, a segment with dense access points and no frontage roads may experience more delay caused by access points. This effect may be significant when comparing a design with low access control and a design with high access control where access is provided through frontage roads and signalized intersections. The delays at access points may also be higher when the arterial volumes are higher.

Although the delays at signalized intersections are much higher in this example than the delays at access points, the results should not be interpreted as indicating that signals should not be installed. Signals should still be installed when warranted.

Module ***(6.5):*** **Aggregate hourly operating costs for the network**

In this example for the off-peak hour, the hourly operating costs determined from TRANSYT-7F are added to the hourly operating costs caused by access points. The total hourly cost in this example rounded to the nearest dollar is $1,461 + $8 = $1,469.

Module ***(6.6):*** **Convert the obtained hourly costs into daily and annual operating costs**

This calculation was done using the *Cost* spreadsheet. The following assumptions were made to allow for further calculations:

1. One morning peak hour,
2. Three afternoon peak hours,
3. 16 off-peak hours,
4. 365 days per year.

The following cost values were used: $4,389 for the morning peak hour, $3,657.50 for the afternoon peak hour, and $1,469 for the off-peak hour. The values for the peak hour costs have been assumed to allow the illustration of the use of the *Cost* spreadsheet for further calculations. The total number of hours in this example is 20 because some of the night hours are neglected.

The data were coded into the *hourly_costs* worksheet of the *Cost* spreadsheet. The number of days per year was coded in Cell C8. The data for the hours and unit costs were entered as shown in Table 13. After the data were entered, the *hourcost* macro was run. The results in Rows 62 to 64 of the *hourly_costs* worksheet indicate a daily cost of $38,865.50 and an annual cost of $14,185,907.50. Thus the annual operating costs for 1999 rounded to the nearest dollar are $14,190,000. The input and results are given in the *Cost_sr26.xls* file.

Table 13 Input hourly cost data for SR 26 example

		Year
Period	Number of Hours/Unit Cost	1999
1	Hours	1
1	Cost	$4,389.00
2	Hours	3
2	Cost	$3,657.50
3	Hours	16
3	Cost	$1,469.00

Module *(7)*: Predict Crash Costs

This example shows detailed calculations of the crash costs for the year 1999. The calculation of crash costs includes predicting crash rates on urban multi-lane arterial segments, other segments in the impact area, and signalized intersections. For the safety analysis, the section was divided into two segments as shown in Figure 12. The division of the segments was made at the I-65 bridge because there is a significant change in traffic volumes on SR 26 at I-65. In addition, the level of development on SR 26 west of I-65 is higher than the level of development east of I-65. The *Safety* spreadsheet was used for the crash cost calculations. The input and results for this example are given in the file *Safety_sr26.xls*. Based on the segments, crash rates were calculated at two signalized intersections: Creasy Lane and Meijer Way. The other traffic signals were considered as signalized access points on the segments with each signal counted as two signalized access points regardless of the number of legs. The segment geometric data were collected in the field.

Module *(7.1)*: Estimate number of crashes for arterial segments

The data for the multi-lane arterial segments were entered in the *arterial_segments* worksheet of the *Safety* spreadsheet. Both of the segments have an outside shoulder. Both of the segments have medians with openings between signals. The segment lengths have been adjusted by subtracting 0.06 km to account for the segment endpoints. The input data are shown in Table 14. The results are shown in Table 15.

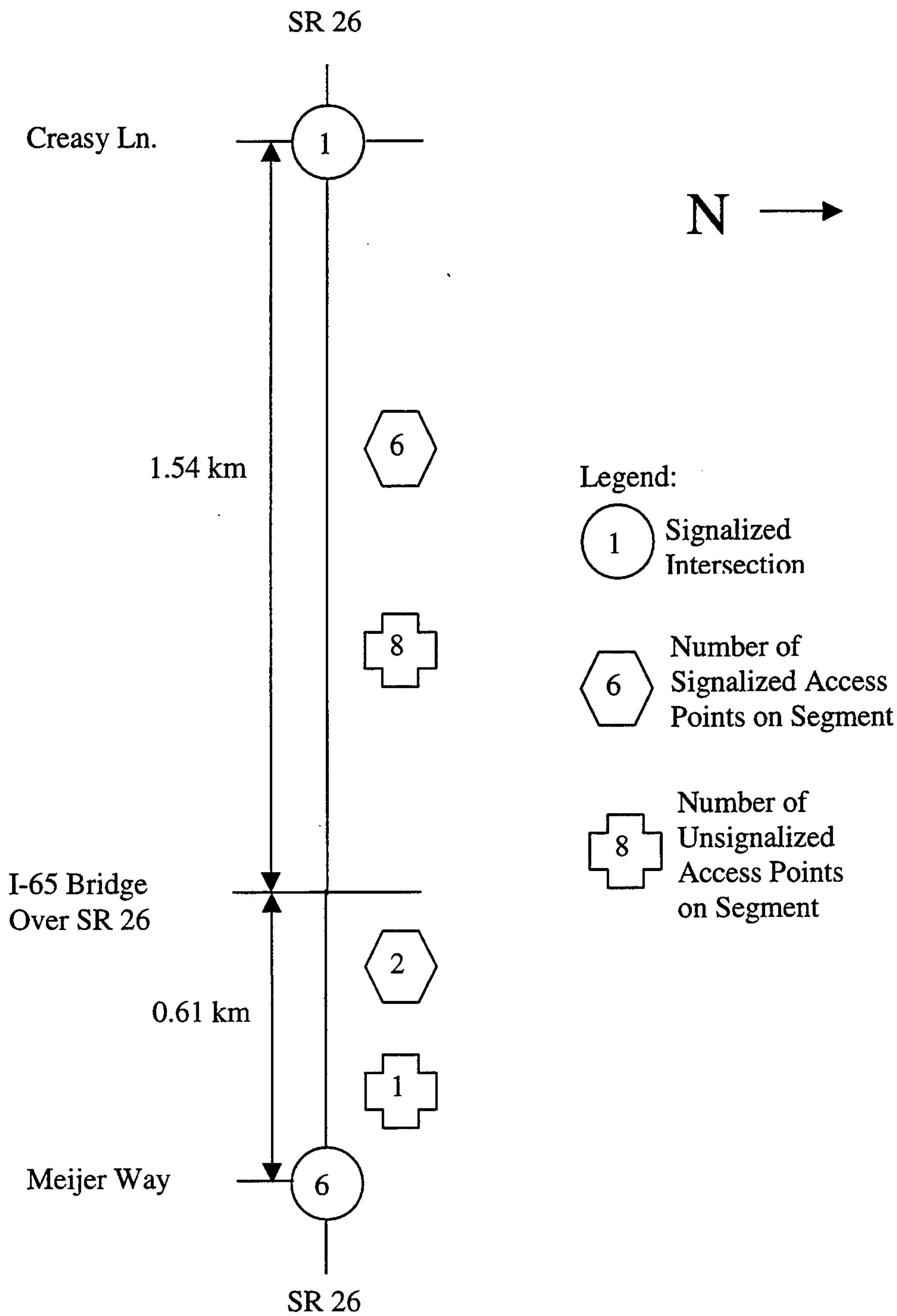

Figure 12 Segments and signalized intersections for SR 26 example

Table 14 Input data for arterial segments for SR 26 example

Segment ID	Segment Length (km)	AADT (1000 veh/day)	Number of Access Points	Number of Signalized Access Points	Is Outside Shoulder Present? (y/n)	Is TWLTL Present? (y/n)	Is Closed Median Present? (y/n)
Creasy to I-65	1.48	29.68	14	6	y	n	n
I-65 to Meijer Way	0.55	15.71	3	2	y	n	n

Table 15 Output data for arterial segments for SR 26 example

Segment ID	PDO Crash Frequency (crash/year)	Fatal/ Injury Crash Frequency (crash/year)
Creasy to I-65	33.2	11.9
I-65 to Meijer Way	11.0	3.5

Module *(7.2)* Estimate annual number of crashes for other segments in impact area

In this example, the impact area is limited to the arterial. In addition, SR 26 is a multi-lane arterial. Thus, both segments are multi-lane arterial segments for which crash frequencies were calculated in Module (7.1). The calculation of crash rates for other segments is not needed in this example.

Module *(7.3)* Estimate annual number of crashes for signalized intersections in impact area

The data for the signalized intersections were entered in the *signalized_intersections* worksheet of the *Safety* spreadsheet. The input data are summarized in Table 16. The output data including the frequency of pdo and fatal/injury crashes are given in Table 17.

Table 16 Input data in *signalized_intersections* worksheet for SR 26 example

Signalized Intersection ID	Average AADT in N/S Direction (1000 veh/day)	Average AADT in E/W Direction (1000 veh/day)	Number of Intersection Approaches	Number of Approaches With Median	Number of Left-Turn Movements Forbidden
1	23.634	29.68	4	2	0
6	10.908	15.71	3	1	0

Table 17 Output data in *signalized_intersections* worksheet for SR 26 example

Signalized Intersection ID	PDO Crash Frequency (crash/year)	Fatal/ Injury Crash Frequency (crash/year)
1	14.2	4.3
6	6.9	1.8

Module *(7.4)*: Aggregate crashes by severity level

The results regarding the crash frequencies were placed in the *results* worksheet after the *calccrsh* macro was run. The results included the annual number of crashes by severity type for arterial segments and signalized intersections as shown in Table 18.

Table 18 Aggregated crash frequencies for SR example

	Arterial Segments	Signalized Intersections	Total
Annual Number of PDO Crashes (crash/year)	44.2	21.1	65.3
Annual Number of Fatal/Injury Crashes (crash/year)	15.5	6.1	21.6

Module *(7.5)*: Calculate annual total cost of crashes

The annual total cost of crashes was found by multiplying the crash frequency by the unit cost of crashes by severity type. The unit costs of crashes were entered in the *cost_data* worksheet before the *calccrsh* macro was run. The unit costs of crashes were based on the values in the INDOT *Road Design Manual* (1994) after assuming three percent inflation per year to convert the unit crash costs to 1999 values. The unit cost of a pdo crash was $3,478, and the unit cost of a fatal/injury crash was $42,893.

The annual total cost of crashes was calculated by the *calccrsh* macro, and the results were placed in the *results* worksheet. The annual cost of crashes rounded to the nearest dollar was $1,152,774. These results are summarized in Table 19.

Table 19 Annual total cost of crashes for SR 26 example

	Arterial Segments	Signalized Intersections	Total
Annual Number of PDO Crashes (crash/year)	44.2	21.1	65.3
Annual Number of Fatal/Injury Crashes (crash/year)	15.5	6.1	21.6
Annual Cost of PDO Crashes ($/year)	$153,743.37	$73,542.18	$227,285.55
Annual Cost of Fatal/Injury crashes ($/year)	$663,439.45	$262,048.98	$925,488.43
Annual Total Cost of Crashes ($/year)	$817,182.82	$335,591.16	**$1,152,773.98**

Module (8): Predict Agency Costs

The agency costs also need to be estimated and incorporated into the analysis. In this example, annual maintenance costs of $100,000 were assumed. Because this alternative is based on the existing conditions, an initial construction cost of $0 was assumed.

Conversion of Costs to Present Worth

The operating costs, crash costs, and agency costs were converted to present worth using the *cost* worksheet of the *Cost.xls* spreadsheet. The input and results are given in the file named *Cost_sr26.xls*. The interest rate was selected as four percent and entered as 0.04 in Cell M1 of the *cost* worksheet. The initial construction cost was assumed to be $0. Thus, a value of 0 was entered in Cell M2 of the *cost* worksheet. The annual cost data were entered beginning in Row 4 of the *cost* worksheet. The annual operating costs for the year 1999 were calculated to be $14,185,908, and the annual crash costs for the year 1999 were calculated to be $1,152,774. These values were entered in Row 4 of the *cost* worksheet.

The operating costs and crash costs have been then estimated for 2018 (20-year lifetime) based on the predicted land development and changes in travel behavior of individuals. The traffic volumes for 2018 have been predicted using TRANPLAN (actually assumed for this example). Steps 6 through 8 have been repeated with the volumes anticipated for the year 2018. The following costs have been obtained:

(1) Operating costs = $18,670,234,
(2) Crash costs = $ 1,454,887.

The costs increase between 1999 and 2018 has been assumed linear since rather gradual development of the area around the considered road segment is anticipated. Other patterns of the costs growth may be assumed if reasonable. The growing operating costs and crash costs have been entered in columns B and C. The annual maintenance costs were assumed to be fixed each year at the level of $100,000. This value was entered for each year in Column D. Table 20 summarizes the input data for annual costs.

Table 20 Annual cost input data for SR 26 example

Year	Operating Costs	Crash Costs	Annual Agency Costs
1999	$14,185,908	$1,152,774	$100,000
2000	$14,421,925	$1,168,675	$100,000
2001	$14,657,942	$1,184,575	$100,000
2002	$14,893,959	$1,200,476	$100,000
2003	$15,129,976	$1,216,377	$100,000
2004	$15,365,993	$1,232,277	$100,000
2005	$15,602,011	$1,248,178	$100,000
2006	$15,838,028	$1,264,079	$100,000
2007	$16,074,045	$1,279,979	$100,000
2008	$16,310,062	$1,295,880	$100,000
2009	$16,546,079	$1,311,781	$100,000
2010	$16,782,097	$1,327,682	$100,000
2011	$17,018,114	$1,343,582	$100,000
2012	$17,254,131	$1,359,483	$100,000
2013	$17,490,148	$1,375,384	$100,000
2014	$17,726,165	$1,391,284	$100,000
2015	$17,962,182	$1,407,185	$100,000
2016	$18,198,200	$1,423,086	$100,000
2017	$18,434,217	$1,438,986	$100,000
2018	$18,670,234	$1,454,887	$100,000

After the cost data were entered, the *preswth* macro was run. This macro calculated the present worth of the agency costs, crash costs, and operating costs. The results were given in the *cost* worksheet. The results are summarized in Table 21.

Table 21 Present worth of costs for SR 26 example

Present Worth of Operating Costs=	$219,122,295
Present Worth of Crash Costs=	$17,440,530
Present Worth of User Costs=	$236,562,825
Present Worth of Agency Costs=	$1,359,033

Discussion of Example

The purpose of this example was to demonstrate the steps involved in calculating operating costs and crash costs. The example also shows the steps involved in calculating the present worth of operating costs, crash costs, and agency costs. The example used several software tools, including AAP, PASSER II-90, TRANSYT-7F, *Access_Delay* spreadsheet, *Safety* spreadsheet, and *Cost* spreadsheet. The example was based on existing conditions on SR 26 in Lafayette, Indiana. The same procedure could be applied to other access control alternatives. After the calculation of the present worth of operating costs, crash costs, and agency costs for each alternative, the alternatives could be compared to select the best access control alternative.

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APPENDIX A: Description of Access Delay Spreadsheet

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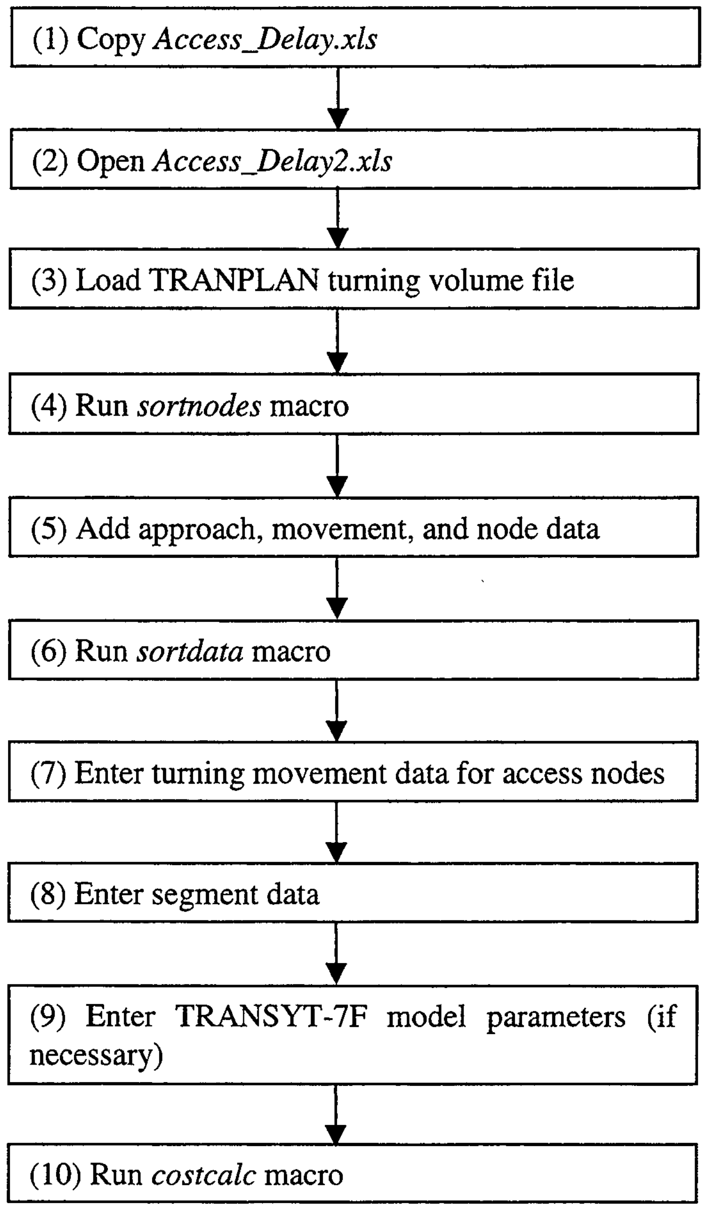


Figure A.1 Steps in using *Access_Delay* spreadsheet

The following terminology is used throughout this section when referring to network characteristics. The TRANPLAN network is a set of *nodes* and *links* between nodes. The nodes may represent *intersections* or *access nodes*. An *intersection* is a crossing of the arterial and side street or driveway that leads to a substantial change in traffic volume or cross-section characteristics on the arterial. For the calculation of operating costs, it is recommended that each signal in the impact area be represented as a separate intersection node because turning volumes are necessary input for the TRANSYT-7F model. An *access node* represents one or more access points on the arterial. An *access point* is defined as a crossing of the arterial street and local street or driveway (commercial or residential) that does not lead to a substantial change in traffic volume and cross-section characteristics of the arterial. An *arterial segment* consists of one or two *traffic directions* that connect intersections on the arterial. An *intersection movement* is a traffic stream at an intersection. An *access movement* is a traffic stream at an access node.

This section describes the use of the *Access_Delay.xls* spreadsheet. This spreadsheet sorts the turning volume data produced by TRANPLAN, separates records with intersection data from records access node data, performs delay calculations for access nodes, and calculates cruise speeds. Figure A.1 summarizes the steps involved in the use of the spreadsheet. While using the spreadsheet, help information for each input worksheet can be accessed by pressing **CTRL+SHIFT+H**. The following paragraphs describe these steps in greater detail.

(1) Copy *Access_Delay.xls*

The *Access_Delay.xls* file should be copied to another file named *Access_Delay2.xls* before any operations are performed. The *Access_Delay2.xls* spreadsheet is used in the operations and calculations while the original *Access_Delay.xls* should be kept in case the *Access_Delay2.xls* becomes corrupted. This precaution ensures that the worksheets can be easily restored in proper formats for use by the macros.

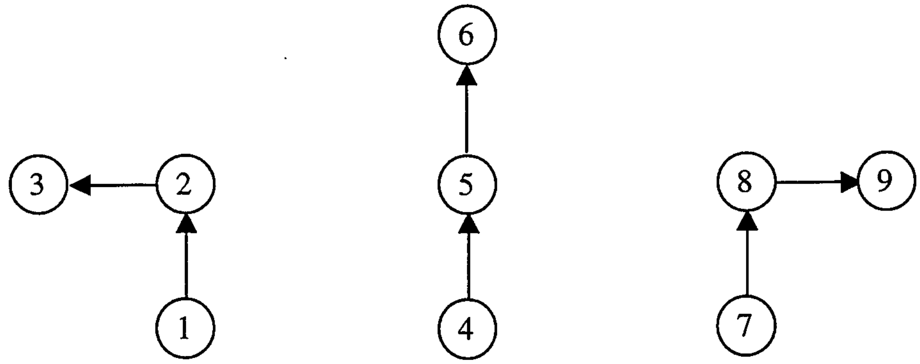
(2) Open *Access_Delay2.xls*

The copied file can be opened and used in the operations and calculations.

(3) Load TRANPLAN turning volume file

An output turning volume file from TRANPLAN is loaded into the *tpdata* worksheet of the *Access_Delay2.xls* workbook. The file should be loaded so that the first record is in row 1 and the first column is in column A. This operation can be done in the following steps:

1. Copy the text in the TRANPLAN output file,
2. Paste the text into Cell A1 of the *tpdata* worksheet,
3. Convert the text to columns by using the *Data/Text to Columns* command in Excel.



Left-Turn Movement
From Node: 1
Through Node: 2
To Node: 3

Through Movement
From Node: 4
Through Node: 5
To Node: 6

Right-Turn Movement
From Node: 7
Through Node: 8
To Node: 9

Figure A.2 Example turning movements

The TRANPLAN output data file contains the following information for each record: *from* node of turning movement, *through* node of turning movement, *to* node of turning movement, and turning volume for the movement. Example turning movements are shown in Figure A.2.

(4) Run *sortnodes* macro

The *sortnodes* macro sorts the data in the *tpdata* sheet by *through* node and *from* node. The macro may be run by using either of the following two methods:

A) Select *Tools/Macro/Macros* from the Excel menus, highlight *sortnodes*, and click on *Run*, or

B) Press the **CTRL+SHIFT+A** keys.

The *sortnodes* macro places the output in the *tpdata2* worksheet.

(5) Add approach, movement, and node data

The user adds the approach, movement, and node data to the *tpdata2* sheet. The input data requirements are given in Table A.1. These data should be added for each turning movement. For intersections outside the impact area, the only input data requirement is the node type (*o* = intersection outside impact area); the approach and movement data are not needed for intersections outside the impact area. The node type is used by the *sortdata* macro to separate the data for intersections from the data for the access nodes.

The correctness of the input is critical for the correctness of results. The codes must be put in small letters and be appropriate to the case. The macros do not check for the reasonableness of the input. Incorrect results can be produced without any warning or error messages. The user should carefully check input before running the macros.

Table A.1 Input data for *tpdata2* sheet

Column	Description	Values
E	Approach*	nb = northbound sb = southbound eb = eastbound wb = westbound
F	Movement*	l = left turn r = right turn t = through
G	Node type	ae = access node on east/west arterial an = access node on north/south arterial m = intersection in impact area o = intersection outside impact area

* Data not needed for node type *o*

(6) Run *sortdata* macro

Once the user enters the required input data in the *tpdata2* sheet, the *sortdata* macro is run. The macro may be run by using either of the following two methods:

A) Select *Tools/Macro/Macros* from the Excel menus, highlight *sortdata*, and click on *Run*, or

B) Press the **CTRL+SHIFT+B** keys.

This macro performs the following tasks:

1. Places the intersection data in the *transyt7f* sheet and places the access node data in the *accesscalc* sheet.
2. Adds TRANSYT-7F movement and link numbers to intersection movements.
3. Prepares access movement data for delay calculations.

The *sortdata* macro places the sorted data for intersections in the *transyt7f* sheet. The movements are sorted by *through* node number and standard TRANSYT-7F movement number. Table A.2 summarizes the standard movement numbering system in TRANSYT-7F.

The TRANSYT-7F link number is also provided in the *transyt7f* worksheet. The TRANSYT-7F link number given in the *transyt7f* assumes that the right and left-turn movements have exclusive lanes. For right or left-turn movements that share a lane with the through movement, the right or left-turn volume should be added to the through volume to obtain the total volume on the TRANSYT-7F link representing the through movement. The TRANSYT-7F link number for the right or left-turn movement is not used. The turning movement data in the *transyt7f* sheet can be used to help prepare input data for TRANSYT-7F.

Table A.2 Standard TRANSYT7-F numbering scheme
(Wallace et al., 1991)

Movement No.	Approach	Movement
1	nb	Through
2	nb	Left
3	sb	Through
4	sb	Left
5	eb	Through
6	eb	Left
7	wb	Through
8	wb	Left
9	nb	Right
10	sb	Right
11	eb	Right
12	wb	Right

The data for access nodes can be found in the *accesscalc* sheet. Each row in the *accesscalc* sheet corresponds to one turning movement at an access node. The movements have been sorted by *through* node and access movement.

(7) Enter turning movement data for access nodes

After the *sortdata* macro has been run, the user should add the input data required for the calculations of the delays at access nodes to the *accesscalc* sheet. In addition, the user may specify own model parameters to override the default values.

The data regarding arterial traffic direction, cruise speed, and number of lanes are entered in the rows that describe arterial through movements. The arterial traffic direction is specified by the ordered pair of intersections that represents one of the two traffic directions (eastbound and westbound for east/west arterials, or northbound and southbound for north/south arterials). The other required input data for the arterial through movements include cruise speed and one-way number of through lanes. In addition, the saturation flow rate and traffic distribution by lane may also be specified as optional input data to override the model parameters. If the traffic distribution is not specified, an equal distribution of traffic between lanes is assumed.

The calculation of delays requires that additional input data be entered for access movements. For the right-turn maneuvers, the following input data are needed: merging/diverging speed and merging/diverging distance. For the left-turn maneuver from the minor street, the merging model is used to calculate the delay of the arterial stream, and the merging speed and merging distance are needed as input. For the left-turn from the arterial, the presence of an exclusive left-turn lane is required as input. The presence of a left-turn lane determines the input data requirements for the arterial left-turn maneuver. When a left-turn lane is present, the diverging model is used to calculate the delay of the arterial stream, and the diverging speed and diverging distance are needed as input. When a left-turn lane is not present, the left-turn model is used to calculate the delay of the arterial stream, and the sight distance is required as input. If the user would like to override default parameter values for the minor streams, other values of the model parameters for minor streams may be specified as needed.

The data cells have been color coded to indicate whether the cell contains required input, optional input, or output as follows:

Red = required input data,
Purple = required input data if left-turn lane is not present,
Brown = required input data if left-turn lane is present,
Blue = optional input data to override default parameters for movements,
Green = output data.

The input data cells for movements with zero volume may be left blank. Table A.3 summarizes the input data columns.

The *accesscalc* worksheet provides some output regarding the delays of minor streams and delays of arterial streams caused by minor streams. A description of the output cells is given in Table A.4. Some of the output cells may contain the #VALUE! message until all of the required input data are entered.

(8) Enter segment data

The data for arterial segments in the impact area need to be entered in the *segment_data* sheet. These data are used in the calculations of cruise speeds and operating costs on the segments. Each row of the *segment_data* worksheet corresponds to a different segment and direction. The data should be entered for the arterial segments in the impact area that contain access nodes. The columns in the *segment_data* sheet are color coded as follows:

Red = required input data,
Green = output data.

The input data requirements for the *segment_data* worksheet are listed in Table A.5.

Table A.3 Input data for traffic movements in *accesscalc* sheet

Column	Description
I	Node number of the first intersection to specify arterial traffic direction
J	Node number of the second intersection to specify arterial traffic direction
K	Arterial speed in a given direction (km/hr)
L	Number of through lanes in one direction (1, 2, or 3)
M	Presence of arterial left-turn lane (y/n)
N	Sight distance of the left-turn queue (m)
O	Merging or diverging speed (km/hr)
P	Merging or diverging distance (m)
Q	Proportion of one-way traffic in lane 1 (right lane)
R	Proportion of one-way traffic in lane 2 (left lane on 2-lane connectors, center lane on 3-lane connectors)
S	Proportion of one-way traffic in lane 3 (left lane on 3-lane connectors)
T	Saturation flow rate (veh/sec/ln)
U	Lag time for merging maneuver (sec)
V	Critical time gap for lane changing for diverging or merging maneuver (sec)
W	Reaction time (sec)
X	Maximum allowable deceleration rate (m/sec^2)
Y	Acceleration rate of through vehicle (m/sec^2)
Z	Proportion of drivers who attempt to change lanes to avoid delay from merging or diverging
AA	Critical gap for minor stream maneuver (sec)
AB	Follow-up time for minor stream maneuver (sec)
AC	Speed reduction of through vehicle approaching left-turning vehicle (km/hr)
AD	Critical time gap for lane change for left-turn maneuver (sec)
AE	Proportion of drivers who will attempt to change lanes to avoid delay caused by left turn

Table A.4 Output data in columns in *accesscalc* sheet

Column	Description
AF	Model used to calculate delays (merging, diverging, arterial left turn)
AG	Delay of minor stream for movement (sec)
AH	Delay of arterial stream caused by minor stream (sec)
AI	Total delay of minor streams in one direction at access node (sec)
AJ	Total delay of arterial streams caused by minor streams in one direction at access node (sec)

Table A.5 Input data requirements for *segment_data* worksheet

Column	Description
A	Node number of the first intersection to specify arterial direction
B	Node number of the second intersection to specify arterial direction
C	Segment length (km)
D	Initial cruise speed on segment (km/hr)

(9) Enter TRANSYT-7F model parameters (if necessary)

If the user would like to override any of the default TRANSYT-7F parameters, these values may be entered in the *transyt7f_params* worksheet. The values should be entered in metric units. The parameters in this worksheet include those parameters needed for the calculation of the additional operating costs caused by access nodes. The default parameters can be overridden by specifying values in cells as given in Table A.6. If these cells are left blank, the default values in Column F are used to calculate the additional operating costs caused by access nodes. The default values are in metric units.

TRANSYT-7F provides default values of unit costs for 1987 (Cells E9, E10, and E11 in Table A.6). These values have to be adjusted for inflation between 1987 and the first year of the project. If the inflation rate during this period can be assumed uniform to all cost components, the default unit costs provided by TRANSYT-7F can be used with a proper inflation factor (Cell E12 in Table A.6). Alternatively, the user can input the unit cost appropriate for the first year of the project and set the inflation factor at one.

Table A.6 Cells for user-defined TRANSYT-7F parameter values in *transyt7f_params* worksheet

Cell	Description
E6	Model coefficient for fuel consumption model (A_{21FC})
E7	Model coefficient for fuel consumption model (A_{22FC})
E8	Model coefficient for fuel consumption model (A_{23FC})
E9	Cost of fuel consumption ($/lit)
E10	Unit cost of vehicle delay ($/1000 veh-hr)
E11	Unit cost of passenger time ($/pers-hr)
E12	Inflation factor to convert costs from base year of 1987
E13	Vehicle occupancy (persons/veh)

(10) Run *costcalc* macro

The *costcalc* macro performs calculations for the segments in the *segment_data* worksheet. The macro may be run by using either of the following two methods:

A) Select *Tools/Macro/Macros* from the Excel menus, highlight *costcalc*, and click on *Run*, or

B) Press the **CTRL+SHIFT+C** keys.

The macro calculates the total delay of minor streams and total delay of arterial streams caused by minor streams for each segment and direction. In addition, this macro calculates the revised cruise speed for each segment and direction. The macro also calculates the additional operating costs due to access nodes for each segment and direction. The output is given in the *segment_data* worksheet. The total additional operating cost due to access nodes is given in Cell W1 of the *segment_data* worksheet. Table A.7 summarizes the output data provided in the *segment_data* worksheet.

Table A.7 Output data in *segment_data* worksheet

Column	Description
G	Total delay of minor streams on segment and direction (sec)
H	Total delay of arterial streams caused by access streams on segment and direction (sec)
J	Average delay per arterial vehicle caused by minor streams (sec/veh)
K	Revised cruise speed on segment and direction (km/hr)
N	Additional operating costs due to access nodes on segment and direction
W (Row 1)	Total additional operating costs due to access nodes for all arterial segments in impact area

Alternative use of spreadsheet if turning volumes from TRANPLAN are not used

In some cases, the user may wish to define the turning volumes instead of using TRANPLAN. In this case, some modifications of the steps outlined previously allow for the calculation of the operating costs caused by access nodes. The following steps should be followed with user-defined turning volumes:

1. Copy *Access_Delay.xls* to *Access_Delay2.xls*.

2. Open *Access_Delay2.xls*.

3. Add turning volume data to *tpdata2* sheet. The required input data are listed in Table A.8. The user may optionally add the movement *from* node (Column A) and movement *to* node (Column C) if needed.

4. Run *sortalt* macro. The macro may be run by using either of the following two methods:

   A) Select *Tools/Macro/Macros* from the Excel menus, highlight *sortalt*, and click on *Run*, or
   B) Press the **CTRL+SHIFT+D** keys.

This macro sorts the movements in the *tpdata2* sheet by through node.

5. Run *sortdata* macro. The macro may be run by using either of the following two methods:

   A) Select *Tools/Macro/Macros* from the Excel menus, highlight *sortdata*, and click on *Run*, or
   B) Press the **CTRL+SHIFT+B** keys.

6. Enter turning movement data for access nodes.

7. Enter segment data.

8. Enter TRANSYT-7F model parameters (if necessary).

9. Run *costcalc* macro. The macro may be run by using either of the following two methods:

   A) Select *Tools/Macro/Macros* from the Excel menus, highlight *costcalc*, and click on *Run*, or
   B) Press the **CTRL+SHIFT+C** keys.

Table A.8 Required input data in *tpdata2* sheet for user-defined turning volumes

Column	Description
B	*Through* node of movement
D	Movement volume (vph)
E	Approach: nb = northbound sb = southbound eb = eastbound wb = westbound
F	Movement: l = left turn r = right turn t = through
G	Node type: ae = access node on east/west arterial an = access node on north/south arterial m = intersection in impact area o = intersection outside impact area

APPENDIX B: Description of Safety Spreadsheet

APPENDIX B: Description of Safety Spreadsheet

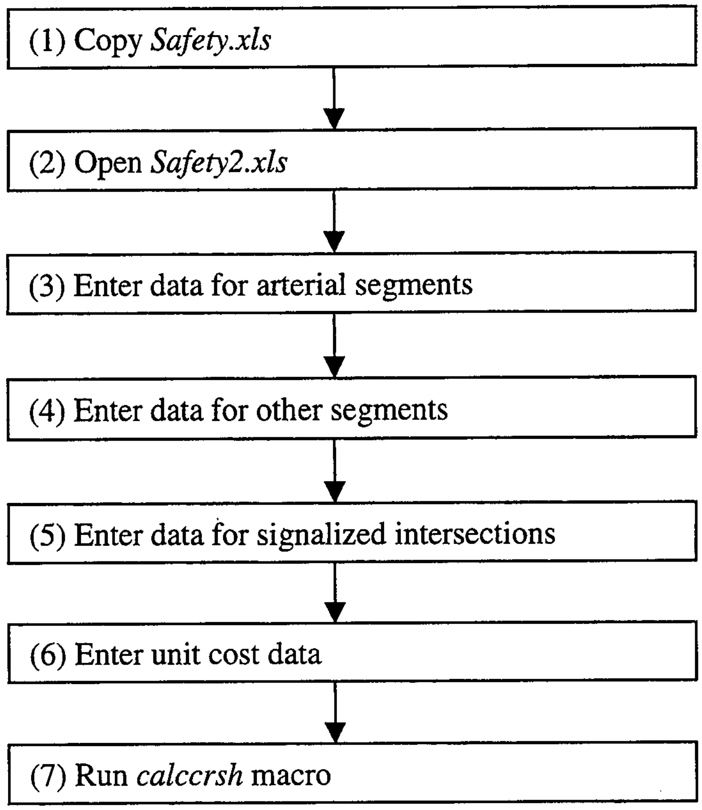


Figure B.1 Steps in using *Safety* spreadsheet

This section describes the use of the *Safety.xls* spreadsheet. This spreadsheet can be used to calculate annual crash frequencies for arterial segments, other segments in the impact area, and signalized intersections. The spreadsheet also aggregates the results for the impact area and calculates the annual cost of crashes. Figure B.1 summarizes the steps involved in the use of the spreadsheet. The following paragraphs describe these steps in greater detail.

(1) Copy *Safety.xls*

The *Safety.xls* spreadsheet should be copied to another file named *Safety2.xls* before any data are entered and before any operations are performed. The *Safety2.xls* spreadsheet is used in the operations and calculations. This step ensures that all worksheets in the workbook are in their proper formats for use by the macros.

(2) Open *Safety2.xls*

The copied file may be opened and used in the operations and calculations.

(3) Enter data for arterial segments

The input data for multi-lane arterial segments are entered in the *arterial_segments* worksheet. Each row of the worksheet, beginning with Row 6, corresponds to a different segment. The input data requirements are summarized in Table B.1. Column A of the *arterial_segments* worksheet may be used to enter a segment identifier or segment name for identification purposes.

Table B.1 Input data requirements for *arterial_segments* worksheet

Column	Description
B	Segment length (km)
C	AADT (thousands of vehicles per day)
D	Total number of access points (signalized and unsignalized) on segment
E	Number of access points on the segment that are signalized (The number of signalized intersections on the segment multiplied by 2)
F	Presence of outside shoulder (y = yes, n = no)
G	Presence of two-way left-turn lane (y = yes, n = no)
H	Presence of median with no openings between signals (y = yes, n = no)

(4) Enter data for other segments

The input data for other segments are entered in the *other_segments* worksheet. Each row of the worksheet, beginning with Row 6, corresponds to a different segment. The input data requirements are summarized in Table B.2. Column A of the *other_segments* worksheet may be used to enter a segment identifier or segment name for identification purposes.

Table B.2 Input data requirements for *other_segments* worksheet

Column	Description
B	Total number of through lanes on the segment
C	Segment length (km)
D	AADT (thousands of vehicles per day)

(5) Enter data for signalized intersections

The input data for signalized intersections are entered in the *signalized_intersections* worksheet. Each row of the worksheet beginning with Row 6 corresponds to a different signalized intersection. The input data requirements are summarized in Table B.3. Column A of the *signalized_intersections* worksheet may be used to enter an intersection identifier or intersection name for identification purposes.

Table B.3 Input data requirements for *signalized_intersections* worksheet

Column	Description
B	Average AADT in North/South direction (thousands of vehicles per day)
C	Average AADT in East/West direction (thousands of vehicles per day)
D	Number of intersection approaches (2, 3, or 4)
E	Number of approaches on which traffic is divided by a median
F	Number of left-turning movements forbidden on all approaches (0, 1, 2, 3, or 4)

(6) Enter unit cost data

The unit cost data should be entered in the *cost_data* worksheet. The unit cost of a pdo crash should be entered in Cell E3, and the unit cost of a fatal/injury crash should be entered in Cell E4. To account for inflation, the cost value should be entered in dollars corresponding to the first year of the project lifetime.

(7) Run *calccrsh* macro

After the input data are entered for arterial segments, other segments in the impact area, and signalized intersections, the *calccrsh* macro should be run. The macro can be run using either of the following two methods:

A) Select *Tools/Macro/Macros* from the Excel menus, highlight *calccrsh*, and click on *Run*, or

B) Press the **SHIFT+CTRL+Z** keys.

This macro calculates the annual crash frequency for each segment or intersection and aggregates the results for the impact area. The aggregate results for the impact area are given in the *results* worksheet. The results given in the *results* worksheet include the frequency of crashes by severity type and the annual cost of crashes for the impact area. Additional results are placed in the worksheets: *arterial_segments*, *other_segments*, and *signalized_intersections*.

1. The *arterial_segments* worksheet contains the output for each arterial segment. For each segment, the frequency of pdo crashes is given in Column N, and the frequency of fatal/injury crashes is given in Column O. The total frequency of pdo crashes on all arterial segments is given in Cell X1, and the total frequency of fatal/injury crashes on all arterial segments is given in Cell X2.

2. The *other_segments* worksheet contains the output for other segments in the impact area. For each segment, the frequency of pdo crashes is given in Column E, and the frequency of fatal/injury crashes is given in Column F. The total frequency of pdo crashes on other segments is given in Cell N1, and the total frequency of fatal/injury crashes on other segments is given in Cell N2.

3. The *signalized_intersections* worksheet contains the output for each signalized intersection. For each intersection, the frequency of pdo crashes is given in Column G, and the frequency of fatal/injury crashes is given in Column H. The total frequency of pdo crashes at signalized intersections is given in Cell P1, and the total frequency of fatal/injury crashes at signalized intersections is given in Cell P2.

APPENDIX C: Description of Cost Spreadsheet

APPENDIX C: Description of Cost Spreadsheet

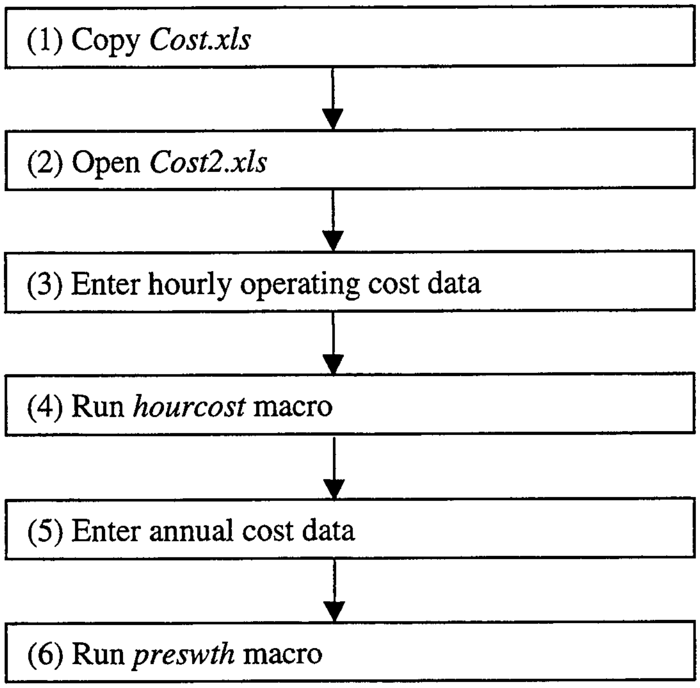


Figure C.1 Steps in using *Cost* spreadsheet

This section describes the use of the *Cost.xls* spreadsheet. This spreadsheet performs two tasks:

1. Convert hourly operating costs to daily and annual operating costs,
2. Convert annual operating costs, annual crash costs, and annual agency costs to present worth.

Figure C.1 summarizes the steps involved in the use of the spreadsheet. The following paragraphs describe these steps in greater detail.

(1) Copy *Cost.xls*

The *Cost.xls* spreadsheet should be copied to another file named *Cost2.xls* before any data are entered and before any operations are performed. The *Cost2.xls* spreadsheet is used in the operations and calculations. This step ensures that all worksheets in the workbook are in their proper formats for use by the macros.

(2) Open *Cost2.xls*

The copied file may be opened and used in the operations and calculations.

(3) Enter hourly operating cost data

The data for the hourly operating costs are entered in the *hourly_costs* worksheet. This worksheet assumes one representative day for each representative year. The number of days per year used to convert the daily operating costs to annual operating costs should be entered in Cell C8. Each column of the worksheet beginning with column C corresponds to a different year. The data requirements for each representative year are similar. The year should be entered in Row 11. Data are then entered for each hourly period beginning with Row 12. For each hourly period, the hourly operating costs and the number of hours represented by the hourly period are needed as input. The user has the flexibility to select any number of representative hours from one to 24. The user may also select any number of representative years.

(4) Run *hourcost* macro

The *hourcost* macro performs calculations of daily and annual operating costs. The macro can be run using either of the following two methods:

A) Select *Tools/Macro/Macros* from the Excel menus, highlight *hourcost*, and click on *Run*, or
B) Press the **SHIFT+CTRL+E** keys.

The output for each representative year is placed in Rows 62 to 64 in the column containing the data for the year. The output is described in Table C.1.

Table C.1 Output data in *hourly_costs* worksheet

Row	Description
62	Year
63	Daily operating costs
64	Annual operating costs

(5) Enter annual cost data

The cost data for each year are entered in the *cost* worksheet. The input data requirements are summarized in Table C.2. The interest rate should be entered as a decimal in Cell M1. The initial construction cost of the project should be entered in Cell M2. The spreadsheet assumes that the initial construction cost occurs at the beginning of the first year of the project lifetime. The operating costs, crash costs, and annual agency costs for each year should be entered. Each row of the spreadsheet corresponds to a given year. The spreadsheet assumes that the annual costs occur at the end of a given year. The cost data for the first year of the project lifetime should be entered in Row 4. The cost data can be entered as follows:

1. Enter cost data for each representative year,
2. Enter cost data for other years by assuming a pattern in annual costs.

The user has the flexibility to determine how cost data for other years are calculated based on the costs for the representative years. For example, the cost data for a representative mid-year could be entered, and the costs for the other years could be assumed to be equal to the costs for the mid-year. Another alternative would be to use the first and last years of the project lifetime as representative years and use linear interpolation to calculate the costs for other years. To account for inflation, the cost values should be entered in base year dollars where the base year is the first year of the project lifetime.

Table C.2 Input data for *cost* worksheet

Column	Description
A	Year
B	Future value of operating costs
C	Future value of crash costs
D	Future value of agency costs
M (row 1)	Interest rate (decimal)
M (row 2)	Initial construction cost of project

(4) Run *preswth* macro

The *preswth* macro calculates the present worth of the operating costs, crash costs, user costs, and agency costs. The output is given in the *cost* worksheet. Table C.3 summarizes the output.

Table C.3 Output data for *cost* worksheet

Cell	Description
M3	Present worth of operating costs
M4	Present worth of crash costs
M5	Present worth of user costs
M6	Present worth of agency costs

The macro can be run using either of the following sequence of steps:

A) Select *Tools/Macro/Macros* from the Excel menus, highlight *preswth*, and click on *Run*, or

B) Press the **SHIFT+CTRL+P** keys.