Sketch Planning Process for Urban Isolated Signalized Intersection Improvements

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A simple and practical procedure involving operational, economic, and safety impact considerations is developed for evaluating improvements to isolated signalized intersections. The result is a step-by-step technique that allows planners and engineers to compare the benefits and costs of improvements to isolated signalized intersections. The procedure (or sketch planning process) was synthesized from the literature and from a survey of current practices in Florida at city, county, and state levels. It incorporates benefit/cost techniques and the Signal Operations Analysis Package (SOAP), thus improving on previous methods. Factors that were incorporated into the process include right-of-way needs, fuel consumption, benefit/cost ratio, staged improvement options, and safety considerations. The average delay and level of service attributable to alternative staged improvement plans during the planning horizon is exhibited graphically in a case study, illustrating the adaptability of the system in achieving an acceptable level of service at a specified future date. The case study shows that the sketch planning process developed through this research can be applied to almost any urban isolated signalized intersection, providing that accurate input data are available and that practical results can be generated.

The objectives of this study were to develop a sketch planning process (SPP) that could be used by planners and design engineers to

- Evaluate the operational impacts of various improvement alternatives on the performance of urban isolated signalized intersections (ISIs),
- Facilitate appropriate right-of-way acquisition and stage improvements of ISIs to meet standards,
- Optimize the benefit/cost ratio of intersection improvement,
- Coordinate the SPP with the application of the Signal Operations Analysis Package (SOAP) and 1985 *Highway Capacity Manual* (HCM),
- Conduct a survey of current methods used to improve urban intersections by the Florida Department of Transportation (FDOT) and by selected counties and cities, and
- Develop a case study of an existing hazardous intersection in the city of Gainesville, Florida, to demonstrate the use of the SPP with a generic example.

The SPP for urban ISIs and its application were developed in response to a request from FDOT in support of long-range planning activities. Florida is experiencing rapid population growth. As a result, a high number of ISIs are operating below acceptable standards. To justify capital expenditures for intersection improvement, benefits must exceed costs. This is particularly true in cases for which improvement funds are limited or when a specific project may be controversial. The application of an SPP could identify critical intersections and would generate alternatives, with average delay as level-of-service (LOS) values versus time. The results would enable local transportation officials to identify the alternatives that could be planned for staged improvements over a specified time.

The variables that are used in the description and analysis of intersection performance are level of service, volume capacity (*V/C*) ratios, saturation flow rates, delay, peak hour volume, headway and so on. Most of these are factors relevant to this research, and they have subsequently been incorporated into the SPP.

In planning improvements to intersections, the SPP takes into account three basic types of consideration: (a) operational, (b) safety, and (c) economic. SOAP was developed at the University of Florida as an operational tool and was incorporated into the SPP for the signal timing optimization and benefit-cost evaluation of ISIs in this research effort.

Sets of questionnaires that covered concepts relevant to this research were developed for a survey of current practice as part of an attempt to improve ISIs within cities, counties, and the state of Florida. Fifteen cities, counties, and districts in Florida were selected, and officials there were interviewed. Survey results showed that there was no step-by-step procedure by which engineers could determine cost-efficient intersection improvements. As a matter of practice, most decisions were being made by engineering judgment and accident records. Consequently the SPP, based on the principle of benefit-cost analysis and signal optimization, was developed as an aid.

The SPP for the improvement of ISIs is a systematic technique that allows the analyst to input existing operational, safety, and intersection geometry data and then estimate future conditions, use SOAP (*1*) and benefit-cost technique to compare alternatives, identify solutions to implement staged construction options to make best use of the available funds, and determine the future right-of-way needs.

The application of the SPP was demonstrated in a case study of a hazardous intersection in Gainesville, Florida. The results of the case study showed that SPP could generate practical results when applied to a typical ISI for which accurate input data are available. The results of the case study allowed local transportation officials in Gainesville to judge the conditions

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under which intersection improvement would be most economically viable (level of service versus time). The improvements can be staged for implementation with specified future timing within the planning horizon.

FORMULATION OF THE SKETCH PLANNING PROCESS

The systematic planning process developed in this research was designed to improve urban isolated signalized intersections. With slight modifications, it can also be applied to other types of urban intersections. It is a systematic process (Figure 1) in which each step requires an input and then a computation or decision, or a combination of the two.

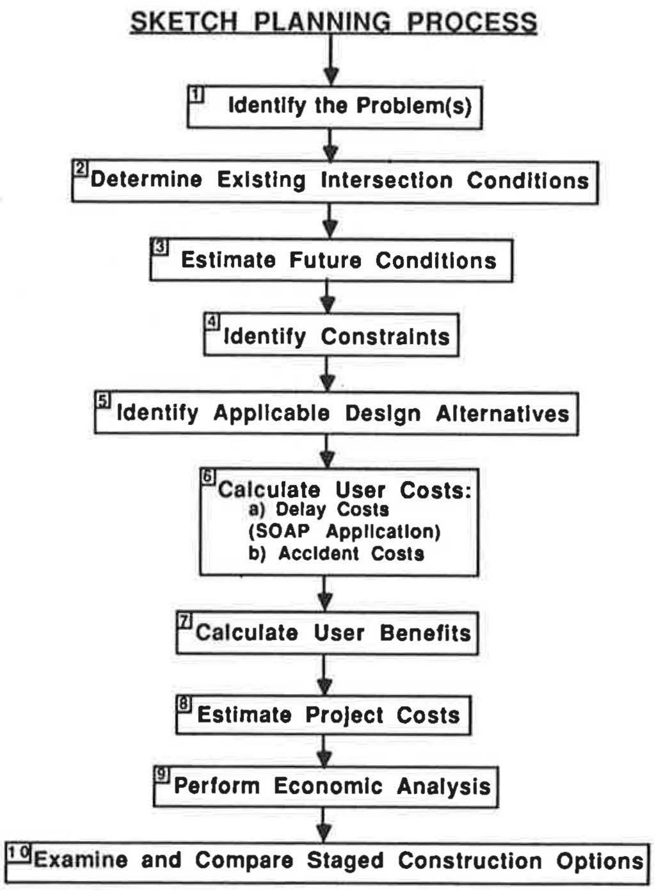

FIGURE 1 Formulation of a systematic planning process to improve urban isolated signalized intersections.

Step 1: Problem Identification

In Step 1 of the SPP (Figure 1) the problems must be identified. Ordinarily, intersection improvements are needed for four basic reasons: (a) problems with signal operations (excessive delay, congestion), (b) safety problems (high rate of property damage, injury, or fatal accidents), (c) occurrence of land development (establishment of new facilities or businesses in the vicinity of the intersection), and (d) need for additional right-of-way to sustain the intersection capacity (excessive delay and fuel consumption, among other problems). It is essential for the analyst to identify any anticipated future problems that are likely to occur within the planning horizon, as well as any existing problems. Periodic traffic volume counts and accident record summaries will help identify existing and future sources of difficulty.

Step 2: Determination of Existing Intersection Conditions

The second step involves the documentation of existing conditions, including traffic counts, and evaluation of available data. The existing intersection conditions are classified into three main categories:

- Geometrics and traffic control, including
  - Plan of the entire intersection layout;
  - Pavement and lane widths;
  - Median geometry (both length and width);
  - Extent of curb parking, with measurements;
  - Right-of-way requirements, with extent of development in adjacent areas that may need to be acquired; and
  - Speed limit.
- Operational conditions, including
  - Traffic volume counts, conducted hourly or in multiples of 15 minutes throughout the prime use hours of a representative day;
  - Number of lanes or capacity of every traffic movement for all directions (SOAP can accommodate both values);
  - Percentage of heavy vehicles (trucks) in each traffic movement for all directions; and
  - Existing phasing and signal timing.
- Safety conditions, including
  - Accident rate (accidents per million vehicles per year);
  - Accident severity distribution (property damage, injury, fatal); and
  - Accident type (rear end, head-on, sideswipe, etc.).

Step 3: Estimation of Future Conditions

The third step of the SPP (Figure 1) is to estimate the future condition of the intersections. Consideration of future traffic movements is required in determining the optimum improvement plan over the planning horizon. The future travel demand can be estimated as a factor of the type of development in the area, population characteristics, and other socioeconomic factors. The growth rate technique is a simplified procedure that was used in the case study to estimate the annual traffic growth rate over the planning horizon. In some urban areas, future development scenarios are reasonably predictable and traffic demand can be forecast with some degree of accuracy. In such areas, planning analyses provide reasonable prediction of trip generation, trip distribution, modal split, and traffic assignment. Assistance from a local planning agency may increase the accuracy and reliability of future projections. Common practice involves a planning period of 20 years. However, whenever possible, better long-term results are obtained by estimating the traffic movement that will occur at the time the area is fully developed, regardless of when this is expected to occur.

At an urban intersection it is usual to expect different rates of traffic volume increase for each approach or even for each traffic movement. This predictable divergence among future traffic movement characteristics can cause important repercussions in the planning process. SOAP allows the user to assign an appropriate growth rate for each traffic movement. When growth is rapid, erratic, or both, frequent future reanalysis of the intersection with the latest available information is recommended.

Projected future conditions over the planning period should include estimates of (a) annual traffic growth rate, (b) proportion of heavy vehicles in the traffic stream, and (c) safety conditions. In an analysis of alternative improvement options for a given intersection, it sometimes happens that no single improvement alternative will last for the entire planning period. In such cases, alternative improvements can be analyzed for an optimum combination. In other words, a series of improvement alternatives can be planned and scheduled for sequential construction at suitable time intervals spanning the planning horizon.

Step 4: Identification of Constraints

It is not unusual to find that only a few alternative solutions are available for dealing with urban intersection improvement projects. For example, as the cost escalates for additional right-of-way, the designers must decide whether to purchase additional road area or to employ other solutions, such as narrowing the existing lanes, removing on-street parking, and so on. The sketch planning process can help designers determine the break-even point for purchasing the added right-of-way needed to improve the intersection condition (this is shown in Figure 5 and illustrated in the case study). In addition, designers also can consider purchasing or otherwise reserving additional strips of right-of-way to be used for staged development of the intersection later within the planning period.

Step 5: Identification of Applicable Design Alternatives

The planner should identify improvement alternatives that are safe and applicable under physical, operational, and economic constraints. Possible alternatives for improving urban at-grade intersections are

- Installation of exclusive turn lanes,
- Upgrading traffic control system and signal coordination,
- Signal timing optimization,
- Addition of through lanes,
- Access control,
- Turning radius treatment,
- Installation of traffic islands, and
- Improvement of sight distance and angle.

For the case study, only signalization improvements and installation of exclusive turn lanes are considered.

Once all the existing and future intersection conditions have been determined, SOAP can be run for two time frames—once for the base year (Year 0) and once for the final year (Year 20)—to determine the operational performance of the intersection over the planning horizon. (It must be recognized that a higher degree of accuracy would result from using shorter intervals of 5, 10, 15, and 20 years.) The measures of effectiveness (delay, percentage stops, fuel consumption, queue length, and V/C ratio) and the results of the left-turn capacity analysis can help evaluate the need for improvement.

Step 6: Calculation of User Costs

The next step, once the applicable design alternatives have been identified, is to calculate the user costs associated with each one of these alternatives. The user costs are divided into two categories: (a) delay costs and (b) accident costs.

Delay Costs (Step 6a)

Delay costs consist of additional time and operating costs due to deceleration prior to a stop and acceleration after a stop at an intersection, plus the cost of idling while stopped. Operating costs include fuel and oil consumption, tire wear, maintenance, depreciation, and other related costs. In the user cost calculations, the operating costs due to deceleration before and acceleration after stops will be referred to as running costs, and those that are incurred while stopped will be called idling costs. Intersection delay costs depend primarily on the type and configuration of the traffic control devices employed, the level of traffic on the section, and the speed at which the signal is approached (2). After the procedures given in the AASHTO manual and two other studies conducted by the California Department of Transportation (2–4) were reviewed, a combined value (for cars and trucks) of $5.50 per vehicle hour was selected for use in the case study.

The running and idling cost factors are obtained from the Federal Highway Administration (FHWA) report Vehicle Operating Costs, Fuel Consumption, Pavement Type and Condition Factors (5). These operating cost factors reflect the 1980 values for passenger cars and must be updated to the year of analysis. The updating procedure outlined in the AASHTO manual (2) is used to convert the 1980 values into 1987 values. The updating multiplier equations for running and idling costs are

$$M_r = c_g\mathrm{CPI}_g + c_o\mathrm{CPI}_o + c_m\mathrm{CPI}_m + c_t\mathrm{CPI}_t + c_d\mathrm{CPI}_d \quad (1)$$

$$M_i = c_g\mathrm{CPI}_g + c_o\mathrm{CPI}_o + c_m\mathrm{CPI}_m + c_d\mathrm{CPI}_d \quad (2)$$

where

M_r = multiplier for updating running costs due to speed change cycles;
M_i = multiplier for updating idling costs;
c_g, c_o, c_m, c_t, c_d = coefficients of multiplier equation for gasoline, oil, maintenance and repair, tires, and depreciation [calculated as the proportion of total cost contributed by a cost item (see Table 1) divided by 1980 Consumer Price Index (see Table 2) for that item];
CPI_g = Consumer Price Index, gasoline;
CPI_o = Consumer Price Index, motor oil;

CPI_m = Consumer Price Index, maintenance and repair;
CPI_t = Consumer Price Index, tires; and
CPI_d = Consumer Price Index, new cars.

TABLE 1 PROPORTIONS OF VEHICLE OPERATING COSTS

	Cost (as percent of total cost)	
Item	Running	Idling
Gasoline	70	85
Motor oil	1	1
Maintenance and repair	3	5
Tires	15	–
Depreciation	11	9
	100	100

TABLE 2 1980 AND 1987 CONSUMER PRICE INDEXES

Item	December 1980	February 1987
Gasoline	373.3	287.5
Motor oil[a]	138.8	154.9
Maintenance and repair	280.1	373.0
Tires	182.1	171.1
New cars	184.5	230.2

NOTE: 1967 = 100, unless otherwise noted.
[a]December 1977 = 100.

The calculation of coefficients of the multiplier equations are shown in Tables 3 and 4. When the values in these tables are used, the multiplier equations to update 1980 running idling cost factors become

$$M_r = 0.0019\ CPI_g + 0.0001\ CPI_o + 0.0001\ CPI_m + 0.0008\ CPI_t + 0.0006\ CPI_d \qquad (3)$$

$$M_i = 0.0023\ CPI_g + 0.0001\ CPI_o + 0.0002\ CPI_m + 0.0005\ CPI_d \qquad (4)$$

Equations 3 and 4 can be used to update the 1980 running and idling cost factors. If the proportions given in Table 1 change significantly due to a differential rate of inflation, the multiplier coefficients have to be recalculated on the basis of new proportions. The 1987 Consumer Price Indexes are applied to Equations 3 and 4 to determine 1987 running and idling cost factors:

$$M_r = 0.0019(287.5) + 0.0001(154.9) + 0.0001(373.0) + 0.0008(171.1) + 0.0006(230.2) = 0.87 \qquad (5)$$

$$M_i = 0.0023(287.5) + 0.0001(154.9) + 0.0002(373.0) + 0.0005(230.2) = 0.87 \qquad (6)$$

Once the user cost factors have been determined and updated, the annual delay costs can then be calculated. The user cost equations require total intersection delay and

TABLE 3 COEFFICIENTS OF THE MULTIPLIER FORMULA TO UPDATE 1980 RUNNING COST FACTORS

Item	Coefficient
Gasoline	70%/373.3 = 0.0019
Motor oil	1%/138.8 = 0.0001
Maintenance and repair	3%/280.1 = 0.0001
Tires	15%/182.1 = 0.0008
Depreciation	11%/184.5 = 0.0006

TABLE 4 COEFFICIENTS OF THE MULTIPLIER FORMULA TO UPDATE 1980 IDLING COST FACTORS

Item	Coefficient
Gasoline	85%/373.3 = 0.0023
Motor oil	1%/138.8 = 0.0001
Maintenance and repair	5%/280.1 = 0.0002
Depreciation	9%/184.5 = 0.0005

percentage of stops values, which can be obtained from SOAP analysis (other computer models also can be used to determine delay). SOAP should be run twice for each alternative, once with the existing traffic volumes and a second time with the estimated future traffic volumes. To convert daily delay cost values into annual values, 365 days/yr has been assumed. (It should be noted that the volumes used are usually weekday volumes.) In the areas for which traffic demand drops significantly during certain periods of the year, a lower value can be used for the length of time during which the low traffic demand occurs. The annual user costs due to delay at an intersection are calculated as shown below.

Travel Time Cost

$$C_t = 365\ u_t D h_t \qquad (7)$$

where

C_t = travel time cost (\$/yr),
u_t = unit value of travel time (\$/vehicle hour),
D = total intersection delay (vehicle hour/day), and
h_t = adjustment factor for heavy vehicles.

Running Cost Due to Speed Change and Stopping

$$C_r = 365\ (VS/1{,}000)\ (f_r M_r) h_r \qquad (8)$$

where

C_r = running cost due to speed change and stopping (\$/yr),
V = traffic volume (vehicles/day),
S = percentage of stops,
f_r = running cost factor (\$/1,000 cycles),

M_r = running cost multiplier for updating 1980 values, and
h_r = adjustment factor for heavy vehicles.

Idling Cost

$$C_i = 365\ D\ (f_i M_i) h_i \qquad (9)$$

where

C_i = idling cost ($/yr),
D = total intersection delay (vehicle hours/day),
f_i = idling cost factor ($/vehicle hour),
M_i = idling cost multiplier for updating 1980 values, and
h_i = adjustment factor for heavy vehicles.

Then the total delay cost (DC) is calculated as the summation of total travel time cost, running cost due to speed change and stopping, and total idling cost:

$$\text{DC} = C_t + C_r + C_i \qquad (10)$$

Accident Costs (Step 6b)

Costs of accidents are the product of estimated accident rates and unit costs of accidents by degree of severity. The procedure for accident cost calculations is shown in Figure 2. Many studies and manuals are available (*2, 6–10*). The analyst is advised to use a reference that is based on statistical data measured in the particular region or state in which the subject intersection is located. Otherwise, a source derived from a large sample localized to describe the subject intersection adequately may be employed. A number of these references give estimated accident reductions in dollars. Here too the analyst should carefully examine the unit accident costs used and then judge the validity of their application to a subject intersection. Otherwise, the estimation of an accident cost in a noncomprehensive manner is speculative and creates questions concerning the accuracy and credibility of the analysis.

Step 7: Calculation of User Benefits

Benefits due to intersection improvements include two major components: user benefits and signal operating benefits. User benefits are calculated as the difference of total user costs associated with existing and improved conditions (*11*), as follows:

$$\text{UB}_i = \text{UC}_0 - \text{UC}_i \qquad (11)$$

where

UB_i = total user benefits for alternative i ($/yr),

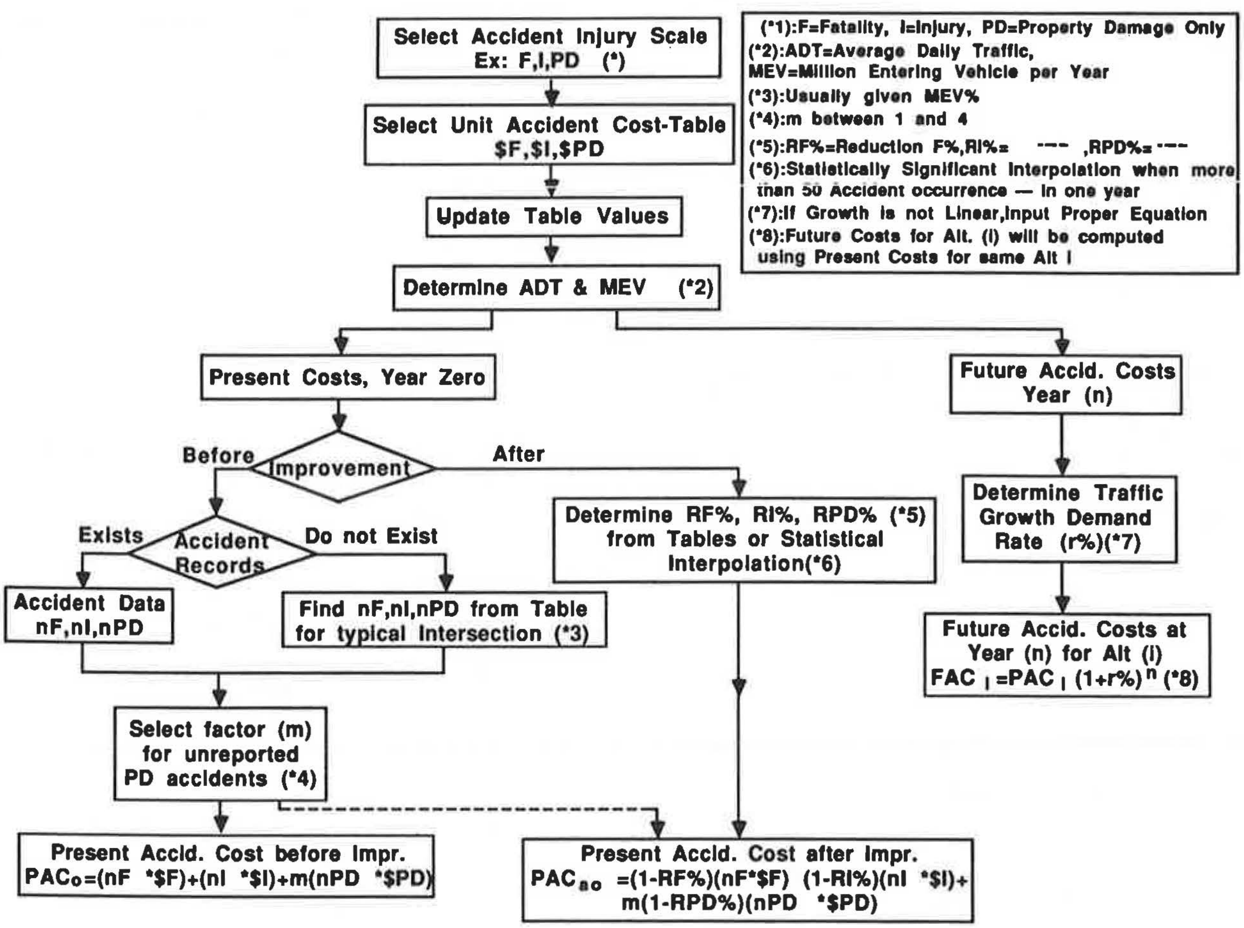

FIGURE 2 Systematic process to formulate accident cost calculation.

UC_0 = total user costs for alternative 0 (the base condition; \$/yr), and
UC_i = total user costs for alternative *i* (\$/yr).

The total user costs are calculated by using the following equation:

$$UC_i = DC_i + AC_i \quad (12)$$

where

DC_i = total delay costs (time, running, and idling) for alternative *i* (\$/yr), and
AC_i = total accident costs for alternative *i* (\$/yr).

The signal operating benefits or disbenefits are calculated similarly, as follows:

$$OB_i = OC_0 - OC_i \quad (13)$$

where

OC_0 = current signal operating costs (\$/yr), and
OC_i = signal operating costs due to alternative *i* (\$/yr).

Then total benefits are obtained by adding the two components:

$$B_i = UB_i + OB_i \quad (14)$$

Step 8: Estimation of Project Costs

The project costs can be divided into investment costs (construction, planning and design, right-of-way acquisition and preparation) and annual costs (maintenance and operations).

Investment Costs

An appropriate estimate for the planning and design expenses would be about 15 percent of construction costs. The right-of-way acquisition costs include the purchase price, legal, title, and other fees (2). The construction costs include labor, materials, equipment, and contractor overhead.

Annual Costs

Annual costs include maintenance costs (patching, striping, painting, etc.), replacements (e.g., pavement, resurfacing), and equipment upkeep. Operating costs include utility charges and traffic surveillance. The signal operating expenses are not included in project costs. Instead, they are considered benefits or disbenefits in the benefit/cost equation.

Step 9: Economic Analysis

The benefit/cost ratio method has been found to be an appropriate tool for the economic analysis of urban intersection improvements. The economic analysis includes (a) determination of present value of benefits (PVB) and present value of costs (PVC), as well as (b) benefit-cost analysis.

Determination of Present Values

Benefits and costs that occur at different times throughout the analysis period can be discounted with an appropriate interest rate to obtain present values. In the case study, a discount rate of 7 percent was used.

The steps in the AASHTO manual (2) for calculating annual benefits and costs are well-documented. First, estimate the rate of growth of annual value (assuming continuous compounding) by

$$r = \ln(a)/Y \quad (15)$$

where

r = rate of growth of annual value (continuous compounding);
a = ratio of future benefits (final year) to early benefits (base year) or the ratio of Year 20 benefits to Year 0 benefits; and
Y = period of the estimate (20 years).

Next, calculate the present worth factor by

$$f = [\exp(r-i)n - 1]/(r - i) \quad (16)$$

where

f = present worth factor,
i = discount rate (interest rate), and
n = analysis period (20 years).

Then the present value is calculated as

$$PV = f * \text{first year's (Year 0) benefits} \quad (17)$$

The use of the present value procedure is limited to determination of the present value of a stream of values that increase or decrease at an equal annual rate. For this reason, this simplified procedure cannot be used to determine the present value of isolated lump sum expenditures for project costs because the project costs occur irregularly over the planning period. In this case, the analyst can estimate these lump sum costs and the year in which the expenditure takes place. Then the future lump sum can be discounted back to the present value at the assumed interest rate to determine the present value of all project costs.

Benefit-Cost Analysis

After the present values of benefits and costs are calculated, the incremental benefit-cost analysis can be performed to select the optimum improvement alternative. The flowchart of the procedure that will be used for this purpose is shown in Figure 3.

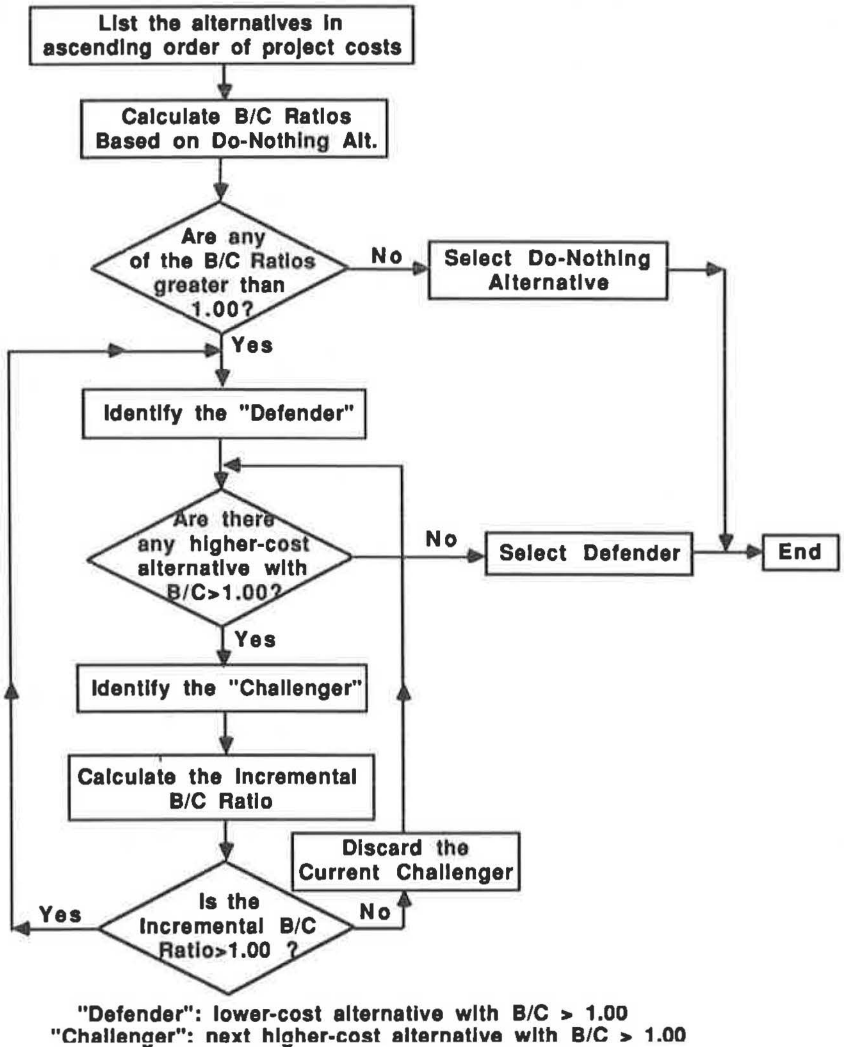

FIGURE 3 Incremental benefit cost procedure.

Step 10: Examination of Staged Construction Options

At this step, the analyst will have to consider whether to implement the selected alternative immediately or whether to implement a less costly alternative now and the higher-cost alternative later. The LOS criterion can be utilized for this purpose and will measure how well the intersection will operate after the improvement until the end of the planning horizon.

CASE STUDY

To illustrate the practical use of the SPP, an existing intersection was analyzed. The intersection used was southwest 34th Street and southwest 2nd Avenue in Gainesville, Florida. This intersection experienced the highest accident rate in the city during 1986 and 1987.

The SPP step-by-step procedure applied and the intersection signalization (Figure 4) used in this case study are assumed to have the following characteristics. Three pretimed dials were in use:

- Dial 1 (90 sec per cycle) from 9:00 a.m. to 4:00 p.m. on weekdays,
- Dial 2 (110 sec per cycle) from 7:00 a.m. to 9:00 a.m. on weekdays,
- Dial 3 (110 sec per cycle) from 4:00 p.m. to 6:00 p.m. on weekdays.

A traffic count was taken in multiples of 15 min over the prime use hours of a representative day (7:00 a.m. to 6:00 p.m.). Five different alternatives to the existing conditions were selected for the purpose of analysis:

1. Add a northbound left-turn lane;
2. Change signal control of an existing condition from pretimed to actuated;
3. Same as alternative 2, but with an added northbound (NB) left-turn lane;
4. Same as alternative 2, but with an added westbound (WB) left-turn lane; and
5. Same as alternative 2, but with added NB and WB left-turn lanes.

The speed limit was 45 mph north-south (N-S), 35 mph east-west (E-W).

All data were input to SOAP and run to determine existing intersection measures of effectiveness. These measures include

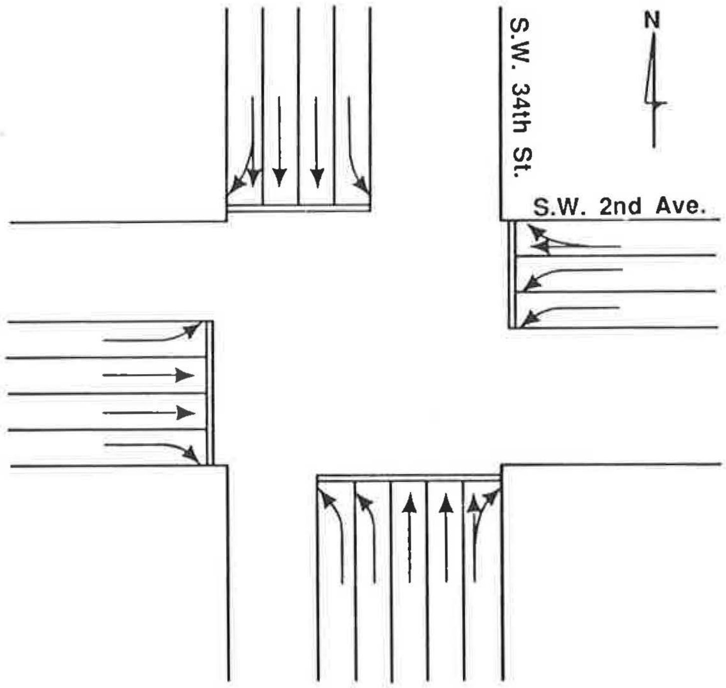

FIGURE 4 Alternative 5, southwest 34th Street and Second Avenue, Gainesville, Florida. Signal changed from actuated to pretimed; NB and WB left lanes added.

delay values, percentage of vehicles stopped, excess fuel consumption, maximum queue lengths, and volume to capacity ratio (V/C). Similar runs were performed for all the alternatives, and Table 5 presents SOAP output for Alternative 5. It must be emphasized that the projection of benefits 20 years into the future (used in the case study) may require more speculation and assumptions than can be justified. This problem can be reduced by using shorter intervals of 5, 10, 15, and 20 years.

Step 6 of the SPP was to calculate the user costs (Table 6). Unit value of travel time is assumed to be \$5.50/vehicle hour for both passenger cars and heavy vehicles; therefore, an adjustment for heavy vehicles is not necessary (i.e., $h = 1.0$).

Running cost factors for N-S and E-W approaches are obtained from reports by the Federal Highway Administration (*5*) and Ismart (*12*) and then weighted by traffic volumes:

	N-S	*E-W*
Speed limit (mph)	45	35
Running cost factor (\$/1,000 cycles)	25.8	17.5
Traffic volume (vehicles/day)	10,912	6,120

The weighted running cost factor is then found to be

$$f = [(10{,}912 * 25.8) + (6{,}120 * 17.5)]/17{,}032 = \$22.8/1{,}000 \text{ cycles}$$

For all user cost factors, an annual rate of increase of 5 percent was found to be appropriate to account for the effect of inflation.

Accident costs were calculated on the basis of historical accident records provided by the city of Gainesville. Accident cost calculations were based on the procedure described earlier. Table 7 presents the total benefits.

The project cost was estimated in Step 8 of the SPP. The cost of installing a new signal (\$14,000) is the average of the values obtained from several Florida traffic departments.

To determine the amount of right-of-way to be acquired, the required length and width of the left-turn lane must be known in each case. The required length of left-turn lane for each alternative is determined by using the maximum queue value

TABLE 5 SOAP OUTPUT FOR ALTERNATIVE 5 AFTER 20 YEARS: MEASURES OF EFFECTIVENESS

Movements	Delay (vehicle hours)	Stops (%)	Excess Fuel (gal.)	Left Turn Interference (number of vehicles)	Maximum Queue	*V/C Ratio*
NB Through	65.43	92.5	128.09		100.8	1.15
NB Left	19.75	99.3	33.18	14.6	24.4	1.15
SB Through	47.84	92.5	99.60		63.7	1.04
SB Left	5.78	99.7	8.73	7.0	6.0	1,000.00
EB Through	57.78	96.7	101.02		83.8	1.15
EB Left	4.31	99.7	6.74	3.7	4.2	1,000.00
WB Through	14.77	94.1	29.39		23.8	1.04
WB Left	15.79	99.5	26.09	10.3	26.5	1.15
Summary	231.45	94.6	432.84	35.6	100.8	1,000.00

TABLE 6 TOTAL DELAY COST CALCULATIONS

Alternative	Year	Volume (Veh/Day)	Total Delay (Veh-hr/day)	% Stops	Time Cost ($/year)	Running Cost ($/year)	Idling Cost ($/year)	Total Delay Cost ($/year)
0	0	17,032	145.03	88.8	291,148	109,587	38,566	439,301
1	0	17,032	113.61	87.5	228,072	107,983	30,211	366,266
2	0	17,032	69.31	93.7	139,140	115,635	18,431	273,205
3	0	17,032	64.14	94.1	128,761	116,128	17,056	261,945
4	0	17,032	63.38	93.2	127,235	115,017	16,854	259,107
5	0	17,032	60.32	93.1	121,092	114,894	16,040	252,027
0	20	30,762	454.80	95.2	2,422,490	563,009	320,887	3,306,386
1	20	30,762	395.99	93.2	2,109,239	551,181	279,393	2,939,813
2	20	30,762	354.27	93.4	1,887,017	552,364	249,957	2,689,338
3	20	30,762	285.99	94.9	1,523,324	561,235	201,782	2,286,341
4	20	30,762	294.78	92.6	1,570,144	547,633	207,984	2,325,761
5	20	30,762	229.98	94.6	1,224,987	559,461	162,264	1,946,712

TABLE 7 CALCULATION OF TOTAL BENEFITS

Alternative	Year	Total Delay Cost ($/year)	Total Acc. Cost ($/year)	Total User Cost ($/year)	User Benefits ($/year)	Signal Opr. Costs ($/year)	Signal Opr. Benefits ($/year)	Total Benefits ($/year)
0	0	439,301	157,100	596,401	---	117,000	---	---
1	0	366,266	114,872	481,138	115,263	117,000	0	115,263
2	0	273,205	140,872	414,077	182,324	101,000	16,000	198,324
3	0	261,945	102,838	364,783	231,618	101,000	16,000	247,618
4	0	259,107	102,838	361,945	234,456	101,000	16,000	250,456
5	0	252,027	76,256	328,283	268,118	101,000	16,000	284,118
0	20	3,306,386	752,847	4,059,233	---	310,436	---	---
1	20	2,939,813	550,484	3,490,297	568,936	310,436	0	568,936
2	20	2,689,338	675,080	3,364,418	694,814	267,983	42,453	737,267
3	20	2,286,341	492,815	2,779,156	1,280,076	267,983	42,453	1,322,529
4	20	2,325,761	492,815	2,818,576	1,240,657	267,983	42,453	1,283,109
5	20	1,946,712	365,430	2,312,142	1,747,091	267,983	42,453	1,789,543

provided in the SOAP output for Year 20 conditions. The calculations are as follows: 85 percent of maximum queue and 20 ft average headway between vehicles are found to be appropriate for design purposes. Alternative 5, in which signal control is changed from actuated to pretimed control and NB and WB left-turn lanes are added, is considered:

Maximum queue per lane (NB)	=	24.4/2 (Table 5)
	=	12.2
Required length of lane	=	(0.85)(12.2)(20)
		207.4 ft (say, 250 ft)

∴ Design value: provide 250 ft of lane

The amount of right-of-way was calculated similarly for the other four alternatives. As a unit cost of land, including administrative and other related expenses, a value of $\$25/\text{ft}^2$ was recommended by experts. The cost of right-of-way for Alternative 5 is

Lane width = 12 ft

$(250\text{ ft})(12\text{ ft})(\$25/\text{ft}^2) + (250\text{ ft})(12\text{ ft})(\$25/\text{ft}^2)$

$= \$150{,}000$

The right-of-way costs were calculated similarly for the other four alternatives.

In Step 9 (Figure 1), the first part of the economic analysis was to determine the present value of annual benefits. The equations used earlier in Step 9 were applied with the following information to determine the present value of the stream of benefits for each alternative: discount rate (i) = 7 percent, analysis period (n) = 20 years, and period of the estimate (Y) = 20 years. The Year 0 and Year 20 benefits were taken from Table 7, and the results are shown in Table 8. Once the present values of benefits (PVB) and project costs (PVC) were determined, the incremental benefit-cost procedure could be applied (Figure 3).

In Step 10, staged construction options were examined for Alternative 5. As stated previously, this is a combination of signalization improvement (Alternative 2), addition of a northbound left-turn lane (Alternative 3), and addition of a westbound left-turn lane (Alternative 4). Alternative 5 was found to be the most economically justified improvement alternative for this particular intersection over a period of 20 years. Because three independent alternatives are included within the selected alternative, staged construction possibilities exist and should be examined. The traffic volumes in Table 9 and total delay values in Table 10 were used to calculate the average delay values for each alternative in 5-year intervals. These values were then used to prepare the average delay versus time graph shown in Figure 5.

The staged construction option for improving Alternative 5 to maintain LOS C is (from Figure 5)

- Year 0, Stage 1: Change signal control (Alternative 2 is accomplished).
- Year 12, Stage 2: Add a NB left-turn lane (Alternative 3 is accomplished).
- Year 15, Stage 3: Add a WB left-turn lane (Alternative 5 is accomplished).

Note that because the present value of benefits associated with Alternative 3 is higher than that for Alternative 4 (Table 11),

TABLE 8 CALCULATION OF PRESENT VALUES OF BENEFITS

Alternative	B_0 (\$/year)	B_{20} (\$/year)	a	r	f	PVB (\$)
1	115,263	568,936	4.94	0.080	22.14	2,551,923
2	198,324	737,267	3.72	0.066	19.22	3,811,787
3	247,618	1,322,529	5.34	0.084	23.08	5,715,023
4	250,456	1,283,109	5.12	0.082	22.6	5,660,306
5	284,118	1,789,543	6.3	0.092	25.12	7,137,044

TABLE 9 TRAFFIC VOLUMES AT STUDY YEARS

	Year				
	0	5	10	15	20
Growth factor	1.000	1.159	1.344	1.558	1.806
Traffic volume (vehicles/day)	17,032	19,745	22,890	26,535	30,762

NOTE: Growth rate: 3 percent/year.

TABLE 10 TOTAL DELAY VALUES

	Total Delay Values (vehicle hours/day)				
Alternative	Year 0	Year 5	Year 10	Year 15	Year 20
0	145.03	185.17	242.56	342.35	454.80
1	113.61	162.39	212.66	289.22	395.99
2	69.31	96.90	138.43	232.72	354.27
3	64.14	82.94	120.40	184.10	285.99
4	63.38	82.31	119.01	184.48	294.78
5	60.32	75.24	99.57	149.90	229.98

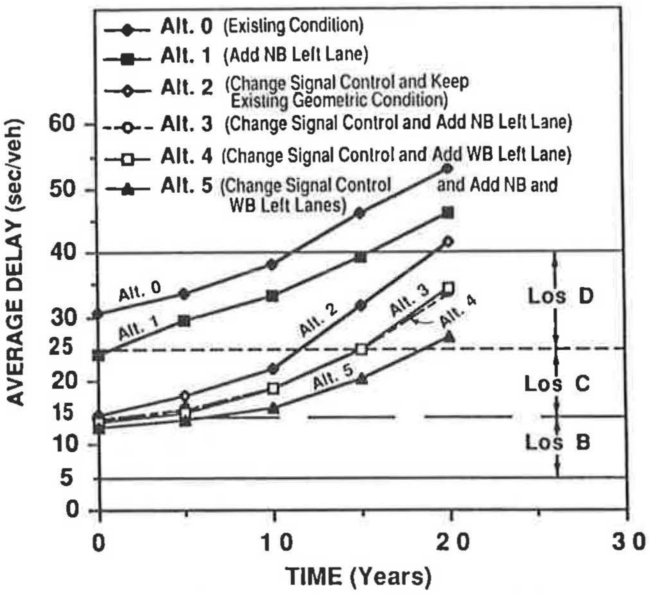

FIGURE 5 Average delay versus time graph for examination of staged construction options.

the choice is made for Alternative 3 at Stage 2. By completion of Stage 3 at Year 15, Alternative 5 will be automatically accomplished. Although the LOS C requirement is not satisfied for the last 2 years of the planning period, this improvement plan is still acceptable. However, further improvement of the intersection has to be planned for Year 20.

TABLE 11 *B/C* RATIOS

Alternative	PVB	PVC	*B/C*
1	2,551,923	101,000	25.3
2	3,811,787	14,000	272.3
3	5,715,023	130,000	44.0
4	5,660,306	130,000	43.5
5	7,137,044	241,000	29.6

The results presented in Table 11 are produced by the following incremental *B/C* procedure. The first defender is the lowest-cost alternative (Table 12), which is Alternative 2.

Defender = Alternative 2 (the lowest-cost alternative with $B/C > 1.0$).

Challenger = Alternative 1 (next higher-cost alternative with $B/C > 1.0$).

$$\text{IBCR}_{1-2} = (B_1 - B_2)/(C_1 - C_2) = -1{,}259{,}864/87{,}000 = -14.5 < 1.0$$

Therefore eliminate Alternative 1:

Challenger = Alternative 3

$$\text{IBCR}_{3-2} = (B_3 - B_2)/(C_3 - C_2) = 1{,}903{,}236/116{,}000 = 16.4 > 1.0$$

Therefore, eliminate Alternative 2:

Defender = Alternative 3

Challenger = Alternative 4

Because Alternative 3 and Alternative 4 are equal-cost alternatives, the one with higher benefits is preferred; therefore eliminate Alternative 4:

Challenger = Alternative 5

$$\text{IBCR}_{5-3} = (B_5 - B_3)/(C_5 - C_3) = 1{,}422{,}021/111{,}000 = 12.8 > 1.0$$

Therefore eliminate Alternative 3 and select Alternative 5.

CONCLUSIONS AND RECOMMENDATIONS

The main objective of this research was to develop a simple and practical step-by-step procedure to improve urban ISIs at grade. The SPP developed in this research will aid engineers and planners in developing intersection improvement options to deal effectively with present and future problems at 5-year intervals or over the long-range 20-year planning horizon. The SPP generates alternative solutions that take into account safety, operational, and economic considerations. From the results of the application of the SPP, engineers and planners will be able to select and schedule desired improvement plans at a fixed future date (stage construction). For instance, average delay versus time (in 5-year intervals until the 20-year planning horizon is reached) could be plotted graphically for each improvement alternative.

TABLE 12 PRESENT VALUES OF PROJECT COSTS

	PVC ($)				
Alternative	Equipment	Construction	Right of Way	Maintenance	Total
1	–	35,000	60,000	6,000	101,000
2	14,000	–	–	–	14,000
3	14,000	35,000	75,000	6,000	130,000
4	14,000	35,000	75,000	6,000	130,000
5	14,000	65,000	150,000	12,000	241,000

From the results, the analyst will be able to determine, in advance, details of right-of-way acquisition and needs for additional lanes or other types of improvements that might be desired. Such preplanning will help avoid such problems as excessive payments for business damage.

SOAP is incorporated into the SPP, along with a cost-benefit technique. The SPP is flexible and is applicable to most isolated signalized intersections. As with any other technique, the results are only as valid as the input data (e.g., future costs of fuel, right-of-way, construction, users' fees, discount rates, accident costs, etc.). Other uncertainties include future traffic growth, traffic distribution, accident rate, and so on. Because of the SPP's step-by-step format, computerization of the procedure is recommended. This will enable the user to generate additional alternatives (or combinations of alternatives) that could be analyzed and implemented over shorter time intervals. The SPP can be incorporated into TRANSYT-7F or NETSIM analysis. This combination is particularly recommended for cases in which the intersection under consideration for improvement is influenced by neighboring intersections.

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