

Computerized Sketch-Planning Process for Urban Signalized Intersections

FAZIL T. NAJAFI, CHARLES JACKS, AND SUMANTH M. NAIK

Urban transportation networks in many cities will continue to experience enormous pressures because of population growth. As a result, the level of service at many signalized intersections will decrease to unacceptable levels within the next 20 years. Continuation of traffic growth over this period will necessitate intersection improvements. Previous research provided a simple methodology [the sketch-planning process (SPP)] based on cost-effectiveness to determine the optimum intersection improvement plan. During the automation of the SPP, many improvements were introduced. These improvements include (a) determination of the exact future year an intersection fails to meet requirements, (b) determination of the intersection's failure mechanisms, and (c) ability to simulate periodic signal timing optimization. A case study illustrates the automated SPP (ASPP) software package, which is a quick and efficient implementation tool that helps planners to rate intersection improvements. This package will enable planners to determine right-of-way needs before development makes costs prohibitive.

One of the most complex locations in an urban traffic system is the signalized intersection. As urban traffic increases, existing signalized intersections will experience additional pressure and the level of service offered by the intersections will deteriorate. This situation will require remedy through signalized intersection improvements.

Previous research on the sketch-planning process (SPP) (1) provided a simple methodology for decision making in rating urban intersection improvements.

The objective of the SPP process was to identify improvements that enable an intersection to meet minimum level of service requirements under a predicted growth rate. In addition, this process analyzed the economic impact of the identified improvements.

The computerized process uses commonly accepted simulation models to accurately determine the effects of an intersection improvement on future traffic conditions year by year. Results of these simulations allow the user to clearly determine which improvements will be needed and for how long these improvements will maintain the intersection within the service requirements. Staged improvement series are accepted as well as alternative improvement series.

A data base is maintained of the improvement type, costs, and results for each series of improvements. From the results, public costs such as fuel, oil, tires, maintenance, repair, and depreciation can be determined. Using this information, comparisons can be made between each series of improvements to determine the optimum plan. Once the optimum plan has been determined, the needed right-of-way can be purchased

before development drives the cost up or makes the cost prohibitive.

Fiscal planning can be enhanced by using this process to improve several intersections. Plans for improving each intersection can be combined to obtain an overall plan that meets monetary, personnel, and equipment constraints.

Automation of SPP is more than a way to execute the process faster because several improvements were implemented. Without automation, such improvements would have been difficult to execute manually. Most of these improvements are the result of simulating the intersection year by year, including

- Determination of the exact future year an intersection fails to meet requirements,
- Introduction of the automatic checking of the measures of effectiveness (MOE) providing information about the failure mechanism on which to base improvement selection,
- Simulation ability for periodic signal timing optimization,
- Generation capability for improvement alternatives showing the specified date at which the intersection must undergo construction (e.g., addition of lanes), and
- Estimation of each year's delay costs on the basis of present worth.

In order to allow the simulation of an exclusive, shared left-turn pair, the *Highway Capacity Manual* (HCM) (2) volume allocation methodology was extended to include exclusive-left- and shared-left-turn-lane groups. TRANSYT-7F's shared-lane model is unable to simulate this situation (3). Modification of the HCM method allows nearly all geometries of an intersection leg to be considered for analysis.

AUTOMATION OF THE SKETCH-PLANNING PROCESS

The SPP, which forms the basis of the automated SPP (ASPP), can be thought of as an algorithm in which each step of the procedure requires from the user an input, computation, or decision, or a combination of these. The 10-step SPP process is shown in Figure 1 (1).

SPP methodology involves a comprehensive evaluation of all aspects of intersection improvement. This evaluation entails user input of various parameters pertaining to existing and future traffic conditions, available right-of-way, and physical and economic constraints for improvement. Constraints used to identify an intersection as a candidate for improvement are volume/capacity (v/c) ratio, delay values, and queue capacities

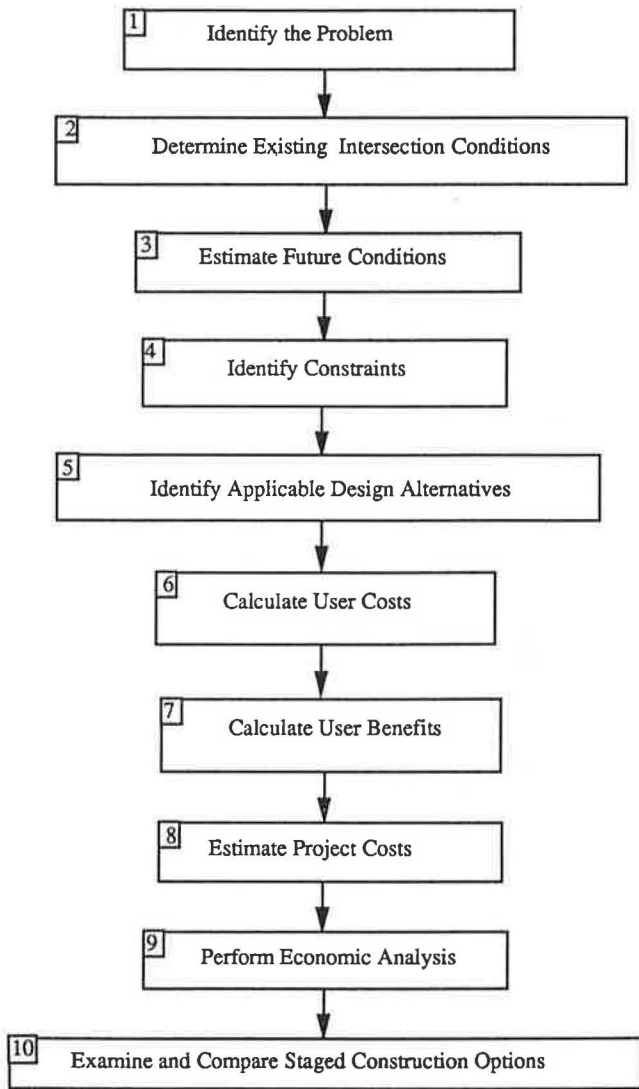


FIGURE 1 Ten-step SPP.

in each leg of the intersection. Calculation of user costs and project costs as well as user benefits from the intersection improvement enable a final economic analysis to be performed for each improvement alternative. This calculation helps determine the benefit-cost ratio of each improvement alternative.

ASPP, unlike SPP, is presently restricted to isolated urban signalized intersections with four or fewer legs, which should cover the majority of intersections experiencing deficiencies as a result of increases in traffic volume.

Assuming an intersection requiring improvement has been identified, the first step of SPP is to identify the problem causing the intersection to require improvement. The usual reasons for an intersection to be considered for improvement are operational and safety problems. Operational problems are characterized by excessive delay, insufficient capacity, or queues larger than available storage. Safety problems are characterized by a high rate of property damage, injury, or fatalities.

Although intersection safety is enhanced by the application of ASPP, sufficient safety parameters did not exist to account

for all conditions to be incorporated into the ASPP model. Therefore, safety parameters were not implemented in ASPP.

Response of an intersection's operation to an improvement can easily be determined by one of a variety of traffic simulation programs (3). TRANSYT-7F was chosen for its ability to optimize signal timing, accurately simulate shared lanes and actuated signals, and meet the requirements of planned revisions. TRANSYT-7F is a common accepted simulation program, and its evaluation of an intersection is constantly being improved.

TRANSYT-7F output contains information needed to determine whether an intersection meets performance requirements. Two requirements are automatically checked by ASPP. These are the v/c ratio for each movement and the queue length for movements having a turn bay. Delay values are displayed so that the user can check excessive delay on the basis of selected criteria.

DEFINING INTERSECTION CONDITIONS

Three sets of conditions define the problem of determining when an intersection fails to meet requirements, including (a) conditions of the existing intersection, (b) conditions of growth, and (c) conditions defining adequate performance. Any change in these conditions will modify the results; therefore, for valid comparisons between different intersection improvement plans the conditions must be identical.

Determination of these conditions correspond to Steps 2 through 4 of the SPP (Figure 1). In ASPP, the user must develop a data set containing values such as number of lanes, growth rate, etc. (Figure 2), that define these three conditions. The first module of ASPP (the input module) was designed to gather values in Figure 2 from the user and create the data set (Figure 3).

Data required to define the three conditions are detailed. Extensive requirements are needed to satisfy the procedures used by the ASPP, including (a) TRANSYT-7F simulation, (b) HCM (2) procedures for estimating capacity, (c) constraint-checking procedures, and (d) delay cost estimation. Users must be responsible for other data such as the extent of existing right-of-way, feasible right-of-way acquisition, and consideration of social and political constraints on intersection improvement.

In order to estimate future traffic volumes, ASPP uses a compound interest formula. The growth rate for each leg of the intersection can be individually entered (Figure 2), allowing differential growth to be modeled (e.g., the different growth rate that would occur at the edge of urban areas as compared to the center of the city). Furthermore, the growth rate for two classes of heavy vehicles are modeled to account for commercial, industrial, and residential zones.

Future traffic volumes, mix of heavy vehicles, and lane capacities are estimated by ASPP using existing conditions and growth rates. Predicted values are placed into a TRANSYT-7F input deck so that the operational conditions can be estimated. These tasks are normally time-consuming, but once the existing conditions have been defined, the user's effort is reduced to entering the growth rates.

ASPP uses capacity estimation procedures of the HCM (2). Capacity value input to TRANSYT-7F is the capacity of the

1. Intersection name _____, City, County or DOT District name _____
(Intersection drawing appears on your PC screen (Figure 5)).

2. GEOMETRICS

- a) no. of lanes at each approach
- b) gradient at each approach
- c) bay length at each approach

3. TRAFFIC

- a) Traffic volume at each approach
- b) % of heavy trucks at each approach
- c) speed limit at each approach
- d) no. of sneakers at each approach
- e) number of pedestrians at each approach

4. Traffic Volume growth at each approach

5. Maximum acceptable v/c ratio (or 0.90)

6. Signal phasing and timing (as in Table 7)

7. Maximum back of queue : < ___ % of of turn bay length (or default value of 100%).

8. Vehicle Spacing _____ (or use a default value of 25 feet).

9. Check input values (Steps 1-8) for consistency and write a TRANSYT-7F data set

projecting existing conditions to future conditions (year-by-year until the end of planning horizon).

FIGURE 2 Input module steps.

SB			WB			NB			EB		
R	T	L	R	T	L	R	T	L	R	T	L

lanes for 1 hr of green time. Furthermore, TRANSYT-7F does not model the effect of heavy vehicles on lane capacity. Therefore, the values calculated by ASPP compensate for geometric conditions (e.g., gradient and lane width) and traffic mix, but assume 100 percent protected green. Calculated capacity values are also entered as the maximum flow rate for unprotected opposed movements during a permitted phase.

In developing ASPP, it was found that TRANSYT-7F would not simulate all the intersection geometries for any number of lanes or type of movement. Specifically, TRANSYT-7F will not simulate a turning movement with one or more exclusive lanes and a shared lane. In order to remedy this situation, it was decided to distribute the approach volume to lane groups such that the resulting v/c ratios for all movements would be equal. This decision is based on the assumption that lane switching would occur to cause the queues to empty at the same time. This assumption, coupled with the restriction on signal timing imposed by the presence of a shared lane, would result in equal v/c ratios. Formulas developed from this assumption are equivalent to HCM (2) formulas when no exclusive turn lanes are present. In order to test the formulas, a range of input conditions was simulated by TRANSYT-7F. Simulated v/c ratios found in TRANSYT-7F were within 1 to 2 percent of the v/c ratios predicted by the formulas.

As mentioned before, ASPP checks each simulation for compliance with constraints on the v/c ratio and queue length. Maximum permissible v/c ratio can be entered for lefts,

throughs, and rights (Figure 2). Users may enter a percentage of bay length use and vehicle spacing. Defaults for these characteristics are 100 percent and 25 ft, respectively.

Constraint on maximum v/c ratio exists for two reasons. First, movements with high v/c ratios are generally not considered acceptable. Second, various delay formulas tend to differ markedly for high v/c (>1) ratios, but are in accord with generally acceptable v/c (<1) ratios. User costs are based on delay; therefore, the predicted cost from the different models will not differ greatly if the v/c ratios are restricted to reasonable values.

Constraint on maximum queue length is optimal. Bay length is used only for this test. If no bay length is entered for a movement, then the bay length constraint is not considered for this particular movement. TRANSYT-7F does not simulate the blockage that would occur when the queue is longer than the turn bays; therefore, the delay value for the blocked movement is underestimated.

DEVELOPMENT AND EVALUATION OF IMPROVEMENT DESIGN ALTERNATIVES

After all values from Figure 2 have been entered and stored, the user can request the input module to write a TRANSYT-7F input deck. This deck will contain sections representing volume and capacity values for the first and up to 20 successive

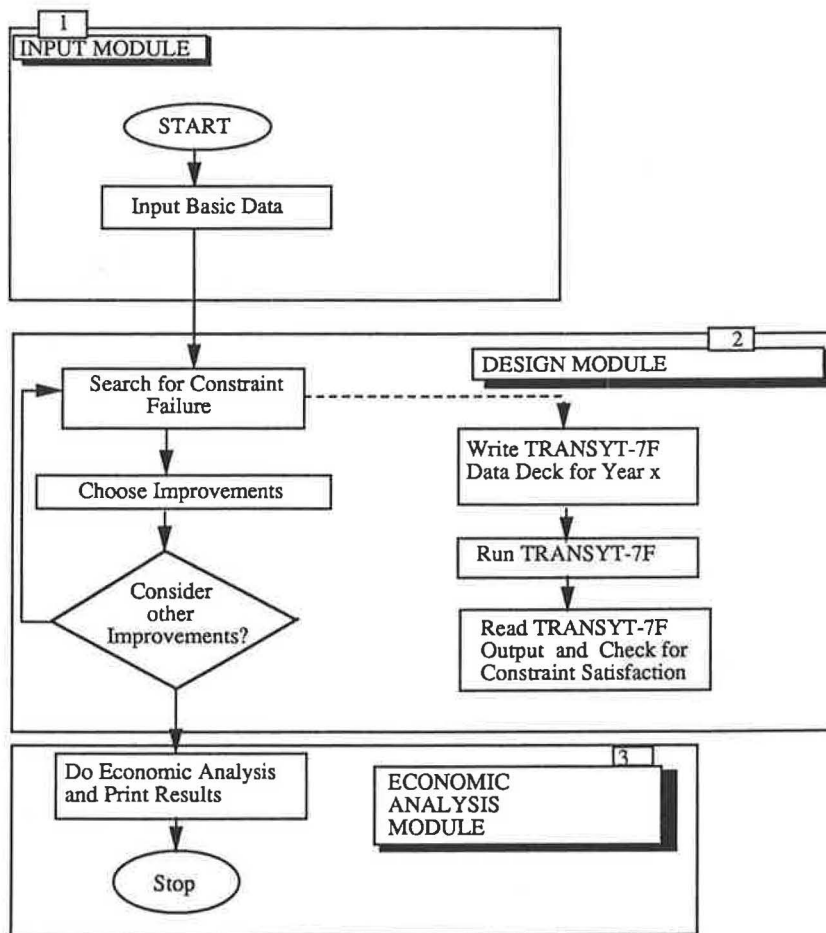


FIGURE 3 Organization of the overall ASPP program.

TABLE 1 INPUT DATA FOR CASE STUDY

	South Bound			West Bound			North Bound			East Bound		
	R	T	L	R	T	L	R	T	L	R	T	L
# of lanes	1	3	1	-1	1	1	-1	3	1	1	2	1
lane width	12	12	12	12	12	12	12	12	12	12	12	12
bay length	100	100	100	100	100	100	100	100	100	100	100	100
volumes	49	450	57	6	46	70	66	1000	73	50	650	49
%3S2 trucks	2	2	2	0	0	0	0	2	2	2	0	0
%SU trucks	0	0	0	0	0	0	0	0	0	0	0	0
% growth rate for car	3	3	3	3	3	3	3	3	3	3	3	3
% growth rate for 3S2 trucks	3	3	3	3	3	3	3	3	3	3	3	3
% growth rate for SU trucks	3	3	3	3	3	3	3	3	3	3	3	3
green ext	1	1	1	1	1	1	1	1	1	1	1	1
startup lost time	1	1	1	1	1	1	1	1	1	1	1	1
gradients		0.0			0.0			0.0			0.0	
parking	0			0			0			0		
speed limit		45			35			45			35	
pedestrian	0			0			0			0		
growth of pedestrians	3			3			3			3		
phases	3	2	0	3	2	0	0					
green time	5	45	0	5	45	0	0					
yellow	5	4	0	5	4	0	0					
all red	0	1	0	0	1	0	0					

years. While calculating future conditions, ASPP calculates an estimate of each movement's v/c ratio. When a v/c estimate is found greater than the user's chosen maximum acceptable v/c value, ASPP stops writing sections.

Once TRANSYT-7F has been run with the previously mentioned input deck, the user is ready to use the second module of ASPP (design module). This module is run iteratively in alternation with TRANSYT-7F (Figure 3) to develop and evaluate intersection improvement designs. An improvement design may include a set of improvements, such as the addition of a northbound left-turn bay and an eastbound exclusive right-turn lane. All improvements in a set are assumed to become effective at the beginning of the selected year for construction. Only one set of improvements can be evaluated in one alternation; however, iterative use will allow a series of improvement sets and also an alternative series of improvement sets to be evaluated. A series of improvement sets will be called an improvement alternative.

Three functions are fulfilled by the second module of the ASPP: (a) scan and store output of the prior simulation, (b) accumulate information about a selected improvement, and (c) create a TRANSYT-7F input deck to evaluate the improvement. These three functions correspond to Steps 5, 8, and 10 of the SPP process (Figure 1). Calculation of delay needed in Step 6 is performed during the simulation of an improvement design.

The first action taken by this module is to search for a TRANSYT-7F output file. If an output file is found, the design module of the ASPP will search for a punch data set. Signal timing optimization causes a punch data set to be created by TRANSYT-7F. If a punch file is found, the optimum timing is read from this file and placed in a data base of designs. After processing the punch data set, the design module of ASPP will scan the output file. Measures of effectiveness (MOE) tables from the output will be copied to a data base of simulation outputs for later use.

These data bases permit users to evaluate simulated intersections by quickly displaying a variety of information, which is then needed to develop TRANSYT-7F input decks and economic analysis. For any simulated year of an improvement alternative, the following information may be displayed: volume and capacity distribution, MOE table, and signal timing. Values indicating constraint failure will be highlighted in the MOE tables. From this information, the user should be able to determine the particular year that the intersection meets all performance requirements.

ASPP can simulate several modifications to an intersection, including (a) addition of lanes, (b) change in lane width, (c) increase of turn bay length, and (d) signal timing optimization. Any combination of these modifications may be selected for the various movements and directions. Signal timing optimization is restricted to cycle length search and split optimization. Changes in signal phasing are not presently allowed. Users should determine a combination of modifications considering physical, political, social, and budgetary limitations that might make the intersection meet requirements.

Each intersection modification must be entered along with associated construction, right-of-way, and additional maintenance costs. These costs and other relevant values about the improvement will be stored in an alternative data base for use in determining the conditions existing at a selected

year. It is recommended that the user maintain sufficient documentation on each improvement set. Details of the costs should include information on right-of-way usage, underground obstructions, etc.

If cycle timing optimization was selected, ASPP writes an input deck requesting a cycle search and split optimization for the modified intersection. On obtaining the optimum timing from the punch data set, ASPP simulates the new signal timing for the remaining years. If signal timing optimization was not selected, ASPP simulates the intersection modifications for the remaining years. As with the existing condition simulation, the minimum required simulations will be executed as previously discussed.

In order to facilitate the alternation of ASPP modules and TRANSYT-7F, an assembly language program was developed that will correctly sequence these programs. To examine or modify the input deck, the user may control the sequence of programs by batch or command entry. One instance in which the modification of the input deck might be useful is for modifying an input deck, requesting a signal timing optimization to meet local regulations on minimum green time.

COSTS MODULE

When the user feels that a sufficient number of alternative improvement series have been evaluated for performance requirements, the user may select the costs module of ASPP (Figure 3). The costs module calculates the delay costs associated with a selected alternative. In addition, it will compare costs among several alternatives.

ASPP uses the same cost calculation procedure as SPP (*I*). Total intersection delay from the MOE tables for each year of the selected alternative is used to estimate the yearly delay costs. Delay costs are defined as travel time cost, running cost caused by speed change and stopping, and idling cost.

The inflation rate used to project the estimated costs to future worth and the discount rate used to return to present worth are assumed to be the same. Comparisons between alternatives are based on the sum of the present worths of each year's costs. Because the inflation and discount rates are the same, the estimate of the present worth of a cost is the estimated value of the cost regardless of the year in which it occurs. This assumption causes the economic analysis to be insensitive to variations in discount rate.

Alternatives are compared on the basis of the following costs: (a) total delay costs, (b) average yearly delay costs, (c) total intersection improvement costs, (d) average yearly intersection improvement costs, (e) total costs over the entire planning horizon [the sum of (a) and (c)], and (f) benefit/cost ratio (B/C) of each improvement alternative.

During the development of ASPP, a problem was noticed in programming the evaluation of B/C ratios. SPP defined the benefit as the difference between delay costs of the unimproved intersection to the delay costs of the improved intersection. However, because of various methods of estimating delay for high v/c ratios and underestimation of delay when queues become longer than bay lengths, the unimproved intersection is not simulated after these conditions occur. These conditions signal the need for a modification of the intersection;

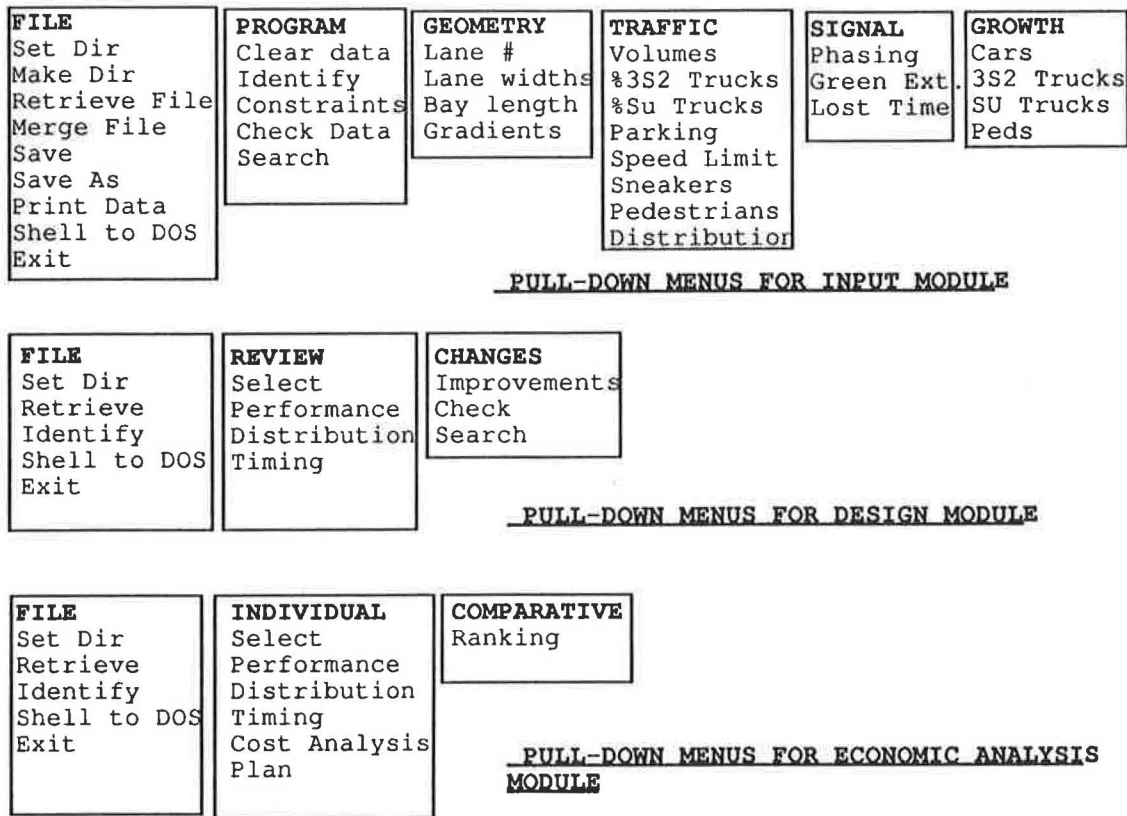


FIGURE 4 Pull-down menus for the three ASPP modules.

therefore, simulation of the modified intersection will occur after simulation of the unimproved intersection stops. Without a value for the delay of the unimproved intersection, the benefit cannot be calculated by the SPP method. ASPP reports B/C ratios and considers delay costs as disbenefits.

CASE STUDY

ASPP software is better illustrated through use of a case study. The selected intersection is SW 34th Street and SW 2nd Avenue, located in the city of Gainesville, Florida. For this intersection, Table 1 presents the values for (a) existing geometric conditions; (b) predicted future traffic growth rate; (c) constraints such as v/c, vehicle spacing, etc.; and (d) signal timing.

Table 1 presents the steps of the input module, whereas Figure 4 shows the menus of the input module. Users may choose menu items either by cursor control or a mouse. Menu items not related to file or program control cause a screen to be displayed for entering the menu item. Input screens are provided for entering identification information and constraint specification. Maximum v/c values are allowed to default to 0.9, whereas bay length and average vehicle spacing are allowed to default to 100 percent and 25 ft, respectively.

All other data in Table 1, except signal timing, are entered on a screen similar to that shown in Figure 5. The relationship of screen position to data item should be intuitive. The number displayed is the number of lanes that service the lefts, throughs, and rights. The negative sign for the right turn indicates the lane is shared with another movement.

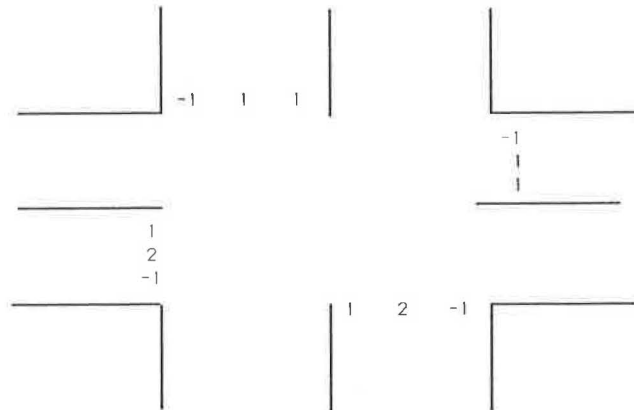


FIGURE 5 ASPP input screen for numbers of lanes.

The data for the signal timing screen are presented in Table 2. Signal phase sequences are selected by menu control. Signal timing is presented as 45 sec of permitted lefts and throughs with a 5-sec yellow clearance followed by 5 sec of protected left with 4 sec of yellow clearance and 1 sec of all red. Both north-south and east-west directions have this sequence.

After the signal timing and all the data from Table 1 were entered, input values were checked for consistency and stored. The simulate option from the menu was selected, to cause the input module to write a TRANSYT-7F input deck. TRANSYT-7F was then run to simulate existing conditions.

The next step is the start of the alternation of the second module of ASPP (design module) and TRANSYT-7F. The

TABLE 2 ASPP INPUT SCREEN FOR SIGNAL TIMING DATA

		Timing		
		Green	Yellow	Red
North/South Subsequence	P	45	4	0
	L	5	4	1
East/West Subsequence	P	45	4	0
	L	5	4	1
Walk Only Subsequence	0	0	0	0

TABLE 3 STATUS OF INTERSECTION PERFORMANCE FOR SELECTING INTERSECTION IMPROVEMENT

YEAR	Alternative 0	Alternative 1	Alternative 2	Alternative 3
0	29.3	29.3	29.3	29.3
1	29.7	29.7	29.7	29.7
2	30.0	30.0	30.0	30.0
3	30.4	30.4	30.4	30.4
4	30.8	30.8	30.8	30.8
5	31.2	31.2	31.2	31.2
6	31.7	31.7	31.7	31.7
7	32.1	32.1	32.1	32.1
8	32.8	32.8	32.8	32.8
9	33.4	33.4	33.4	33.4
10	34.3	34.3	34.3	34.3
11	35.1	35.1	35.1	35.1
12	36.1	36.1	36.1	36.1
13	37.3	37.3	37.3	37.3
14	38.8	34.5i	34.5i	34.5i
15		35.5	35.5	35.5
16		36.9	35.2i	33.7i
17			36.3	36.3
18			34.2i	34.2i
19			35.2	35.2

second module read the TRANSYT-7F output and placed the MOE tables in a data base. The select menu item was chosen, displaying a screen similar to Table 3. At this time, only the alt0 (alternative "0") column contained data. The last row containing data in this column corresponds to year 14, indicating that the existing intersection arrangement will fail to meet requirements in year 14. This year was selected for examination.

Figure 6 is the product of SPP applied to this case study, a graphical presentation of average delay versus time (in years). ASPP uses data in Table 3, which is consistent with Figure 6. The important point about Figure 6 is the relationship between construction timing of an alternative to its level of service. The effect of any improvement on level of service can be determined from the values displayed in Table 3.

In the case study, all displayed values represent level of service (LOS) D. Normally, the user would attempt to con-

struct a series of improvements that kept the intersection at LOS C. The other aspects of ASPP were better illustrated by having the intersection fail to meet programmed constraints.

The MOE table was requested by choosing the performance menu item. Examination of the MOE table (Table 4) indicated that the northbound through-*v/c* value exceeded the constraints. Three modifications come to mind: (a) add a northbound lane, (b) retime the intersection, and (c) add an adjacent right-turn bay. Combinations of these three may also be simulated by the ASPP.

In order to determine whether one of the previously mentioned options will be effective, the user may display other information about the simulated intersection, such as volume distribution and lane capacities. The distribution menu item was chosen next to display the volume distribution and lane usage (Table 5). From this screen, it can be seen that the predicted volume of through vehicles in the shared right lane

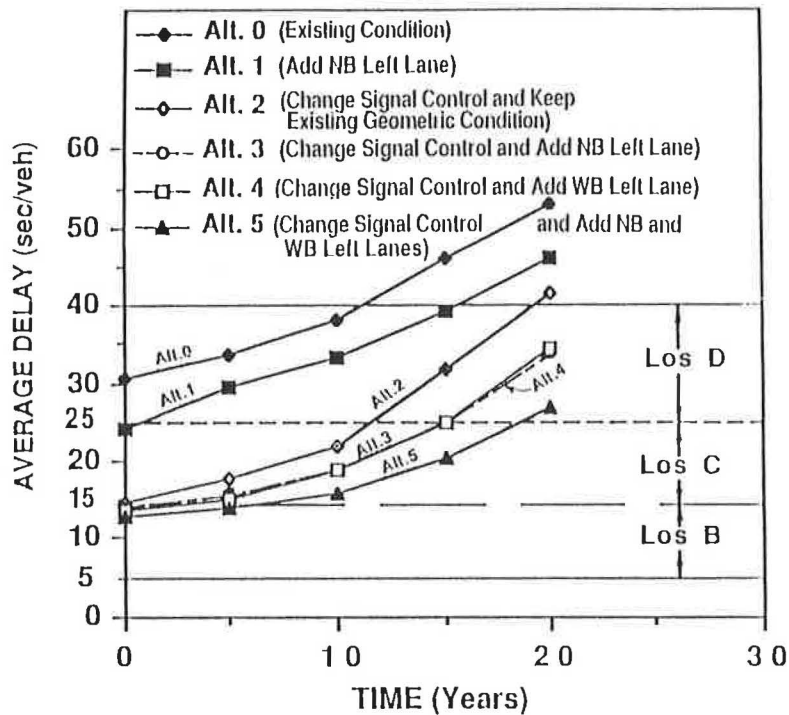


FIGURE 6 Average delay versus time graph to examine staged construction options over the design period.

is not small. Not much benefit could be expected from adding a right-turn bay.

In the MOE tables (Table 4), some high v/c ratios occur in the eastbound and westbound movements. Because of these high v/c ratios, split optimization would not be expected to solve this constraint without breaking another. The remaining choice is to add a through lane.

Before simulating the addition, the user needs to obtain information on the costs of adding the through lane. Construction costs were estimated at \$115,000, right-of-way (R-W) costs at \$792,000 for a through length of 2,640 ft at an average of \$25/ft² R-W cost, and additional maintenance costs at \$5,000. These costs assume a lane width of 12 ft. These cost values were then entered into the design module and the simulation process executed.

Returning to the selection screen (Table 3), one can see that adding a northbound through-lane extended the life of the intersection to year 16 (Alternative 1). MOE tables (Table 6) indicate the westbound left v/c value is the cause of failure. Two modifications may improve the intersection: (a) adding a lane to the westbound left-turn bay, and (b) adding an eastbound through-lane. No evidence existed to indicate that either would not work; therefore, both were evaluated. Construction, right-of-way, and additional maintenance costs for Option 1 are estimated as \$40,000, \$30,000, and \$0, whereas these costs for Option 2 are \$115,000, \$396,000, and \$2,500, respectively.

Exercising Option 1 (Alternative 2 in Table 3) allowed the intersection to meet the constraints until year 18. Failure occurred because of the high v/c value at the eastbound through-lane. At this point, adding an eastbound through-lane allowed the intersection to meet requirements for the rest of the planning horizon (20 years).

The eventual need for adding an eastbound through-lane in this alternative indicates Option 2 might be a better solution. Adding the eastbound through-lane (Alternative 3 in Table 3) reduced the westbound left v/c value to acceptable levels, but only until year 18. Here, adding a westbound left lane seems proper. By adding such a lane, the intersection meets performance requirements until the end of the planning horizon.

From the application of ASPP, the user has learned three significant points about the future needs of the case study. The user must add (a) a northbound through-lane, (b) an eastbound through-lane, and (c) a westbound left-turn lane.

At this point, it was decided to execute the cost module of ASPP. In Table 4, the difference in Alternatives 2 and 3 occurs in years 16 and 17, with Alternative 3 having the smaller average vehicular delay. The cost analysis (Table 7) indicates that Alternative 3 has the lower delay costs because of the addition of the eastbound through-lane in year 16.

The comparative menu item ranks the alternatives, on the basis of several costs functions (Table 8). This figure indicates Alternative 3 is the best alternative considering all comparison methods (e.g., total user costs and total government costs), except the B/C ratio.

As mentioned earlier, B/C ratio treats delay costs as dis-benefits and reports this ratio as negative. Therefore, using this technique for the evaluation of intersection improvement alternatives is not proper.

Another reason exists for selecting a different technique for evaluating intersection improvement alternatives other than using the B/C method. Decisions as to which one of two alternatives is better depend on whether all the years within the planning horizon are observed, or only the portion in which the alternatives are different.

TABLE 4 PERFORMANCE TABLES FOR YEAR 14, ALTERNATIVE 0

<u>NB Movements</u>									
Exc. Left	68	2.05	1.04	0.99	32.5	88(80)	2	4	1.37
E/S Thru	90	20.26	13.15	12.70	42.1	989(91)	34	8	22.49
Sha. Thru R	87	7.94	5.46	5.29	44.7	89(89)	16	4	8.96
Shared R	87	1.86	1.28	1.24	44.7	89(89)			1.54
<u>SB Movements</u>									
Exc. Left	75	1.60	1.84	1.80	75.3	82(95)	3	4	1.89
E/S Thru	38	12.69	5.50	5.22	27.6	477(70)	16	12	10.29
Exc. R	14	1.38	0.55	0.52	25.1	47(63)	2	4	0.74
<u>WB Movements</u>									
Exc. Left	83	1.98	2.34	2.28	77.5	102(96)	3	4	2.38
Sha. Thru R	13	1.30	0.52	0.48	24.9	44(63)	2	4	0.70
Shared R	13	0.19	0.07	0.07	24.9	65(63)			0.10
<u>EB Movements</u>									
Exc. Left	13	1.38	0.42	0.38	18.7	41(56)	1	4	0.61
E/S Thru	81	18.32	10.55	10.03	36.7	84(86)	29	8	14.58
Exc. Right	15	1.42	0.57	0.53	25.1	48(63)			0.76

TABLE 5 VOLUME DISTRIBUTION FOR DIFFERENT MOVEMENTS FOR YEAR 14, ALTERNATIVE 0

	Exc. Left	Shared Left	Shared Left	S/E	Shared Right	Shared Right	Exc. Right
		Left	Thru	Thru		Right	
SB VOLUMES	86	0	0	512	169	74	0
# of Lanes	1	0	0	2	1	1	0
Capacity	1526			1606			1365
WB VOLUMES	106	0	0	0	70	10	0
# of Lanes	1	0	0	0	1	1	0
Capacity	1539			1620			1377
NB VOLUMES	110	0	0	1087	426	100	0
# of Lanes	1	0	0	2	1	1	0
Capacity	1526			1606			1365
NB VOLUMES	74	0	0	983	0	0	76
# of Lanes	1	0	0	2	0	0	1
Capacity	1539			1620			1377

TABLE 6 PERFORMANCE TABLES FOR YEAR 16, ALTERNATIVE 1

	V/C (%)	TOTAL TIME (V-MI)	TOTAL TIME (V-HR)	TOTAL DELAY (V-HR)	AVG. DELAY SEC/V	UNIFORM STOPS No. (%)	MAX. OF QUEUE No.	BACK OF QUEUE Cap.	FUEL CONS. (Gal.)
WB Movements									
Exc. Left	92	2.09	3.42	3.36	108	108. (97)	4	4	3.22
Sha. Thru R	14	1.38	0.55	0.51	25	47. (63)	2	4	0.74
Shared R	14	0.19	0.07	0.07	25	6. (63)	0	0	0.10
EB Movements									
Exc. Left	14	1.47	0.46	0.41	18.9	45. (57)	1	4	0.66
E/S Thru	86	19.44	11.84	11.29	39.0	926. (89)	32	8	16.14
Exc. R	15	1.49	0.60	0.56	25.2	51. (63)	2	4	0.80

TABLE 7 COST ANALYSIS FOR ALTERNATIVES 2 AND 3

Present Value Costs (k\$) for Alternative 2.										
Year	delay	%stops	Travtime	Running	Idling	Sum	Maint	Const	RightW	Sum
0	20.90	73	1258.5	341.4	118.9	1719	0	0	0	0
1	21.08	74	1311.1	356.5	123.9	1792	0	0	0	0
2	22.07	75	1366.8	372.1	129.1	1868	0	0	0	0
3	23.07	75	1425.1	383.3	134.6	1943	0	0	0	0
4	24.07	76	1488.3	400.0	140.6	2029	0	0	0	0
5	25.08	76	1552.7	412.0	146.7	2111	0	0	0	0
6	27.00	77	1623.7	430.0	153.4	2207	0	0	0	0
7	28.20	78	1695.8	448.6	160.2	2305	0	0	0	0
8	29.60	79	1781.9	468.0	168.3	2418	0	0	0	0
9	31.10	79	1870.3	482.1	176.7	2529	0	0	0	0
10	32.90	80	1976.8	502.8	186.7	2666	0	0	0	0
11	34.60	81	2081.5	524.4	196.6	2802	0	0	0	0
12	36.70	82	2207.2	546.8	208.5	2962	0	0	0	0
13	39.10	83	2351.0	570.0	222.1	3143	0	0	0	0
14	37.20	80	2237.9	565.9	211.4	3015	5	215	792	1012
15	39.50	81	2375.0	590.2	224.4	3190	5	0	0	5
16	40.30	82	2423.8	615.4	229.0	3268	5	40	30	75
17	42.80	82	2573.5	633.8	243.1	3451	5	0	0	5
18	41.50	80	2497.7	636.9	236.0	3371	7	115	396	518
19	44.10	80	2650.5	656.0	250.4	3557	7	0	0	7
Present Value totals						52346				1622

TABLE 7 (continued on next page)

TABLE 7 (continued)

Present Value Costs(k\$) for Alternative 3.										
Year	delay	%stops	Travtime	Running	Idling	Sum	Maint	Const	RightW	Sum
0	20.90	73	1258.5	341.4	118.9	1719	0	0	0	0
1	21.08	74	1311.1	356.5	123.9	1792	0	0	0	0
2	22.70	75	1366.8	372.1	129.1	1868	0	0	0	0
3	23.70	75	1425.1	383.3	134.6	1943	0	0	0	0
4	24.70	76	1488.3	400.0	140.6	2029	0	0	0	0
5	25.80	76	1552.7	412.0	146.7	2111	0	0	0	0
6	27.00	77	1623.7	430.0	153.4	2207	0	0	0	0
7	28.20	78	1695.8	448.6	160.2	2305	0	0	0	0
8	29.60	79	1781.9	468.0	168.3	2418	0	0	0	0
9	31.10	79	1870.3	482.1	176.7	2529	0	0	0	0
10	32.90	80	1976.8	502.8	186.7	2666	0	0	0	0
11	34.60	81	2081.5	524.4	196.6	2802	0	0	0	0
12	36.70	82	2207.2	546.8	208.5	2962	0	0	0	0
13	39.10	83	2351.0	570.0	222.1	3143	0	0	0	0
14	37.20	80	2237.9	565.9	211.4	3015	5	215	792	1012
15	39.50	81	2375.0	590.2	224.4	3190	5	0	0	5
16	38.50	79	2317.9	592.9	229.0	3130	5	115	396	518
17	41.00	79	2467.1	610.6	243.1	3311	5	0	0	5
18	41.50	80	2497.7	636.9	236.0	3371	7	40	30	77
19	44.10	80	2650.5	656.0	250.4	3557	7	0	0	7
Present Value totals						52068				1626

TABLE 8 RANKING OF ALTERNATIVES

Alternative	2	3
Years to finish	19	19
Ranking of alternative	2	1
Total user. cost	52346.08	52067.96
Ranking of alternative	2	1
User cost/year	2755.057	2740.419
Ranking of alternative	2	1
Total Govt. cost	1622	1626
Ranking of alternative	2	1
Govt. Cost/year	85.36842	85.57895
Ranking of alternative	2	1
Total Cost	53968.08	53693.96
Ranking of alternative	2	1
B/C Ratio	-32.27255	-32.02211
Ranking of alternative	2	1

This argument can be illustrated by considering two alternatives having identical first 10 years with a benefit of 10 and a cost of 1. For the next 10 years, let both Alternatives A and B have a benefit of 2 and a cost of 1, and a benefit of 5 and a cost of 2, concurrently. Then for the entire 20 years, B/C ratios are 6 and 5 for Alternatives A and B, respectively, whereas the B/C ratios for the last 10 yr for Alternatives A and B are 2 and 2.5. On the basis of the 20-year B/C ratios, Alternative A would be chosen. However, at the end of the first 10 years, the choice of Alternatives A or B is still valid. At this point in time, Alternative B becomes the better choice.

It can be seen from Table 8 that Alternative 3 has a smaller total cost than Alternative 2. The final intersection geometry is the same for Alternatives 2 and 3; however, the year in which each modification occurred is different (Table 7). This result indicates the importance of finding the optimum year at which the modification must occur. ASPP may be used to identify the optimum improvement year.

For any alternative in Table 3, adding the northbound lane 1 year earlier will not change the present value of both construction and R-W costs (on the basis of constant dollars). However, one must recognize that the future construction and R-W costs will be different, on the basis of inflation.

Moving the construction timing forward will add additional years of maintenance costs, and the present value of public expenditure (maintenance, construction, and R-W) will increase. However, the public will benefit as a result of reduced delay costs.

As construction time is moved year by year toward the beginning of the planning period, additional benefits because of reduction in delay costs will accordingly decrease, as indicated by the decreasing vertical distance separating the lines representing Alternatives 2 and 3 in Figure 6.

In order to determine the optimum construction timing, the total cost can be minimized. This minimum will occur the first year in which the benefit exceeds the maintenance cost.

In order to determine the optimum improvement timing, ASPP is simulated as if the intersection construction would occur at year zero. Then each year of this alternative is compared to the base alternative by subtracting their delay costs. The difference is the benefit resulting from reduction in delay

costs. The year in which this benefit exceeds the maintenance cost is the optimum year to finish the intersection construction.

CONCLUSION

As demonstrated, the ASPP software package is a quick and efficient implementation of the SPP, which helps planners order urban signalized intersection improvements by priority.

From the analysis, the need for future acquisition of R-W can be determined in advance. R-W can be purchased at predevelopment cost as compared to postdevelopment cost. As a result, significant cost savings should be realized.

During the effort to automate the existing SPP, several other improvements to the SPP were incorporated. For instance, the year-by-year detailed generation of improvement alternatives helps engineers to extensively examine intersection performance. In addition, the capability of the existing TRANSYT-7F was enhanced by incorporating a procedure to simulate exclusive-left- and shared-left-lane groups. Furthermore, the economic analysis module for comparing improvement alternatives has made the SPP process more accurate.

Existing ASPP is capable of handling only isolated signalized intersections. However, TRANSYT-7F is capable of simulating a coordinated network of intersections. Future research is planned to extend the capability of the existing process to include a coordinated network of intersections.

REFERENCES

1. F. T. Najafi. Sketch-Planning Process for Urban Isolated Signalized Intersection Improvements. In *Transportation Research Record 1160*, TRB, National Research Council, Washington, D.C., 1988, pp. 78-89.
2. *Special Report 209: Highway Capacity Manual*. TRB, National Research Council, Washington, D.C., 1985.
3. C. E. Wallace et al. *TRANSYT-7F User's Manual*. Office of Traffic Operations, FHWA, U.S. Department of Transportation, Feb. 1983.

Publication of this paper sponsored by Committee on Transportation System Management.