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# LCCA-based Decision Assistance Tool for Indirect Left Turn (ILT) Intersections using Excel-driven Highway Capacity Software

## **Abstract**

This paper explains the principles involved in the development of an MS Excel - based decision assistance tool for indirect left (ILT) intersections. this tool, termed Signalized Intersection Life Cycle Cost Analysis (SILCC), analyzes three types of ILT intersections; (i) MUT, (ii) CFL, and (iii) jughandles. SO far, no tools have been developed that are capable of analyzing ILT intersections while incorporating cost and benefit aspects. In contrast, SILCC is designed to incorporate cost and benefit aspects in the evaluation of ILT intersections. It is interfaced with the Highway Capacity Software (HCS) and hence can perform macro-level operational analysis. It considers delay, fuel consumption, and emissions as operational performance measures. It is capable of performing life cycle cost analysis (LCCA) and providing net present value (NPV) and benefit-to-cost ratio (B/C) as surrogate measures of performance. Planners can use NPV or B/C for decision support while deciding among several alternatives for economic and efficiently operating ILT intersections. Additionally, SILCC feature the flexibility to alter input values so that it can be used for multiple conditions and criteria. A case study of rural traffic volume conditions indication that a MUT intersection had the highest NPV of benefits for both new construction and retrofits. However, because the construction cost for MUT retrofits was high for the particular condition, an MUT intersection had the highest B/C for new construction an a jughandle had the highest B/C for retrofits.

## **Keywords**

Benefit cost analysis, Decision support systems, Highway design, Left turns, Life cycle costing, Signalized intersections, Turning traffic

## **Disciplines**

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## **Comments**

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**LCCA-based Decision Assistance Tool for Indirect Left Turn (ILT) Intersections using  
Excel-driven Highway Capacity Software**

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**1 ABSTRACT**

2 This paper explains the principles involved in the development of an MS Excel–based decision  
3 assistance tool for indirect left turn (ILT) intersections. This tool, termed Signalized Intersection  
4 Life Cycle Cost Analysis (SILCC), analyzes three types of ILT intersections: (i) MUT, (ii) CFI,  
5 and (iii) jughandles. So far, no tools have been developed that are capable of analyzing ILT  
6 intersections while incorporating cost and benefit aspects. In contrast, SILCC is designed to  
7 incorporate cost and benefit aspects in the evaluation of ILT intersections. It is interfaced with  
8 the Highway Capacity Software (HCS) and hence can perform macro-level operational analysis.  
9 It considers delay, fuel consumption, and emissions as operational performance measures. It is  
10 capable of performing life cycle cost analysis (LCCA) and providing net present value (NPV)  
11 and benefit-to-cost ratio (B/C) as surrogate measures of performance. Planners can use NPV or  
12 B/C for decision support while deciding among several alternatives for economic and efficiently  
13 operating ILT intersections. Additionally, SILCC features the flexibility to alter input values so  
14 that it can be used for multiple conditions and criteria. A case study of rural traffic volume  
15 conditions indicated that an MUT intersection had the highest NPV of benefits for both new  
16 construction and retrofits. However, because the construction cost for MUT retrofits was high for  
17 the particular condition, an MUT intersection had the highest B/C for new construction and a  
18 jughandle had the highest B/C for retrofits.

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## 1 INTRODUCTION

2 Indirect left turn (ILT) intersections are being adopted at locations where conventional  
 3 intersections fail to satisfy expected operational and safety levels. There are multiple ILT  
 4 configurations that provide superior performance to conventional intersections for a range of  
 5 volume configurations. The present analytical procedure for evaluating the performance of ILT  
 6 intersections ignores the economic aspect. A decision based on such an analysis may lead to a  
 7 cost-insensitive solution. Meanwhile, the construction of ILT intersections is associated with a  
 8 relatively large investment. Therefore, it is imperative for planners to weigh the intersection  
 9 designs based on the benefit of the services and the related costs throughout the service period  
 10 prior to deciding on a design for implementation. In this context, this study was designed to  
 11 develop a tool called Signalized Intersection Life Cycle Cost Analysis (SILCC), which can  
 12 incorporate the economic aspect along with the traffic operational elements to provide decision  
 13 assistance for the selection of optimal alternatives.

14 SILCC is capable of analyzing three types of ILT intersections: (i) median U-turn  
 15 (MUT), (ii) continuous flow intersections (CFI), and (iii) jughandles. Each type is compared to a  
 16 standard four-legged intersection with a protected left turn movement on both a major street and  
 17 minor street. The tool provides a marginal net present value (NPV) of benefits as well as a  
 18 benefit-to-cost ratio (B/C) for ILT intersections as decision support for planners during the  
 19 selection of suitable alternatives.  
 20

## 21 LITERATURE REVIEW

22 There is a significant body of literature that reports superior performance for ILT intersections,  
 23 such as MUT, CFI, and jughandles, as compared to a conventional intersection under a range of  
 24 volume conditions (*1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23,*  
 25 *24, and 25*). A few studies (*5, 8, 14, and 26*) have also discussed the construction costs of ILT  
 26 intersections. Despite an exhaustive body of literature documenting the performance of ILT,  
 27 there are no decision assistance tools to quickly compare multiple ILT intersections while  
 28 considering operational benefits in terms of system-level performance and the cost associated  
 29 with the construction, operation, and maintenance of such intersections throughout the life cycle  
 30 period. Even in terms of operational performance, the existing tools either produce very  
 31 simplistic performance measures or are very time consuming to use. This section provides a brief  
 32 overview of the tools available to help planners choose an appropriate ILT for a given  
 33 intersection.

34 Most studies use micro-simulation tools to compare the operational performance of ILT  
 35 intersections (*9, 10, 12, 13, 16, 19, 25, 27, and 28*). These studies invest significant resources  
 36 into running the micro-simulation models. Some of the time consuming steps involved in  
 37 performing micro-simulation runs are as follows:

- 38 i. Collecting and coding detailed data on origin and destination volumes and signal  
 39 control inputs.
- 40 ii. Calibrating models to replicate the observed driver behavior.
- 41 iii. Performing multiple runs for different volume scenarios. For example, 1,920  
 42 simulation runs are needed to evaluate 24 hourly volumes over a design life of 20  
 43 years for 4 intersection types.
- 44 iv. Analyzing the results and reporting the decision choice can be time consuming.  
 45

1           Several studies have developed statistical models that predict the micro-simulation–  
2 generated performance measures using a range of volume-based input variables (24, 29, and 30).  
3 These models reduce the time spent in step three listed above, but steps one and four are still  
4 time consuming. These statistical models also require re-calibration and re-evaluation prior to the  
5 evaluation of new conditions.

6           Another set of tools used for decision assistance includes tools based on simplistic critical  
7 lane volume analysis. Examples of such tools include (i) Intersection Design Alternative Tool  
8 (IDAT), (ii) Alternative Intersection Selection Tool (AIST), and (iii) Capacity Analysis and  
9 Planning of Junctions (CAP-X). These MS Excel–based tools compare multiple intersection  
10 types on the basis of volume-to-capacity ratios generated using critical lane volume analysis (31,  
11 32, 33, 34, and 35). The drawback for such tools is that the volume-to-capacity ratio is a  
12 relatively simplistic performance measure. The volume-to-capacity ratios are not easily  
13 understood by decision makers or the general public and hence cannot be used to effectively  
14 communicate the results. Additionally, the volume-to-capacity ratios cannot be monetized to  
15 perform a benefit-to-cost analysis for the selected ILT intersections.

16           The Highway Capacity Software (HCS) can also be used to compare the performance of  
17 multiple ILT intersections. The benefits of using HCS as a screening tool are as follows:

- 18           i.       HCS is faster than micro-simulation in generating estimates of performance  
19           measures.
- 20           ii.     HCS is based on multiple studies conducted throughout United States. HCS uses  
21           results from these studies to generate appropriate calibration factors to calibrate  
22           HCS for existing operating conditions. For example, the gap acceptance threshold  
23           for heavy vehicles can easily be selected from the appropriate table to model  
24           given field conditions. These thresholds are a result of multiple validation and  
25           calibration studies.
- 26           iii.    HCS produces several important performance measures, such as delays, that can  
27           easily be understood and monetized.

28           The current version of HCS (6.50 at the time of this study) does not allow direct coding  
29 of ILT intersections. However, a few studies have used indirect techniques to successfully code  
30 ILTs in HCS 6.50 (26, 36). There is also a plan to include the direct coding of ILT intersections  
31 in the next release of HCS. Despite of the benefits listed above, performing multiple runs of HCS  
32 can be time consuming. Additionally, there are no tools that can quickly compile and report the  
33 performance of different ILT intersections for a given intersection.

34           An important aspect that the current tools and past studies about ILT intersections are  
35 missing is the inclusion of cost and benefit in the evaluation. Because the implementation of ILT  
36 intersections is associated with a relatively large investment, it is imperative for planners to  
37 evaluate ILT intersections in terms of costs and benefits before reaching a decision. A few  
38 studies (26, 37) provide an economic analysis of ILT intersections. However, they were more  
39 focused on either specific types of ILT intersections or specific engineering projects, and a  
40 generic decision support system cannot be developed based on those findings. Against this  
41 backdrop, the incorporation of cost and benefit into the evaluation of ILT intersections for the  
42 development of a decision support system is a new concept. It should be noted that a similar tool  
43 using micro-simulation could potentially be developed but will be significantly more time  
44 consuming to use and would need external optimization routines.

## 1 DELAY ESTIMATION

### 2 Volume Input and HCS Network

3 SILCC provides for the input of bidirectional hourly volumes for a 24 hour period for major  
4 streets and unidirectional hourly volumes for a 24 hour period for minor streets. The  
5 bidirectional volume can be multiplied by a user's defined balance factor (BF) to compute each  
6 approach volume for a major street, which can be further divided into through and left turn  
7 volumes by multiplying by a user's defined left turning percentage (LTP). For minor streets,  
8 SILCC considers 0.5 as the BF and 5% as the LTP and performs the calculation internally.  
9 Similarly, users have the flexibility to input different truck percentages. SILCC projects the  
10 volumes throughout a life cycle period of 20 years based on the user's defined annual increment.  
11 By default, SILCC considers a 2% annual increment of traffic on major streets and a 1% annual  
12 increment of traffic on minor streets. Each of the four intersections, (i) standard signalized  
13 intersections, (ii) MUT, (iii) CFI, and (iv) jughandles, have a total of 480 volume combinations,  
14 including a 20 year projection for each hourly volume for 24 hour periods. All the intersections  
15 were coded in HCS Streets. Network coding for MUT and CFI was adopted from the method  
16 prescribed in a report published by the University of Florida (36), and it was further extended for  
17 jughandles. Fully actuated signal operation was taken into account.

18

### 19 Batch Processing and Estimation of Control Delay

20 To run all 480 combinations for each of the four intersection types, HCS was interfaced with MS  
21 Excel by developing macros to administer the batch processing of HCS files through MS Excel.  
22 The HCS output provided the control delay (seconds/vehicle) for each movement of signalized  
23 intersections and signalized crossovers.

### 24 Travel Delay and Delay at Median Openings and Crossovers for MUT and Jughandle

25 SILCC considers 45 mph and 35 mph to be the default speeds on major and minor streets,  
26 respectively. However, users have the flexibility to alter the speeds by adjusting all the  
27 parameters that depend on speed in the input sheet as well as in the HCS file. The travel delay for  
28 left turn movements was calculated based on speed and distance. The distances are based on the  
29 geometry of the ILT intersections, which can be altered by users. The estimation of delay at  
30 median openings and crossovers at the ramp merge points of jughandles was performed using  
31 queueing flow theory assuming Poisson distribution of arrivals and exponential distribution of  
32 service with a single server. This is also known as an M/M/1 queue. The total system delay of an  
33 M/M/1 queue is the sum of queue delay and server delay expressed by the following equation:

34

$$35 \quad W_s = \frac{\lambda}{\mu \times (\mu - \lambda)} + \frac{1}{\mu} \quad 1$$

36 where  $W_s$  is the total system delay,  $\lambda$  is the arrival flow rate, and  $\mu$  is the departure flow rate.

37 The departure flow rates for the median opening and crossover are the same as for the  
38 capacity of the opening or ramp junction. The rates are based on opposing flow, critical gap, and  
39 follow-up headway, as provided by the Highway Capacity Manual 2010 (HCM 2010) (38)  
40 equation to compute the capacity of stop-controlled movement using a gap acceptance model.  
41 The follow-up headway and critical gap were calculated based on HCM 2010 equations 19-30  
42 and 19-31 for the respective values for U-turn movements at MUT median openings and right  
43 turn movements at jughandle crossovers. These equations are expressed as follows:

$$C_{p,x} = \frac{V_{c,x} e^{-\frac{v_{c,x} t_{c,x}}{3600}}}{1 - e^{-\frac{v_{c,x} t_{f,x}}{3600}}} \quad 2$$

$$t_{c,x} = t_{c,base} + t_{c,HV} P_{HV} \quad 3$$

$$t_{f,x} = t_{f,base} + t_{f,HV} P_{HV} \quad 4$$

where  $C_{p,x}$  is the potential capacity of movement x (vehicles/hour),  $V_{c,x}$  is the conflicting flow rate for movement x (vehicles/hour),  $t_{c,x}$  is the critical headway for minor movement (s),  $t_{f,x}$  is the follow-up headway for minor movement x (s),  $t_{c,base}$  is the base critical headway,  $t_{c,HV}$  and  $t_{f,HV}$  are the adjustment factors for heavy vehicles,  $P_{HV}$  is the proportion of heavy vehicles for movement, and  $t_{f,base}$  is the base follow-up headway.

The values for base critical headway and follow-up headway can be obtained from HCM 2010 Exhibit 19-10 and Exhibit 19-11, depending on the type of movement. For median openings, the corresponding values from these exhibits for a U-turn from a major street should be used. Similarly, for crossovers of jughandles, corresponding values from these exhibits for a right turn from a minor street should be used. The adjustment factors for heavy vehicles for critical headway and follow-up headway are dependent on lane configurations and are also provided by HCM 2010.

## ESTIMATION OF FUEL CONSUMPTION AND EMISSIONS

### Estimation of Fuel Consumption

The American Association of State Highway and Transportation Officials (AASHTO) Red Book has provided a table that gives fuel consumption in gallons per minute delay ( $gal_{c,min}$ ) by vehicle type, such as small car, big car, sport utility vehicle (SUV), two-axle single unit vehicle, three-axle single unit vehicle, and combo, according to free-flow speed (39). This table was utilized to compute fuel consumption at intersections and crossovers. Six vehicle categories were combined to form two categories: cars and heavy vehicles. The  $gal_{c,min}$  of vehicle type car is the average of the  $gal_{c,min}$  values of small cars, big cars, and SUVs. Similarly, the  $gal_{c,min}$  of heavy vehicles is the average of the  $gal_{c,min}$  values of two-axle single unit vehicles, three-axle single unit vehicles, and combos. Table 1 shows the  $gal_{c,min}$  value of cars and heavy vehicles computed by this method. To compute fuel consumption, the delay (seconds/vehicle) for each intersection was converted to delay in vehicle minutes separately for cars and trucks. The vehicle minute delay values of cars and trucks were multiplied by the respective  $gal_{c,min}$  values from Table 1 to get fuel consumption by each vehicle type. Similarly, to calculate fuel consumption from travel delay especially related to MUT and jughandles, a table was referenced in the AASHTO Red Book that provides the fuel consumption in gallons per mile for autos and trucks with respect to operating speed. The values from that table from the AASHTO Red Book are shown in Table 2.



1                    **TABLE 1 Fuel Consumption (Gallons) per Minute of Delay by Vehicle Type**

Free Flow Speed (mph)	Small Car	Heavy Vehicle (Truck)
20	0.02	0.12
25	0.02	0.16
30	0.03	0.19
35	0.03	0.23
40	0.03	0.26
45	0.04	0.30
50	0.04	0.34
55	0.05	0.37
60	0.06	0.41
65	0.06	0.45
70	0.07	0.49
75	0.08	0.53

2

3

**TABLE 2 Fuel Consumption Related to Operating Speed**

Speed (mph)	Gallons per Mile	
	Autos	Trucks
5	0.117	0.053
10	0.075	0.316
15	0.061	0.254
20	0.054	0.222
25	0.05	0.204
30	0.047	0.191
35	0.045	0.182
40	0.044	0.176
45	0.042	0.170
50	0.041	0.166
55	0.041	0.163
60	0.040	0.160
65	0.039	0.158

4

**5 Estimation of Emissions**

6 This study estimated four major types of vehicular emissions: carbon monoxide (CO), oxides of  
7 nitrogen (NO<sub>x</sub>), volatile oxygen compounds (VOCs), and carbon dioxide (CO<sub>2</sub>). Cobian et al.  
8 (40) developed the factors to convert fuel consumption in gallons to gram unit weight of  
9 emissions like CO, NO<sub>x</sub>, and VOCs. These factors are 69.9 grams/gallon for CO, 13.6  
10 grams/gallon for NO<sub>x</sub>, and 16.2 grams/gallon for VOCs. Similarly, the U.S. Department of  
11 Energy has published a document (41) that correlates CO<sub>2</sub> emissions in grams to fuel  
12 consumption for gasoline and diesel. The conversion factor for gasoline consumption to CO<sub>2</sub>

1 emissions is 17.59 grams/gallon. The conversion factor for diesel consumption to CO<sub>2</sub> emissions  
2 is 22.37 grams/gallon.

#### 3 4 **MARGINAL USERS' AND NON-USERS' COSTS AND MONETIZATION**

5 A user's marginal cost pertains to the difference in the cost of delay and fuel consumption when  
6 new ILT intersections are constructed instead of signalized intersections or when a standard  
7 signalized intersection is retrofitted with ILT intersections. Similarly, a non-user's cost pertains  
8 to the difference in the cost of emissions when new ILT intersections are constructed instead of  
9 signalized intersections or when a standard signalized intersection is retrofitted with ILT  
10 intersections. These costs are calculated by subtracting the amount of each item produced by a  
11 standard signalized intersection from the amount of each item produced by an ILT intersection.  
12 If the deducted value is negative, it is called a negative cost or a benefit. Unit prices of each item  
13 can be calculated either by their own rate analysis or by referencing past literature. The default  
14 unit price of time in congestion (price of delay) was considered to be \$16.79/hour based on the  
15 2012 Urban Mobility Report (42). The default unit prices of fuel for diesel and gasoline were  
16 calculated by averaging the 2012 average gas prices for Nebraska provided by AAA's Fuel  
17 Gauge Report (gasoline was \$3.704/gallon, diesel was \$3.956/gallon) (43). The default unit price  
18 of CO<sub>2</sub> (\$0.02/kg) was taken from the 2010 Annual Supplement to the National Institute of  
19 Standards and Technology (NIST) (44). The default unit price of CO (\$200/ton) was taken from  
20 a technical paper by Bishop et al. (45). Similarly, unit prices for NO<sub>x</sub> (\$250/ton/year) and VOCs  
21 (\$180/ton/year) were taken from Muller and Mendelson (46) considering median damage cost.  
22 These prices are listed in Table 3. In SILCC, users are allowed to alter these prices if needed.  
23 These marginal benefits were monetized by multiplying the quantities by respective unit prices.

#### 24 25 **MARGINAL AGENCY COST AND MONETIZATION**

26 The marginal agency cost includes the marginal agency cost for both new construction of ILT  
27 intersections and retrofits of ILT intersections compared to the cost for standard signalized  
28 intersections. The marginal agency cost includes the cost of construction, preliminary  
29 engineering (PE) costs, and the additional operation and maintenance (O&M) cost. The marginal  
30 construction quantities for new construction were estimated based on the additional pavement  
31 requirement, additional signals and installations with the related accessories, and additional right  
32 of way needed for new ILT intersections compared to those values for standard signalized  
33 intersections. The construction quantities for retrofits were estimated based on the additional  
34 pavement requirement, removal of existing pavements, additional signals and installations with  
35 the related accessories, etc., needed while retrofitting standard signalized intersections with ILT  
36 intersections. The latest English average unit prices (AUP) from the Nebraska Department of  
37 Roads (NDOR) (47) were used as the default unit prices of items in SILCC. The default unit  
38 price of land (\$4,142.5/acre) was calculated with reference to the United States Land Values  
39 2012 Summary (48) by averaging the unit price of real estate land (\$2,590/acre), cropland  
40 (\$4,480/acre), irrigable land (\$6,000/acre), and non-irrigable land (\$3,500/acre). However, the  
41 users were provided flexibility to alter these rates. The PE cost involves expenses for activities  
42 from planning to final design of a project. According to Turochy et al., most state departments of  
43 transportation (DOTs) consider PE cost to be in the range of 5% to 20% of the construction cost,  
44 depending on the project size and scope (49). Remaining in that range, this study considered the  
45 PE cost to be 10% of the construction cost. Contingency was assumed to be 20% of the  
46 construction cost (26). These costs are listed in Table 3. The O&M unit price for CFI was

1 estimated based on the service requirement for additional signal heads and detectors, signal  
 2 retiming cost, and power supply cost. Similarly for MUT and jughandles, the unit price of O&M  
 3 was fixed based on the cost for landscaping medians and the area enclosed by reverse ramps. The  
 4 agency costs were monetized by multiplying the quantities of each item by respective unit prices.  
 5 The computed marginal costs of all three ILT intersections having the configuration of a four-  
 6 lane major street and a two-lane minor street for new construction and retrofits corresponding to  
 7 the default values in SILCC are shown in Table 4.

8  
 9 **TABLE 3 Variables and Related Information**

10

<b>Construction Cost Related</b>		
<b>Items</b>	<b>Prices</b>	<b>Source of Information</b>
Land (Right of Way)	\$4142.5/Acre	United States Land Values 2012 Summary
All other Constructed related Unit Prices	According to AUPs from NDOR	NDOR website
PE Cost	10% of construction cost	Turochy et al. (2001)
Contingency	20% of construction cost	Boddapati (2008)
<b>Unit Prices of Operational Performance Measures</b>		
<b>Items</b>	<b>Unit Prices</b>	<b>Source of Information</b>
Delay	\$ 16.79/hour	2012 Urban Mobility Report
Petrol	\$ 3.704/gallons	AAA's Fuel Gauge Report
Diesel	\$ 3.956/gallons	
CO <sub>2</sub>	\$ 0.02/kg	U.S. Department of Energy: NIST (2010)
CO	\$ 200/ton	Bishop et al. (1993)
NO <sub>x</sub>	\$ 250/ton/year	Muller and Mendelson (2009)
VOC <sub>s</sub>	\$180/ton/year	

**TABLE 4 Computed Marginal Cost of ILT Intersections**

Intersection Type	Construction Cost + Soft Cost Including Contingency (US \$)		O&M Cost (US \$)	
	New Construction	Retrofit	New Construction	Retrofit
MUT	36, 763	680, 426	2, 000	2, 000
CFI	279, 226	439, 799	24, 000	24, 000
Jughandle	64, 551	64, 635	2, 000	2, 000

**LIFE CYCLE COST ANALYSIS (LCCA)**

SILCC is capable of performing life cycle cost analysis (LCCA) on monetized agency, user's, and non-user's marginal costs to determine the NPV and B/C of new construction and retrofits for ILT intersections. The life cycle period of the retrofits was assumed to be 20 years. The default discount rate was kept at 3% with no inflation for each year (26). However, users may alter it. The annual increase of traffic was considered to be 2% for major streets and 1% for minor streets. The delay for each of the projected volumes for a 20 year period was estimated by batch running the HCS 2010 . The respective fuel consumption and emissions and their annual costs were estimated. The operation and maintenance cost was assumed to be the same throughout the life cycle period. The NPV was estimated using the following equations:

$$NPV \text{ of Total} = NPV \text{ of Benefits} - NPV \text{ of O\&M Cost} - \text{Construction Cost} - PE \text{ Cost} \quad 5$$

$$\begin{aligned} \text{Benefit to Cost Ratio (B/C)} \\ = NPV \text{ of Benefits} / \{ NPV \text{ of O \& M Cost} \\ + (\text{Construction Cost} \\ + PE \text{ Cost}) \} \quad 6 \end{aligned}$$

$$NPV \text{ of O \& M Cost} = \left( \frac{1}{i} \right) \times \left\{ 1 - \frac{1}{(1+i)^N} \right\} \quad 7$$

$$NPV \text{ of Benefits} = \sum_{N=0}^{20} P_N \times \frac{1}{(1+i)^N} \quad 8$$

where N is the life cycle period, i is the discount rate (3%), and P<sub>N</sub> is the yearly negative or positive benefits.

If any retrofits or new ILT intersections failed due to high demand in any year throughout the life cycle period, the NPVs of those retrofits were calculated assuming a reduced life cycle period. The reduced life cycle period equals the time period up to which intersection operation is feasible. This case is applicable for MUT and jughandles because they were evaluated with

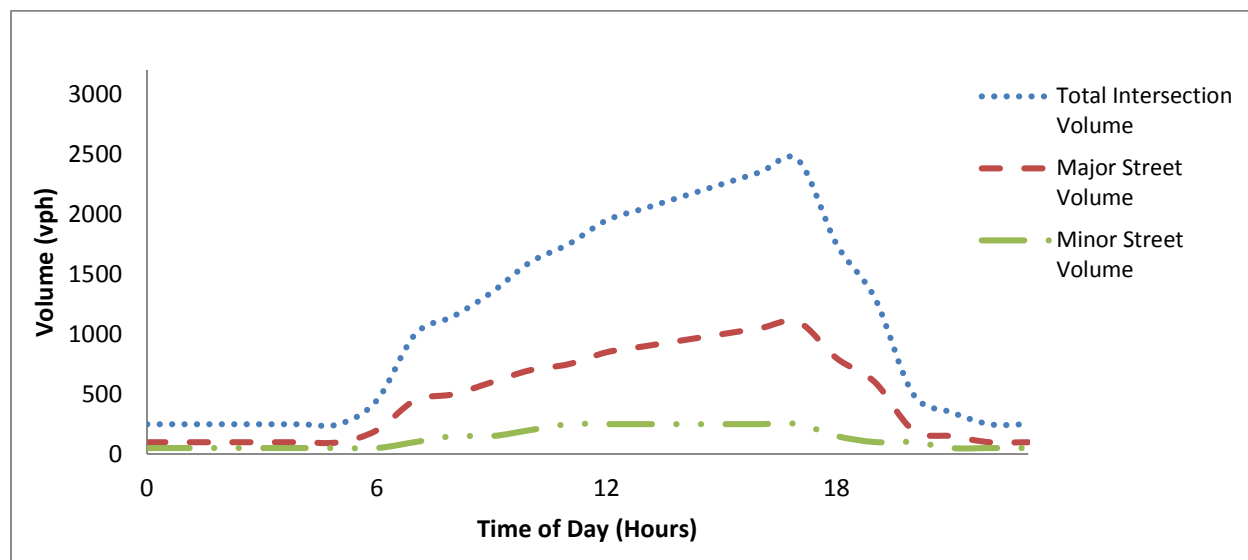
1 M/M/1 queues, where the server's capacity should not be exceeded by demand. This is because  
 2 the queuing system works until the utilization factor (ratio of demand to service capacity)  
 3 remains less than 1.

4

#### 5 **A CASE STUDY PERFORMED WITH SILCC**

6 As a case study, a volume pattern was developed for a rural road following one of the 24 hour  
 7 data patterns provided by Williams and Ardekani (50). The developed pattern is shown in Figure  
 8 1. The delay, fuel consumption, and emissions were estimated for each unit of 24 hour volume  
 9 data considering 10% truck and 5% left turning traffic using SILCC for the whole 20 years of the  
 10 life cycle period and considering a default annual increment in traffic (2% on major streets and  
 11 1% on minor streets). A default lane configuration of a four-lane major street with a speed of 45  
 12 mph and a two-lane minor street with a speed of 35 mph was considered. The construction  
 13 estimates for retrofits and new construction for ILT intersections were the same as those  
 14 discussed in previous sections. Similarly, corresponding default rates of items were used as  
 15 mentioned in previous sections. SILCC provided the results from the LCCA, as displayed in  
 16 Table 5. The results indicate that an MUT intersection would have the highest NPV total for both  
 17 retrofit and new construction. However, due to its high construction cost for retrofit, the B/C  
 18 ratio of MUT is lower than that of a jughandle. MUT has the highest B/C for new construction. It  
 19 should be noted that NPV is considered a more stable measure because the B/C ratio might  
 20 produce different results if a cost is replaced as a negative benefit by the analyst.

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**FIGURE 1 Volume pattern for a rural road**

**TABLE 5 LCCA Results for Case Study**

Cases	LCCA Outcomes	MUT	CFI	Jughandle
New Construction	Marginal Construction + Marginal Soft Cost (US \$)	36,763	279,226	64,551
	NPV of Marginal O&M Cost (US \$)	29,755	357,059	29,755
	NPV of Marginal Operational Benefit (US \$)	4,398,266	949,519	2,349,585
	NPV Total (US \$)	4,331,748	313,233	2,255,279
	B/C	66.12	1.49	24.91
Retrofits	Marginal Construction + Marginal Soft Cost (US \$)	680,426	439,799	64,635
	NPV of Marginal O&M Cost (US \$)	29,755	357,059	29,755
	NPV of Marginal Operational Benefit (US \$)	4,398,266	949,519	2,349,585
	NPV Total (US \$)	3,688,084	152,660	2,255,195
	B/C	6.19	1.19	24.89

## CONCLUSION

Realizing the need to incorporate cost and benefit aspects in the decision making process, the tool developed from this study took into account the costs and benefits related to ILT treatments of standard signalized intersections, whether with new construction or with a retrofit. This is the first time that the economic aspect has been incorporated into a decision assistance tool for ILT intersections. Additionally, the tool utilizes a macroscopic-level analysis of the operation of intersections using HCS software, which provides widely acceptable estimations of performance measures. The tool also considers fuel consumption and emissions in operational analysis as well as in economic analysis. The tool was developed by keeping it as simple as possible and providing flexibility for users to alter the input to fit with the required local conditions. Overall, the developed tool can perform as a very good decision assistance tool for planners when making crucial decisions about suitable ILT treatments. Finally, a study is recommended to incorporate safety aspects and the impact of multimodal users into updates for the tool. Because past studies have noted that ILTs are relatively safe compared to conventional intersections, one can expect a safety component to increase the benefits. Similarly, a future study can further evaluate the potential impact of each cost variable in the LCCA results.

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