DEVELOPMENT OF A NEW PROCEDURE TO PRIORITIZE INTERSECTION SAFETY IMPROVEMENT PROJECTS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

As traffic demands increases, it is essential that transportation planners and traffic engineers consider possible improvements to the existing conditions of roadway systems. A roadway intersection needs to be analyzed in terms of its safety, geometric and operational conditions for the purpose of potential improvements. This report presents results obtained from a research project performed to develop a new procedure to prioritize intersections for safety improvements. The procedure developed through the study considers both safety performance and traffic operational performance. For safety, the benefit cost (B/C) ratio was considered, and for traffic operational, average total delay. The study was conducted by reviewing existing reports and information databases, conducting field data collection for traffic turning movements and geometric conditions, and developing a new model with the use of a utility function and a logit model to prioritize intersections. A case study was performed to test the model. Three priority lists for the year 1996 were determined as the application of the new procedure. The first priority list was based on safety factors, the second priority list on operational factors, and the third priority list on safety and operational factors.

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CHAPTER 1. INTRODUCTION

Urban populations and traffic volume have expanded significantly over the past 30 years. The traffic volume increase has deteriorated travel conditions in the roadway system. The knowledge of existing conditions of the roadway system becomes an essential element for transportation planners and traffic engineers because this knowledge provides the basis for decisions regarding highway system improvements and improvement priorities [1]. These highway system improvements require a proper assessment based on current and anticipated operational deficiencies and safety problems. These improvements are particularly significant at an intersection because it establishes urban arterial system capacity and operational conditions.

Improvement programs for the highway system including intersections are developed and implemented in each state of the United States. Currently, the Federal Highway Administration sets the policy for the improvement program called Highway Safety Improvement Program (HSIP). The overall objective of the HSIP is to reduce the number and severity of crashes and decrease the potential for crashes. This program contains components for planning, implementation, and evaluation of safety projects and programs. The procedures of the HSIP are appropriate for individual highway systems and any portion of the highway, including all public roads.

The HSIP mostly refers to safety concerns, and many state departments of transportation use methodologies based on safety conditions to analyze highway improvements. In relation to intersections, the procedures used by most transportation agencies to prioritize their improvements are based on crash data and construction costs without considering operational factors such as delay and level of service [2]. The prioritization process is mostly done using the economic analysis denominated benefit cost ratio (B/C). This B/C ratio analyzes cost effectiveness of an intersection improvement project, based on the benefit of preventable crashes at a location due to proposed safety improvements and the total cost to implement the proposed improvements. This implicates that problems such as traffic congestion, vehicle delays, and vehicle emissions along with their cost are not addressed in the methodologies. Another aspect to be considered is the possible relationship between traffic volume and crash number, as it is referred in several studies. Jadaan and Nicholson [3] concluded that this relationship for urban road links is statistically significant.

If safety factors and operational factors are included in the procedure to prioritize intersection improvements, the results may be more cost-effective and may more practically reflect the safety improvement needs. It could also be possible to analyze safety factors and operational factors separately or to combine them together to get a better idea about the needs to improve each intersection. One of the operational factors at an intersection is the average total delay [4]. The total delay is defined by the 1994 Highway Capacity Manual (HCM) as the time spent by an individual vehicle stopped in a queue while waiting to enter an intersection. The average total delay is the total delay experienced by all vehicles arriving during a designated period divided by the total volume arriving during the same period [5]. The inclusion of operational factors such as delay along with safety factors in the process would permit the analysis of a greater set of problems at these locations such as crash number, crash severity, traffic congestion, traffic delay, and vehicular emissions. Such an analysis would reflect a greater number of benefits in improvement programs and a better assessment in the allocation of available funds.

Current methodologies used to prioritize intersections consider safety performance and operational performance separately. The methodology used in Tucson, Arizona evaluates short to medium term improvements at signalized intersections, and ranks intersection operational deficiencies based on a deficiency index [1]. Another methodology used in Brooklyn, New York identifies the most severe problems in locations affecting travel corridors in Brooklyn without involving massive investments [6]. A quantity formula is used in the methodology to evaluate the severity of delay and the frequency of crashes at each intersection. The methodology used in Beaumont/Port Arthur, Texas looks for potential transportation improvements related to reduction in vehicular emissions [7]. This methodology considers emission reductions, delay reductions and project costs for prioritizing proposed Congestion Mitigation and Air Quality (CMAQ) intersection improvement projects. In Florida, the existing methodology considers only safety factors. The benefit cost ratio (B/C) is used to prioritize intersections. This procedure does not consider operational factors. In fact, intersection safety performance is somehow related to traffic operational performance at the intersection or nearby area.

This report is based on a research project sponsored by Hillsborough County, Florida. The main objectives of the study were to develop a new procedure considering safety and operational factors for intersections prioritization purposes based on the data collected in 1994 and to apply the new procedure to prioritize the intersections to be included in the improvement list for 1996 in Hillsborough County. This new procedure includes the benefit-cost analysis and capacity/delay analysis.

CHAPTER 2. THE NEW PROCEDURE

Identification of Intersections for Preliminary List

Figure 1 presents the conceptual steps of the new procedure developed in the study. The first step in the new procedure is to select the intersections for a preliminary list to be analyzed for possible improvements. The number of preventable crashes at each location determines the intersections on this list. Intersections are first identified according to number of crashes, which is available from the Sheriff's Office. For each crash listed at each location, the crash type is determined by checking the corresponding crash report. The crash type allows an estimate of the number of crashes that could be prevented if an improvement is implemented at the intersection. The intersections with the greatest number of preventable crashes would be included in the preliminary list for prioritization.

Data Collection

Once the preliminary list is ready, the next step is to find the necessary data. The basic data types include the number and type of crashes, traffic turning movement volumes, traffic signal timing, intersection traffic control methods and regulations, and intersection geometric conditions. The crash data can be obtained from the Sheriff's Office. Traffic turning movement, geometric data, and signal timing plans for signalized intersections can be obtained from the county's office or by field data collection.

Intersection Delay Analysis

After all necessary data are collected; the average total delay of the existing signalized and unsignalized intersections can be analyzed. This delay defined as d_1 is a performance indicator for an existing intersection before improvement. For a signalized intersection, Chapter 9 of the 1994 Highway Capacity Manual (HCM) [4] can be used to estimate this delay with the following equations:

$$d_1 = d_u DF + d_I \qquad (1)$$

$$d_u = \frac{0.38C[1-(g/C)]^2}{[1-(g/C)x]} \qquad (2)$$

where

d_u = uniform delay term (sec/veh),

$$d_i = 173x^2\left[(x-1)+\sqrt{(x-1)^2+\frac{mx}{c}}\right] \quad (3)$$

d_i = incremental delay term (sec/veh),

DF = delay adjustment factor for quality of progression and control type,

C = cycle length (sec),

g = effective green time,

g/C = ratio of effective green time to cycle length,

c = capacity (veh/hr),

x = degree of saturation, and

m = incremental delay calibration factor.

For a noncoordinated intersection, DF depends on the control type. If it is a pre-timed control, DF = 1.0. If it is a semi-actuated or full-actuated control, DF = 0.85. For a coordinated intersection, DF is calculated as follows:

$$DF = \frac{(1-P_g)}{(1-g/C)} f_p \quad (4)$$

where

P_g = percent arrivals on green, and

f_p = early or late platoon arrival factor.

Three components of delay are considered in the delay model. The first term of the delay model accounts for the uniform delay with the assumption that vehicles arrive at a uniform rate. The second term represents random delay and delay due to oversaturation. The signalized intersection delay model accounts for platoon arrivals through the use of the delay adjustment factor DF. The adjustment factor is applied to the uniform delay of the first term in the delay model. To account for the non-random arrivals, the variable m is applied to the second term of the delay model. Along an arterial, the random delay may be affected by the upstream intersection. As traffic volume approaches the capacity, the delay at downstream intersection increases, but the random component of the delay decreases. However, the influence of random component may increase as traffic volume approaches the capacity because the interaction between vehicles becomes more significant. The 1994 HCM delay model uses the variable m to reflect the non-random arrivals from the neighboring intersections. Hence, the effects from neighboring intersections can be taken into consideration when intersection delay is to be estimated.

For unsignalized intersections, the delay models are included in Chapter 10 of the 1994 HCM. To estimate the average total delay at a two-way STOP-controlled (TWSC) intersection, the movement volumes should be collected and corresponding movement capacities should be estimated. The average total delay (d_1) model for TWSC intersections is listed as follows:

$$d_1 = \frac{3600}{c_{m,x}} + 900T\left[\frac{V_x}{c_{m,x}} - 1 + \sqrt{\left(\frac{V_x}{c_{m,x}} - 1\right) + \frac{\left(\frac{3600}{c_{m,x}}\right)\left(\frac{V_x}{c_{m,x}}\right)}{450T}}\right] \quad (5)$$

where

V_x = volume for movement x (veh/hr),

$c_{m,x}$ = capacity of movement x (veh/hr), and

T = analysis period (hr).

To estimate the average total delay at a four-way STOP-controlled (FWSC) intersection, approach volumes should be collected and approach capacities should be estimated. The model to estimate the average total delay (d_1) at FWSC intersections is listed as follows:

$$d_1 = e^{3.8V/c} \quad (6)$$

where

c = capacity of subject approach (veh/hr), and

V = volume of subject approach (veh/hr).

The United States Federal Highway Administration developed a computer package called Highway Capacity Software (HCS) [8]. Basically, the HCS simulates the models included in the 1994 HCM. Practically, to estimate intersection average total delays at signalized intersections and unsignalized intersections, the HCS can be used. However, in order to use the HCS, field data should be collected to include intersection turning movements, traffic compositions, intersection geometric conditions, and intersection control methods including timing plans. The intersection timing plans at upstream intersections and arrival types should also be considered so that the adjustment factors DF and m can be correctly used. More details can be found from the HCM and other references [9,10]

Warrants for Traffic Signals

The next step is to check the warrants included in the Manual on Uniform Traffic Control Devices [11] to determine whether or not unsignalized intersections included in the preliminary list meet the warrants for signals. Three of the eleven warrants can be used in the process based on available data. They are accident experience, peak hour delays, and peak hour volumes. The warrant related to accident experience refers to an accumulated number of crashes in a specific time period. The peak hour delay warrant relates traffic volumes to an expected vehicle waiting time. The peak hour volume warrant considers volumes from major and minor streets during peak hour. These warrants are used to decide whether a signal is warranted as a way to improve existing unsignalized intersections. Principally, at least one of the warrants should be met to warrant a traffic signal. Also, engineering studies should indicate that the installation of the signal will improve the overall safety and/or operational performance of the intersection.

Proposed Improvement Projects

Feasible improvements for each intersection need to be proposed and discussed based on engineering considerations, identified crash types, warrant study results and field visits. Usually, one or more improvement projects can be determined for a particular intersection. Before improvements are proposed, crash types at each intersection need to be reviewed. This review process may result in corresponding countermeasures. The Institute of Transportation Engineers (ITE) provides a very comprehensive overview of probable causes and generally effective countermeasures compiled by the United States Federal Highway Administration as published at the ITE Manual of Transportation

Engineering Studies [12]. Table 1 lists two typical crash types (left turn and head-on crashes at signalized intersection and right angle crashes at unsignalized intersections) and corresponding probable causes and countermeasures. More crash types can be checked from the ITE Manual of Transportation Engineering. Many countermeasures for safety and operational improvements have been implemented in the United States. These countermeasures can be categorized into several major groups, including (1) signalization, (2) channelization, (3) regulation, (4) delineation, (5) signing, (6) lighting, (7) flashing lights, (8) obstacle treatment, and (9) reconstruction. In the past, research studies have been performed to justify the countermeasures and estimate the crash reduction due to corresponding improvements based on the countermeasures. Table 2 provides some typical countermeasures and corresponding estimation of the crash reduction (percentage) for a particular crash type. Table 2 is based on a study conducted by Florida Department of Transportation (FDOT) in 1988 [13]. The database used to develop the crash reduction factors covered the crash data collected from the entire Florida state road system with a duration of 12 years. The data were stored in 24 magnetic tapes. Table 2 only lists part of the results summarized in the FDOT's study due to limited space of the report. More details can be found from the report by Wattleworth et al [13]. In summary, to determine improvement projects at an intersection, the ITE Transportation Engineering Manual can be checked to identify possible causes and countermeasures for each type of crashes that have happened at the intersection. Then, Table 2 or the tables summarized in the FDOT study can be used to estimate the percentage reduction of the preventable crashes based on the proposed countermeasures or improvement projects.

Safety and Cost-Benefit Analysis

Once the improvement projects at each intersection are proposed, safety and operational performances should be analyzed based on proposed improvements. For the safety analysis, two different steps need to be considered. First, the number of preventable crashes should be estimated. Each proposed improvement will specifically reduce the number of crashes with a particular crash type. The main way to estimate the number of preventable crashes is to check Table 2 presented in this report or the tables summarized in the FDOT study. Therefore, based on the table and proposed improvements, the number of preventable crashes could be estimated. Second, based on preventable crashes and proposed improvements, the benefit/cost ratios can be calculated. The total annual benefit for each intersection is determined by multiplying the number of preventable crashes by the crash cost, which is based on fatal, injury, and property damage. According to the study performed by FDOT, the crash costs are as follow [13]:

Fatal Crash	$1,700,000
Injury Crash	$ 14,000
Property Damage Only (PDO) crash	$ 3,000

The process to estimate the benefits is relatively easy. For example, for a STOP-controlled channelized intersection, there were 12 injury crashes and 30 PDO crashes in last year. If a traffic signal is proposed to replace the STOP signs at the channelized intersection, according to Table 2, the potential percentages of crashes reductions would be 42% and 43% for injury crashes and PDO crashes, respectively. Thus, the potential reductions of crashes would be:

Injury Crashes:	12 x 0.42 = 5.04
PDO Crash:	30 x 0.43 = 12.9

The potential benefits due to the installation of signals at the channelized intersection would be:

Benefit from Injury Crash Reduction:	5.04 x $14,000 = $70,560
Benefit from PDO Crash Reduction:	12.9 x $3,000 = $38,700

The total annual cost of the improvements includes costs resulted from items such as right of way, preliminary engineering and construction inspection factors (P.E.-C.E.I.), roadway, and signals. The cost of right-of-way is estimated by the county office for planning purposes. The P.E.-C.E.I. is calculated based on a FDOT procedure. A service life of 20 years is considered for this type of improvement. The roadway cost is calculated by the Traffic Engineering Division of Hillsborough County. Its service life is 20 years. The signal cost is a pre-estimated cost. The service life for the signals is 15 years. According to the service life, a Capital Recovery Factor (CRF) is assigned. Each cost item needs to be multiplied by its CRF and the sum of all these products gives an annual cost. The cost for crash clean up should be subtracted from this annual cost. The clean up cost value is determined by multiplying the number of preventable crashes by an estimated value of $100 per crash. This value is equal for any crash type. The final result is denominated the total annual cost. The B/C ratio is then calculated by dividing the total annual benefit by the total annual cost.

Operational Analysis

For the operational analysis, the following procedure should be considered. First, intersection delay would conceptually change from d_1 to d_2 after intersection improvements are completed, where d_1 is the delay before improvements, and d_2 is the delay after improvements. The HCS is used to estimate d_1 and d_2 based on the existing conditions and proposed improvements. For an intersection where a traffic light is warranted, it is necessary to estimate signal timing first before delay d_2 can be calculated. Finally, a new parameter (Δd) can be calculated from the difference between delays before and after improvements, or $\Delta d = d_1 - d_2$. Δd is called delay reduction due to improvements.

Priority Lists

The next step is to determine three priority lists. The first priority list (priority list I) refers to B/C ratio, the second list (priority list II) is ranked based on the sum of d_1 and Δd, and the third priority list (priority list III) is calculated using the variables B/C ratio, d_1, and Δd and a logit model.

The priority list I is determined by ranking the intersections included in the preliminary list according to the B/C ratio. It is ranked from the greatest B/C ratio to the lowest B/C ratio for the intersections. Each intersection should have a B/C ratio greater than one in order to be considered beneficial.

The priority list II is determined based on an average total delay rank. This average total delay rank is obtained considering delay (d_1) and Δd. d_1 and Δd are ranked separately with the highest value getting the highest rank (or rank 1). A final rank for delay is determined by adding the ranks of d_1 and Δd, and the lowest sum obtained gets the highest rank.

For the priority list III, a utility function (U) is used. The factors included in the utility are benefit/cost ratio (B/C), delay before improvements (d_1), and delay reduction due to improvements (Δd). The utility is based on the following linear equation:

$$U = a_0 + a_1 (B/C) + a_2 d_1 + a_3 \Delta d \tag{7}$$

where

U = utility,

B/C = benefit/cost ratio,

d_1 = delay before improvements,

Δd = delay reduction due to improvements, and

a_0, a_1, a_2, and a_3 = coefficients.

In fact, the selection of intersections for safety improvements is a discrete choice problem which can be modeled with a logit model. The attributes such as the benefit/cost ratio, delay before improvements, and delay reduction due to improvements affect the selection of alternatives (intersections). A reasonable intepretation of the output of a logit model is the probability (between 0 and 1) to select a particular intersection for safety improvements. Thus, the logit model was proposed to generate the priority list. The logit model has the following form:

$$p = \frac{e^U}{1 + e^U} \tag{8}$$

where

P = output of the logit model, and

U = utility.

The logit model is mainly used to combine the safety and operational performances to generate a priority list of intersections for improvements. The logit model was developed in a previous study based on three priority lists for intersection improvements in 1994, 1995, and 1996 [2]. In that study, a preliminary priority list of intersections for each year was developed and intersections were ranked by the research team and transportation engineers from Hillsborough County with the considerations of safety, cost-effectiveness, and operational performance. Basically, if an intersection had relatively high traffic crash rate, poor traffic performance, and good cost-effectiveness of improvements, the intersection should get relatively high priority in the priority list. In this way, a preliminary priority list was developed. The logit model was calibrated based on the intersection ranks included in the priority list for each year and corresponding data (including B/C, d_1, and Δd). Due to the simplicity of the logit model, a Log-linear regression analysis was performed to calibrate the logit model and obtain the coefficients included in the utility. As a result of the analysis, the utility has the following form:

$$U = -1.4635 + 0.1380\ B/C + 0.0285\ d_1 + 0.0025\ \Delta d \qquad (9)$$

The P value obtained from the logit model is between 0 and 1. A larger P value means a higher priority. The third list (priority List III) is based on P values. The intersection with a larger P value has a higher priority for improvements.

The three priority lists are very useful for prioritizing purposes. Each one has a specific emphasis. List I is based on safety concerns; List II is based on traffic operations concerns; and List III combines both performances (safety and operational performances).

TABLE 1. Examples of Probable Causes and Possible Countermeasures for Some Crash Types

Crash Pattern	Probable Cause	Possible Countermeasures
Left-turn, head on	Restricted sight distance	Provide left-turn signal phase, Reduce speed limit,
		Remove sight obstruction, Install or improve warning sign,
		Provide turn lane, Provide adequate channelization.
	Amber phase to short	Adjust amber phase, Provide all-red phase.
	Absence of left-turn phase	Provide left-turn phase.
	Excessive speed	Reduce speed limit.
Right angle at unsignalized intersection	Restricted sight distance	Provide adequate channelization, Provide traffic signal,
		Remove sight obstruction, Install or improve warning sign,
		Provide STOP sign.
	Excessive speed	Reduce speed limit, Adjust amber phase, Install ramble strips.
	Inadequate roadway lighting	Improve roadway lighting.
	Large intersection volume	Provide traffic signal, Reroute through traffic.

TABLE 2. Estimated Crash Reductions (%) for Some Improvements

Improvement		Crash Reduction (%)											
		All	Fatal	Injury	PDO**	Rear End	Angle	Left Turn	Right Turn	Side Swipe	Fixed Obj.	Night	Ped.***
Signalization	New signal at Channelized Intersection	42	N/A	42	43	N/A	88	45	65	N/A	N/A	N/A	N/A
	Modify Both Signal and Channelization	52	N/A	71	43	N/A	54	86	N/A	87	N/A	N/A	N/A
Signing	Intersection Directional or Warning Sign	41	47	47	26	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Reconstruction & Miscellany	Install Accel./ Decel. Lanes	17	N/A	23	N/A	21	N/A	44	46	N/A	N/A	N/A	N/A
	Upgrade Signal and Add Feature for Pedestrians	56	N/A	56	61	N/A	N/A	81	N/A	N/A	N/A	N/A	N/A
Traffic Marking	Intersection General Marking	70	N/A	67	71	74	46	77	76	61	72	N/A	75
Lighting	New Lighting at Intersections	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Upgrade Lighting at Intersections	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Channelization	Modify Channelization at Signalized Intersection	36	N/A	47	30	28	N/A	67	50	27	N/A	27	83
	Add Right Turn	61	N/A	49	67	66	90	N/A	N/A	100	N/A	N/A	N/A

* This table is based on the results from the FDOT Study.[13]

** PDO – Property Damage Only

*** Ped. – Pedestrians

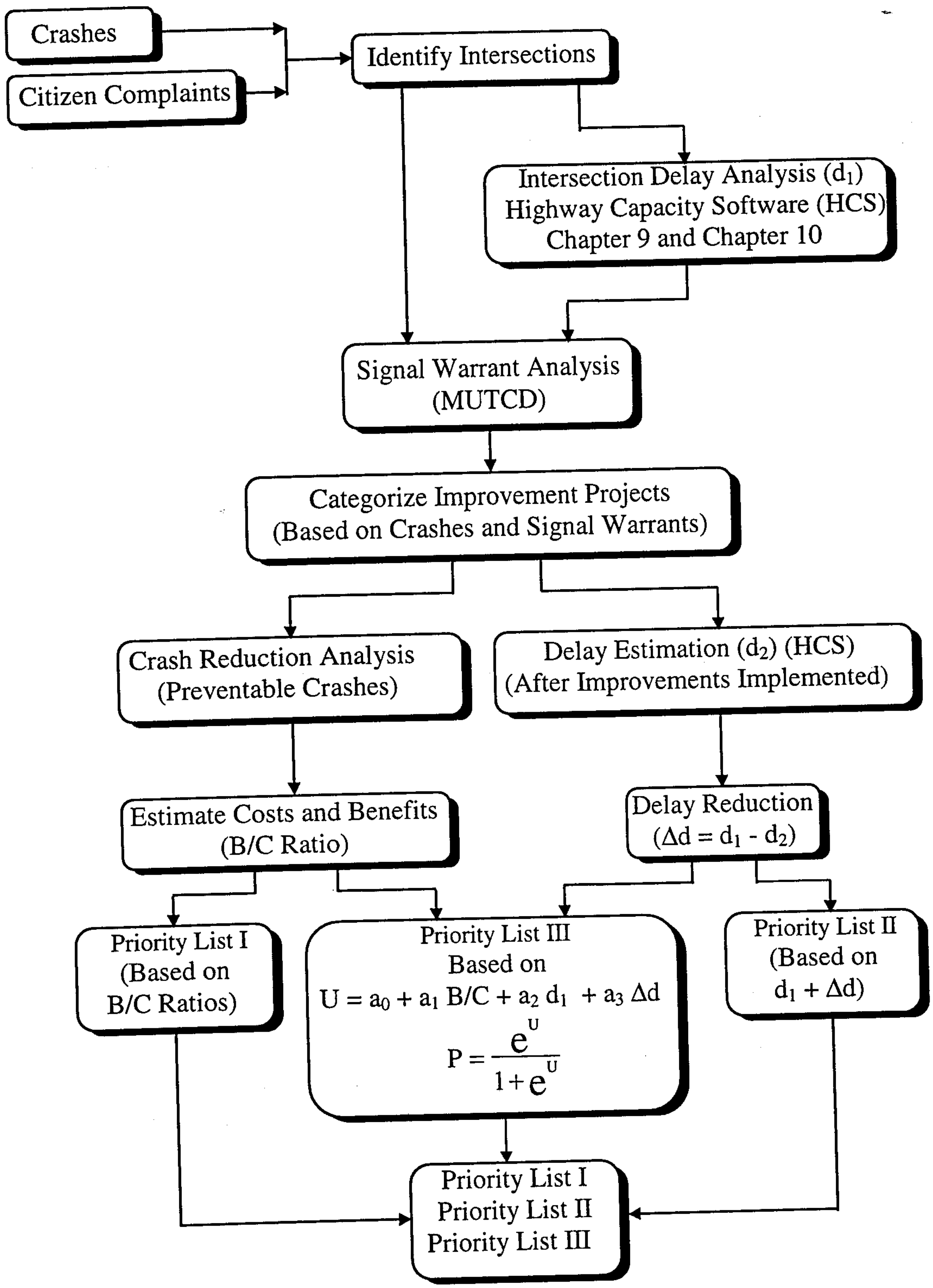

FIGURE 1. Proposed Methodology to Prioritize Intersection Improvements

CHAPTER 3. APPLICATION

A case study was done to apply the methodology developed in this research to prioritize intersections included in Hillsborough County's 1996 intersection priority list. The case study resulted in three priority lists, including a priority list (List I) based on safety performance, a priority list (List II) based on operational performance, and a priority list (List III) based on both performances.

Identification of Intersections for Preliminary List

The intersections studied in the case study were selected from the existing list for intersection improvements from Hillsborough County for 1996. These intersections were first identified based on number of crashes. The hazardous crash type for each intersection was determined based on crash records. Then, the number of preventable crashes for each intersection was estimated according to the hazardous crash type. Intersections with the highest number of preventable crashes were included in the preliminary list. Table 3 lists the intersections included in the list for 1996.

Data Source

The necessary data for the procedure consisted of crash data, traffic turning movements, traffic signal plans, and geometric data. The number of crashes at each intersection was determined by the county's office from a terminal station located at its office and connected to the Sheriff's Office database. For each intersection, the crashes considered should be within one hundred feet from the intersection. Once the crash data was completed, traffic and geometric data were collected for all the intersections considered in the case study. A total of 22 intersections (including 2 signalized intersections and 20 unsignalized intersections) were analyzed. The intersection type and improvements considered necessary for each one are also shown in Table 3.

Intersection Delay Analysis

After the necessary data were completed for 1996, the average total delay d_1 for existing conditions of all intersections considered in this case study were calculated using the Highway Capacity Software. In this analysis, all signalized intersections were noncoordinated pre-timed intersections and there were 17 TWSC unsignalized intersections and 3 AWSC unsignalized intersections. The delay adjustment factor DF for quality of progression and control type and the incremental delay calibration factor m were selected based on the guidelines presented in the 1994 HCM. Table 4 shows the existing delay data for the intersections listed for 1996.

Traffic Signal Warrants

Proposed improvement projects for the intersections considered in the case study included road geometric improvements and traffic light installation. Road geometric improvements were determined by the county's engineers. To determine if traffic lights were warranted at unsignalized intersections, the MUTCD warrant study was performed. Three of the eleven warrants were considered in this warrant study, including accident experience, peak hour delays, and peak hour volumes. The crash data used for the study was collected from the last three years and the traffic data used was collected during rush hours. Table 5 presents the warrant study summary.

Safety and Cost-Benefit Analysis

The B/C ratio was calculated based on the number of preventable crashes. The total annual benefit was determined by multiplying the number of preventable crashes by the crash cost, which was based on fatal, injury, and property damage values as discussed previously. The total annual cost was determined by adding different costs related to the implementation of the necessary improvements to prevent the estimated number of preventable crashes. These costs included right of way, construction costs, and traffic signal installation. The B/C ratio was determined by dividing the total annual benefit by the total annual cost. The B/C ratio data are presented in Table 6.

Operational Analysis

The average total delay after improvements (d_2) was calculated for all intersections. For intersections that warranted a traffic light, it was necessary to determine the signal timing based on the geometric conditions, proposed improvements, and predicted traffic turning movements. Table 7 shows the delay after improvements d_2 and delay reduction Δd ($\Delta d = d_1 - d_2$) for the intersections included in the 1996 list.

Priority Lists

Three priority lists for the year 1996 were determined based on considerations of safety factors, operational factors, and the combination of safety and operational performance. Priority list I was based on B/C analysis with the highest B/C ratio at the top of the list. Table 8 presents the 1996 priority list I. Priority list II was based on average total delay values d_1 and delay reduction Δd due to improvements. Table 9 shows the priority list II for 1996. Priority list III was based on the consideration of both safety and operational factors. The variables used in determining List III were B/C ratio, d_1 and Δd. The utility model presented previously was used to calculate the utility for each intersection. Then P values were calculated based on the logit model presented previously. According to P values, List III can be obtained. The intersection with a larger P value got a higher priority for improvement. Table 10 presents the priority list III for 1996.

TABLE 3. Intersections to be Prioritized in 1996

No	Intersection	Type	Improvement
01	Skipper & 42nd St.	AWSC[1]	Install traffic signal
02	Boyette & McMullen	TWSC[2]	Install traffic signal
03	Durant & Valrico	AWSC	Install traffic signal
04	Livingston & Vandervort	TWSC	Construct NB left turn lane
05	Hanna & Sunset Lane	AWSC	Install traffic signal
06	Gunn Highway & Race Track	TWSC	Install traffic signal
07	Bruce B. Downs & 42nd St.	TWSC	Install traffic signal
08	Waters Ave. & Rustic Dr.	TWSC	Install traffic signal
09	Himes & Idlewild	TWSC	Install traffic signal
10	Gunn Highway & N. Mobley	TWSC	Install traffic signal and construct LT lanes
11	Falkenburg & Princess Palm	TWSC	Install traffic signal
12	131 St. & 22nd St.	Signalized	Construct turn lanes
13	Broadway & Tampa East	TWSC	Install traffic signal and construct LT lanes
14	Lithia PineCrest & Guiles Rd.	TWSC	Construct turn lanes
15	Lumsden & Pauls	TWSC	Install traffic signal and construct LT lane on Paul's
16	Durant & Dover/Little	TWSC	Realign offset intersection (Dover/Little)
17	Bell Shoals & Rosemead	TWSC	Install traffic signal and construct LT lanes
18	Oakfield & Vonderburg	TWSC	Install traffic signal
19	Dale Mabry & Hamilton	TWSC	Install traffic signal and construct LT lanes
20	Palm River & US 301	Signalized	Construct EB RT lane
21	Sabal Industrial & US 301	TWSC	Install traffic signal and construct LT lanes
22	Savarese & Waters	TWSC	Install traffic signal

(1) AWSC = All Way Stop Control (2) TWSC = Two Way Stop Control

TABLE 4. Average Total Delay Before Improvements (1996 Data)

No	Location	d_1 (sec)
1	Skipper & 42nd St.	31.4
2	Boyette & McMullen	15.7
3	Durant & Valrico	10.2
4	Livingston & Vandervort	4.1
5	Hanna & Sunset Lane	11.5
6	Gunn Highway & Race Track	147.0
7	Bruce B. Downs & 42nd St.	112.2
8	Waters Ave. & Rustic Dr.	2.5
9	Himes & Idlewild	4.9
10	Gunn Highway & N. Mobley	19.1
11	Falkenburg & Princess Palm	11.3
12	131 St. & 22nd St.	43.3
13	Broadway & Tampa East	14.6
14	Lithia PineCrest & Guiles Rd.	114.3
15	Lumsden & Pauls	1.6
16	Durant & Dover/Little	2.3
17	Bell Shoals & Rosemead	4.0
18	Oakfield & Vonderburg	4.7
19	Dale Mabry & Hamilton	3.4
20	Palm River & US 301	20.3
21	Sabal Industrial & US 301	43.9
22	Savarese & Waters	0.9

TABLE 5. MUTCD Warrant Study Summary

No	Intersection	MUTCD warr.
01	Skipper & 42nd St.	Warranted
02	Boyette & McMullen	Warranted
03	Durant & Valrico	Warranted
04	Livingston & Vandervort	Warranted
05	Hanna & Sunset Lane	Warranted
06	Gunn Highway & Race Track	Warranted
07	Bruce B. Downs & 42nd St.	Warranted
08	Waters & Rustic Dr.	Warranted
09	Himes & Idlewild	Warranted
10	Gunn Highway & N. Mobley	Warranted
11	Falkenburg & Princess Palm	Warranted
12	131 St. & 22nd St.	Signalized
13	Broadway & Tampa East	Warranted
14	Lithia PineCrest & Guiles Rd.	Not warranted
15	Lumsden Ave. & Pauls Drive	Warranted
16	Durant & Dover/Little	Not warranted
17	Bell Shoals & Rosemead	Warranted
18	Oakfield & Vonderburg	Warranted
19	Dale Mabry & Hamilton	Warranted
20	Palm River & US 301	Signalized
21	Sabal Industrial & US 301	Warranted
22	Savarese & Waters	Not warranted

TABLE 6. B/C Ratio Data for Intersections (1996 Data)

No	Location	B/C
1	Skipper & 42nd St.	31.3
2	Boyette & McMullen	18.0
3	Durant & Valrico	10.4
4	Livingston & Vandervort	10.0
5	Hanna & Sunset Lane	9.7
6	Gunn Highway & Race Track	9.4
7	Bruce B. Downs & 42nd St.	7.4
8	Waters Ave. & Rustic Dr.	7.0
9	Himes & Idlewild	5.2
10	Gunn Highway & N. Mobley	5.0
11	Falkenburg & Princess Palm	3.5
12	131 St. & 22nd St.	3.1
13	Broadway & Tampa East	2.8
14	Lithia PineCrest & Guiles Rd.	2.8
15	Lumsden & Pauls	2.0
16	Durant & Dover/Little	1.9
17	Bell Shoals & Rosemead	1.9
18	Oakfield & Vonderburg	1.7
19	Dale Mabry & Hamilton	0.9
20	Palm River & US 301	0.8
21	Sabal Industrial & US 301	0.7
22	Savarese & Waters	0.7

TABLE 7. Average Total Delay After Improvements (d_2) and Delay Difference (Δd)

No	Location	d_2 (sec)	Δ d (sec)
1	Gunn Hwy & Racetrack	40.2	106.8
2	Lithia-Pinecrest & Guiles Rd	1.4	112.9
3	Bruce B. Downs & 42nd St.	14.1	98.1
4	Sabal Industrial Blvd. & US 301	4.2	39.7
5	131 St. & 22nd St.	19.6	23.7
6	Skipper & 42nd St.	9.0	22.4
7	Gunn Hwy & N. Mobley	9.5	9.6
8	Palm River & US 301	13.2	7.1
9	Broadway & Tampa East	6.3	8.3
10	Falkenburg & Princess Palm	4.7	6.6
11	Hanna & Sunset Lane	7.3	4.2
12	Durant & Valrico	5.8	4.4
13	Livingston & Vandervort	4.1	0.0
14	Boyette & McMullen	35.7	-20.3
15	Bell Shoals & Rosemead	4.0	0.0
16	Oakfield & Vonderburg	5.6	-0.9
17	Durant & Dover/Little	2.3	0.0
18	Dale Mabry & Hamilton	3.8	-0.4
19	Himes & Idlewild	27.9	-23.0
20	Waters Ave & Rustic Dr	7.7	-5.2
21	Lumsden Ave & Pauls Drive	3.8	-2.2
22	Savarese & Waters Ave.	3.0	-2.1

TABLE 8. Priority List I for 1996

No	Location	B/C	List I
1	Skipper & 42nd St.	31.3	1
2	Boyette & McMullen	18.0	2
3	Durant & Valrico	10.4	3
4	Livingston & Vandervort	10.0	4
5	Hanna & Sunset Lane	9.7	5
6	Gunn Highway & Race Track	9.4	6
7	Bruce B. Downs & 42nd St.	7.4	7
8	Waters Ave. & Rustic Dr.	7.0	8
9	Himes & Idlewild	5.2	9
10	Gunn Highway & N. Mobley	5.0	10
11	Falkenburg & Princess Palm	3.5	11
12	131 St. & 22nd St.	3.1	12
13	Broadway & Tampa East	2.8	13
14	Lithia PineCrest & Guiles Rd.	2.8	14
15	Lumsden & Pauls	2.0	15
16	Durant & Dover/Little	1.9	16
17	Bell Shoals & Rosemead	1.9	17
18	Oakfield & Vonderburg	1.7	18
19	Dale Mabry & Hamilton	0.9	19
20	Palm River & US 301	0.8	20
21	Sabal Industrial & US 301	0.7	21
22	Savarese & Waters	0.7	22

TABLE 9. Priority List II for 1996

No	Location	d_1 (sec)	Rank #	Δd (sec)	Rank #	Rank Sum	List II
1	Gunn Hwy & Racetrack	147.0	1	106.8	2	3	1
2	Lithia-Pinecrest & Guiles Rd	114.3	2	112.9	1	3	2
3	Bruce B. Downs & 42nd St.	112.2	3	98.1	3	6	3
4	Sabal Industrial Blvd. & US 301	43.9	4	39.7	4	8	4
5	131 St. & 22nd St.	43.3	5	23.7	5	10	5
6	Skipper & 42nd St.	31.4	6	22.4	7	13	6
7	Gunn Hwy & N. Mobley	19.1	8	9.6	6	14	7
8	Palm River & US 301	20.3	7	7.1	9	16	8
9	Broadway & Tampa East	14.6	10	8.3	8	18	9
10	Falkenburg & Princess Palm	11.3	12	6.6	10	22	10
11	Hanna & Sunset Lane	11.5	11	4.2	12	23	11
12	Durant & Valrico	10.2	13	4.4	11	24	12
13	Livingston & Vandervort	4.1	16	0.0	13	29	13
14	Boyette & McMullen	15.7	9	-20.3	21	30	14
15	Bell Shoals & Rosemead	4.0	17	0.0	15	32	15
16	Oakfield & Vonderburg	4.7	15	-0.9	17	32	16
17	Durant & Dover/Little	2.3	20	0.0	14	34	17
18	Dale Mabry & Hamilton	3.4	18	-0.4	16	34	18
19	Himes & Idlewild	4.9	14	-23.0	22	36	19
20	Waters Ave & Rustic Dr	2.5	19	-5.2	20	39	20
21	Lumsden Ave & Pauls Drive	1.6	21	-2.2	19	40	21
22	Savarese & Waters Ave.	0.9	22	-2.1	18	40	22

TABLE 10. Priority List III for 1996

No	Location	B/C	D_1 (sec)	Δd (sec)	P.Index	List III
1	Gunn Hwy & Racetrack	9.4	147.0	106.8	0.99	1
2	Skipper & 42nd St.	31.3	31.4	22.4	0.98	2
3	Bruce B. Downs & 42nd St.	7.4	112.2	98.1	0.95	3
4	Lithia-Pinecrest & Guiles Rd	2.8	114.3	112.9	0.92	4
5	Boyette & McMullen	18.0	15.7	-20.3	0.80	5
6	Durant & Valrico	10.4	10.2	4.4	0.57	6
7	Hanna & Sunset Lane	9.7	11.5	4.2	0.55	7
8	131St & 22nd St.	2.1	43.3	23.7	0.53	8
9	Livingston & Vandervort	10.0	4.1	0.0	0.51	9
10	Sabal Industrial Blvd. & US 301	0.7	43.9	39.7	0.50	10
11	Gunn Hwy & N. Mobley	5.0	19.1	9.6	0.45	11
12	Waters Ave & Rustic Dr	7.0	2.5	-5.2	0.39	12
13	Broadway & Tampa East	2.8	14.6	8.3	0.35	13
14	Falkenburg & Princess Palm	3.5	11.3	6.6	0.34	14
15	Himes & Idlewild	5.2	4.9	-23.0	0.34	15
16	Palm River & US 301	0.8	20.3	7.1	0.32	16
17	Bell Shoals & Rosemead	1.9	4.0	0.0	0.25	17
18	Oakfield & Vonderburg	1.7	4.7	-0.9	0.25	18
19	Durant & Dover/Little	1.9	2.3	0.0	0.24	19
20	Lumsden Ave & Pauls Drive	2.0	1.6	-2.2	0.24	20
21	Dale Mabry & Hamilton	0.9	3.4	-0.4	0.22	21
22	Savarese & Waters Ave.	0.7	0.9	-2.1	0.21	22

CHAPTER 4. CONCLUSIONS

Highway improvements are required to enhance travel conditions. Prioritization of intersections for improvements is an element of the highway improvement programs. Current methodologies used to prioritize intersection improvements are based only on safety factors. A procedure involving safety and operational factors is an alternative to prioritize intersections. Considering safety and operational factors in the prioritization process gives results that will better reflect the different improvements needed at the intersections.

Three priority lists can be developed by the procedure described in the report. Priority list I is based on safety factors; priority list II on operational factors; and priority list III on safety and operational factors. These lists allow the traffic safety engineers and planners to analyze these factors separately, giving the opportunity to prioritize intersections from a safety, or operational, or a combined safety and operational point of view.

The priority list III is generated using a logit model based on the variables of Benefit/Cost ratios, average total delay before improvements and delay reduction due to improvements. The results for priority list III reveals the influence of operational performance on the prioritization process.

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