REGIONAL PRIORITIZATION OF CORRIDORS FOR TRAFFIC SIGNAL RETIMING

Sasanka Pulipati [1] and Stephen P. Mattingly [2*]

ABSTRACT

Every three to four years, the North Central Texas Council of Governments (NCTCOG) funds signal retiming projects to improve air quality in the Dallas-Fort Worth region. As sufficient funds are not available to retime all signals in the region at the same time, the retiming must be completed in phases. To optimize the impact of the retiming projects, the candidate corridors must be rank ordered or prioritized. NCTCOG applies a ranking model, which uses variables like delay, number of stops and system type, a dummy variable based on centralized control. The weighting for each factor is based on expert input from a group forum using direct allocation of the percentage weighting.

This paper proposes a new, improved methodology based on signal retiming benefits rather than the severity of existing traffic conditions. Benefits are estimated from the before and after studies conducted along the corridors where retiming is executed recently. Benefits in delay, fuel consumption and emissions are to be modeled in terms of various physical characteristics and traffic flow characteristics of the corridors. This model helps in estimating benefits beforehand and prioritizing the retiming projects based on these benefits. Appropriate conversion rates are identified to convert all benefits into dollars.

KEYWORDS

Traffic Signal Retiming, Air Quality, Transportation System Benefits, Decision Making, Weighting

INTRODUCTION

According to the Institute of Transportation Engineers (2004), there are about 300,000 traffic signals in the United States. Delay at signalized intersections is a major part of the total vehicular traffic delay. Traffic signal retiming is one of the most cost effective ways to reduce delays and is one of the most basic strategies to help mitigate congestion. Signal retiming can reduce variations in vehicle-speeds, which reduces vehicle emissions and improves the air quality of a region. After three to four years, traffic signals may need to be retimed, where new timing plans are established to match the current demand.

This paper is concerned about the signal retiming projects proposed in the Dallas-Fort Worth (DFW) region. This is a moderate non-attainment zone with respect to air quality

---

[1] Dept. of Civil and Env. Engineering, University of Texas, Arlington, Box 19308, Arlington, Texas, 76019-0308, USA, Phone 817-896-8124, FAX 817/272-2630, bushan515@yahoo.com

[2] Dept. of Civil and Env. Engineering, University of Texas, Arlington, Box 19308, Arlington, Texas, 76019-0308, USA, Phone 817/272-2859, FAX 817/272-2630, Mattingly@uta.edu

* - corresponding author

requirements. The North Central Texas Council of Governments (NCTCOG) funds signal retiming projects in this region. NCTCOG works with an aim of improving air quality as well as congestion through these projects.

As sufficient funds are not available to retime all the signals in the region at the same time, the retiming must be completed in phases. For each phase, candidate corridors must be prioritized to make sure the funds are efficiently utilized. NCTCOG has its own ranking model, which uses delay, number of stops and a dummy variable, system type. Here, system type indicates whether or not the signals along a corridor are connected to a centralized coordinated system. Delay and number of stops are used to indicate the severity of the existing traffic conditions.

This paper presents a new methodology for prioritization, which models expected benefits based on both the system's physical characteristics and traffic conditions before signal retiming. In this model, all benefits like reduction in delay, fuel consumption and emissions are converted into money terms using a reasonable dollar rate. While this paper proposes the structure for this model it is not estimated because the before and after studies associated with the recent traffic signal retiming projects in this region have not been completed.

This paper is structured in the following manner. First, the paper considers the various factors affecting the prioritization process. Next, the authors explain the ranking model currently used by NCTCOG and their rank ordering of projects. Finally, the paper discusses the estimation of benefits from the before and after studies and proposes the new methodology.

FACTORS AFFECTING THE PRIORITIZATION OF RETIMING PROJECTS

Traffic signal retiming improves traffic flow conditions at a low cost. One must clearly understand the potential benefits of signal retiming to decide whether or not to retime a set of intersections. Sunkuri (2004) discusses various benefits of signal retiming. One of the direct benefits is the reduced delay experienced by motorists. When a street has a coordinated system of signals, travelers often take notice of this fact. Also, motorists experience fewer stops at red lights, which reduces fuel consumption.

Apart from the direct benefits, signal retiming reduces motorists' frustration due to delays and stops and improves safety. Because of the low costs, traffic signal retiming projects, typically, have a benefit to cost ratio of about 40:1 (Sunkuri, 2004). The various factors that make signal retiming necessary should be considered while prioritizing these projects.

DELAY

The reduction of travel time along a corridor is one of the major benefits of signal retiming. Vehicle delay along a corridor occurs when a vehicle's travel time increases above the desired travel time. The desired travel time is the time taken to travel along a corridor at the desired speed, which is normally free flow speed. If the free flow speed is not available, it can be surrogated by the speed limit. Total corridor delay is the delay of an individual vehicle multiplied by the traffic volume along that corridor. When ranking retiming projects, a project with the potential for a higher reduction in delay should be given more priority.

NUMBER OF STOPS

The number of stops along a corridor is counted as the total number of occasions where the vehicle speed drops below a specified speed, typically five to ten mph. The number of stops indirectly increases the fuel consumption and the emissions because of the accelerations and decelerations associated with the stops. The number of stops may be measured using travel time runs along the corridor where projects that have a greater reduction in the number of stops should receive priority.

FUEL CONSUMPTION

When the variation in speeds after retiming reduces, fuel consumption is expected to decrease. Sunkuri (2004) gives examples where fuel consumption reduction related to signal retiming can be as high as nine percent. Fuel consumption can be estimated using travel time measuring instruments and simulation. Projects, which result in higher reductions in fuel consumption, should receive higher priority than other similar projects.

EMISSIONS

Emissions can be measured in real time or they can be estimated through simulation or traffic signal retiming software. Some of the travel-time measuring instruments may also provide emission estimates. Since signal retiming is expected to reduce the emissions and improve the air quality, a project with a greater reduction in the emissions, should receive higher priority.

SAFETY

Sunkuri (2004) writes that signal retiming indirectly reduces driver frustration, which reduces red light running. Disregarding the signal is one of the major causes of crashes (Tindale and Hsu, 2005); therefore, a reduction in red light running improves intersection safety. As a successful example given by Sunkuri (2004), adjusting the signal timing in Lexington, KY, USA reduced accidents by thirty-one percent. Safety measures can be determined from the crash history of an intersection.

However, based on a study of crashes on a coordinated one-way street in Florida, Tindale and Hsu (2005) suggest that signal coordination can be an incentive for red light running. They indicate that drivers may speed or engage in other unsafe behavior to stay in the ‘‘platoon’’ of the traffic flow. The perception is that this can ensure their passage through the corridor without stopping. Safety may have to be considered as a disbenefit under some circumstances and its exact impact depends on each particular case.

EXISTING METHODOLOGY USED BY NCTCOG

Generally every three to four years, traffic signals are retimed in the Dallas/Fort Worth region. The cities in the region provide the initial candidate corridors. Each city may identify any number of corridors in its jurisdiction where they think travel times are affected and signals should be retimed. In that way, about 200 corridors are listed as needing retiming but because of the lack of funds, corridors with the highest need are to be picked first.

NCTCOG needs to sort these projects in an order of importance. At present, it uses a ranking model for this purpose. After an order of priority is achieved, thirty to forty corridors are selected as per the availability of funds. Later, some engineering judgment is used to arrive at the final list of corridors to be retimed. Along each of the candidate corridors, one travel time run is conducted. The existing travel time and the number of stops from the start to the end of the corridor are measured. The variables used in the model and their weightings are discussed in the next section followed by the actual rank ordering of a set of corridors.

VARIABLES AND WEIGHTINGS

Total Delay: Individual vehicular delay is the difference between the measured travel time (average of both directions) and the travel time at the posted speed. To find total delay per intersection, the individual vehicular delay is divided by the number of intersections in that corridor and multiplied by the annual daily traffic (ADT) along the corridor.

No. of Stops: Average number of stops per vehicle per intersection multiplied by the traffic volume along the corridor.

System type: There are three types of existing systems. A value of one indicates that all intersections are part of an existing system with communications. A value of two indicates that some but not all intersections are part of an existing system with communications. A value of three indicates that there is no system (currently an isolated operation).

The weighting for each factor is selected based on expert input in a group forum using direct allocation of the percentage weighting. Weightings are given as below:

Table 1: Variables Used in NCTCOG's Ranking Model and Their Weightings

Variable	Weighting
Total Delay (DELAY)	50%
# of stops (STOPS)	30%
System type (SYSTEM_TYPE)	20%

The input variables are based on the severity of present conditions with no consideration of possible future values post-retiming. Furthermore, the potential for improvement in traffic flow conditions is not considered.

CALCULATION OF RANKING ORDER

Using the weightings applied by the NCTCOG, the following equation is developed.

$$Total\ Score(S) = \frac{DELAY}{Max(DELAY)} \times 50 + \frac{STOPS}{Max(STOPS)} \times 30 + SYSTEM\_TYPE \times 20 \qquad (1)$$

Where SYSTEM_TYPE = 1.0 for type 1
0.5 for type 2
0 for type 3

Quantitative variables DELAY and STOPS are normalized by dividing by the maximum value, which precludes any single variable dominating the total score because of its magnitude relative to the other variables. After normalization, each variable is expressed on a zero-to-one scale and the weights are an expression of the relative importance of each criterion. Witkowski (1992) discusses three kinds of normalization methods and pros and cons of each. For this research, the maximum value of a variable in the given data is used for normalization.

Equation one is applied to the travel time data for all the corridors and their initial ranks are calculated. As previously discussed, higher delay and higher numbers of stops should receive a higher priority to the corridor. The highest priority goes to the corridor with the maximum of all total scores. The priority decreases with the total score. Table 2 shows the first twenty on the priority list calculated using the NCTCOG model.

Table 2: Results of the NCTCOG Ranking Model

Rank	Arterial segment	# of signals	Length (miles)	Score for Total delay/per signal	Score for stops/signal	system type score	total score
1	Bryant-Irvin	7	3.0	50.0	30.0	10	90.00
2	Belt Line	8	3.1	46.2	14.4	20	80.59
3	Illinois	16	5.9	40.5	19.7	20	80.15
4	Hampton	16	4.6	40.8	17.7	20	78.53
5	Harry Hines	15	5.9	41.0	14.7	20	75.67
6	Abram/Jefferson	12	4.0	35.5	16.6	20	72.12
7	FM 1171	16	4.2	36.5	15.1	20	71.62
8	University	4	0.6	29.5	18.4	20	67.92
9	Jupiter	16	4.6	37.2	10.5	20	67.70
10	Green Oaks SE/SW	12	6.6	23.9	21.9	20	65.79
11	Spring Valley	8	2.7	27.8	17.1	20	64.85
12	Alpha	7	2.1	29.2	15.0	20	64.23
13	Coit	19	5.4	32.1	11.6	20	63.74
14	Northwest Hwy	19	7.6	32.6	11.1	20	63.63
15	Jupiter	10	4.7	26.9	15.8	20	62.68
16	Camp Bowie	8	2.2	22.6	18.4	20	60.98
17	Oaklawn	11	1.5	29.3	11.5	20	60.78
18	Jupiter	10	3.5	27.8	12.6	20	60.38
19	US 377	19	8.9	41.4	19.0	0	60.36
20	Camp Bowie/7th	6	1.5	24.2	15.8	20	59.94
33	Pioneer Pkwy	9	4.2	18.1	16.3	20	54.46
38	Great Southwest Pky	15	5.1	20.4	11.2	20	51.64

The results indicate that almost all the first few on the list belong to system type one; therefore, system type plays a significant role in this decision making. In this paper, the benefits are estimated for two different corridors, Pioneer Parkway and Great Southwest Parkway. They have ranks of 33 and 38, respectively.

ESTIMATION OF BENEFITS

Benefits from signal retiming projects can be estimated through before and after studies. NCTCOG hired consultants to perform travel time (TT) studies before and after retiming for each of the corridors where signal retiming was implemented. Five runs were performed during each of AM peak, midday and PM peaks before and after retiming. Using the study results summary for each time of day, the researchers calculate the average reductions in travel time, delay, number of stops, fuel consumption as well as emissions. This provides an estimate of the actual benefits per vehicle per mile. The estimated benefits for Great Southwest Parkway, a north-south arterial, and Pioneer Parkway, an east-west arterial, are shown in table 2 and table 3, respectively.

CORRIDOR BENEFITS

The total corridor benefits that are going to be obtained prior to the next retiming project based on total traffic volume during this period are to be calculated and used in prioritization. Turning movements for all the intersections along the corridor are available for AM, midday and PM cases. The authors assume that the AM peak is from 6:30 am to 9:30 am and the PM peak is from 4:00 pm to 8:00 pm, and the remaining period from 9:30 am to 4:00 pm is considered as midday. The length of the Great Southwest Parkway segment is 5.38 miles and the length of the Pioneer Parkway segment is 2.33 miles.

Table 2: Benefits from Signal Retiming Along Great Southwest Parkway Corridor

North Bound – Savings per vehicle per mile						
	#of stops /mile	Total Delay (sec/mile)	Fuel (gal/mile)	Emissions		
				HC(gm/mile)	CO(gm/mile)	NOx(gm/mile)
AM	0.11	20.85	4E-3	0.42	3.85	0.04
MD	0.08	2.44	-3E-4	-0.15	-2.20	-0.19
PM	0.15	18.39	3E-3	0.46	3.06	0.18
South Bound – Savings per vehicle per mile						
AM	0.04	-3.83	-1E-3	-0.05	-1.26	0.04
MD	0.08	3.26	1E-4	0.10	0.21	0.06
PM	-0.49	-23.95	-3E-3	-0.11	0.57	0.28
North Bound - Total savings in three years						
	# of stops	Total Delay (Hours)	Fuel (gal)	HC (Tonnes)	CO (Tonnes)	NOx (Tonnes)
AM	1656850	83885	59007	6.1	55.8	0.5
MD	1185014	10566	-4337	-2.3	-34.2	-2.9
PM	1564402	53893	33837	4.8	32.2	1.9
South Bound - Total savings in three years						
AM	225990	-6138	-4410	-0.3	-7.3	0.2
MD	1138209	13744	864	1.5	3.1	0.9
PM	-9337614	-127865	-55190	-2.2	10.9	5.4

Negative values indicate that traffic conditions have worsened. By adding the savings in both directions and for all the times of day, the overall daytime savings for a corridor for the next three years can be obtained. Table 4 gives the total daytime (6:30 am – 8:00 pm) corridor savings for both the corridors over the next three years.

Table 3: Benefits from Signal Retiming Along Pioneer Parkway Corridor

East Bound – Savings per vehicle per mile						
	#of stops /mile	Total Delay (sec/mile)	Fuel (gal/mile)	Emissions		
				HC(gm/mile)	CO(gm/mile)	Nox(gm/mile)
AM	1.36	53.99	0.02	3.03	25.31	2.37
MD	1.01	36.48	0.01	1.69	9.16	1.34
PM	1.45	54.00	0.01	2.86	17.36	2.32
West Bound – Savings per vehicle per mile						
AM	-035	-10.40	-5E-3	-0.67	-4.51	-0.56
MD	-0.01	1.02	-3E-3	-0.50	-7.64	-0.48
PM	0.85	31.95	3E-3	0.31	-5.51	-0.01
East Bound - Total savings in three years						
	# of stops	Total Delay (Hours)	Fuel (gal)	HC (Tonnes)	CO (Tonnes)	NOx (Tonnes)
AM	8194918	90206	98093	18.2	152.2	14.3
MD	10268503	102577	91329	17.1	92.8	13.6
PM	13320863	137493	132181	26.2	159.1	21.2
West Bound - Total savings in three years						
AM	-1531918	-12733	-20060	-2.9	-19.9	-2.4
MD	-110568	2966	-31622	-5.3	-80.1	-5.1
PM	8352109	87074	32370	3.1	-54.1	-0.1

Table 4: Total Daytime Corridor Savings

	# of stops	Total Delay (Hours)	Fuel (gal)	HC (Tonnes)	CO (Tonnes)	NOx (Tonnes)
Great Southwest Pkwy	-3567149	28085	29771	7.6	60.5	6
Pioneer Pkwy	38493907	407583	302291	56.4	250	41.5

ESTIMATION OF BENEFITS IN EMISSIONS USING PC TRAVEL

Computer software estimates HC, CO and NO_x emissions from the travel time data. It takes the variation in speed as a basis for the estimation. The model used in the program PC Travel (Jamar, 2004) is the MICRO2 model developed by the Colorado Department of Highways. The equations used in PC-Travel for Window manual (Jamar, 2004) are:

$$\text{Fuel (ml/sec)} = k_1+k_2*V+k_3*V^3+k_4*A*V+k_5*A^2*V \qquad (2)$$

Where $k_1=0.7$, $k_2=0.00442$, $k_3=0.0000022$, $k_4=0.00762$, $k_5=0.000886$

Hydrocarbons (grams/sec) = $hc_1+hc_2*A*V+hc_3*A*V^2$ (3)

Where $hc_1 = 0.018$, $hc_2 = 0.0005266$, $hc_3 = 0.0000061296$

Carbon Monoxide (grams/sec) = $co_1+co_2*A*V+co_3*A*V^2$ (4)

Where $co_1 = 0.182$, $co_2 = 0.0079776$, $co_3 = 0.00036227$

Nitrous Dioxide (grams/sec) = $noxa_1+noxa_2*A*V$, $A>0$ (5)

or $noxb_1+noxb_2*A*V$, $A<0$

Where $noxa_1 = 0.00386$, $noxa_2 = 0.00081446$, $noxb_1 = 0.00143$, $noxb_2 = 0.000017005$

In all the above equations, V = velocity in ft/sec, A = acceleration in ft/sec/sec

For each corridor, the reduction in emissions is calculated for each direction. These are the actual estimated emissions benefits due to retiming.

PROPOSED METHODOLOGY

As previously discussed, NCTCOG's model is built on the severity of existing traffic flow conditions. A reasonable objective for any infrastructure projects is to improve societal benefits. Traffic flow conditions along a corridor being severe may not indicate that retiming signals along that corridor will produce a good benefit to cost ratio. Therefore, a new prioritization strategy may provide greater overall societal benefits.

In this research, an effort is made to relate the benefits to various independent variables. All the benefits are converted into a dollar amount so that the relative importance of any one benefit may be compared with the other benefits. The following benefits are considered:

S_D = Saving in delay (in sec)

S_F = Saving in fuel consumption (gallons)

S_E = Saving in NOx emissions (Tonnes)

Reducing the number of stops indirectly reduces fuel consumption and emissions and driver frustration, which is difficult to quantify. Hence, the number of stops is not considered a direct benefit. NO_x emissions are the major component of vehicle emissions; therefore, savings in CO and HC are not currently included. At this time, safety is not included because of its long time horizons and stochastic characteristics.

Value of time

Mattingly *et al*. (2004) analysed a stated preference survey conducted in the Dallas/ Fort Worth region to find out the value of time in the context of HOT lanes and HOV lanes. They concluded that the respondents' value of time is $8.39 per hour. Though the present research is concerned with time savings of a few seconds, which poses some aggregation concerns, this value of time is still reasonable for comparison purposes. Further surveys may indicate how to address the aggregation difficulties for this particular case.

Fuel Price

At this time, according to the American Automobile Association (2006), \$2.18 per gallon is the regional average gasoline price in southwest USA.

Value of NO_x emissions

Trading of NO_x emissions is still an emerging topic. NO_x trading is considered by Evolution Markets LLC. Zabrowsky, (2006) Managing Director, Environmental Markets, from Evolution Markets LLC specified a rough estimate of NO_x value as \$2500 per short ton, which is \$2756 per a metric ton.

Each one of these benefits is modeled using the independent variables shown below:

N = Number of signals along a corridor

Y = Spacing between any two intersections

V = Traffic Volume

S = Average Speed along the corridor

Z = System type (type 1, 2 or 3)

D = Delays

NS = number of stops

TT = travel times

M = Turning movements as a percent of total volumes

Regression analysis is to be used to understand which variables are significant in predicting the dependent variables.

APPLICATION OF METHODOLOGY

Once the model is estimated, it is applied to the data collected for the candidate corridors. Benefits in delay, fuel consumption and emissions are calculated using the model. Now, to obtain one single score for each corridor, these three benefits are added. This score is named the Project Benefit Score.

$$\text{Project Benefit Score (PBS)} = V_D * S_D + V_F * S_F + V_E * S_E \qquad (6)$$

Where, V_D=\$8.39/hour, V_F = \$2.18/gallon, V_E = \$2756/tonne for the existing condition.

Weighted Project Benefit Score

The PBS is calculated assuming that equal importance is given to all the benefits, but the funding organization may set different importance to each one of these benefits. In that case, their relative importance has to be quantified according to the organization’s policies. If the weightings for delay, fuel consumption and emissions are W_D, W_F, W_E respectively,

$$\text{Weighted Project Benefit Score (WPBS)} = W_D V_D S_D + W_F V_F S_F + W_E V_E S_E \qquad (7)$$

Sorting WPBS for all the candidate projects, a priority list is obtained.

NEXT STEPS

For modeling the benefits in the above fashion, benefits must be estimated for a sufficient number of corridors. At present, around thirty to forty corridors are currently being retimed and before and after studies are being completed on each to document the benefits. After this data is collected a model may be built. Once the model is built and dollar rates and weights are applied, this methodology will be ready to use for the next phase of signal retiming projects.

CONCLUSIONS

This paper proposes a methodology for prioritization of traffic signal coordination projects in the DFW region. NCTCOG's existing ranking model may not produce satisfactory results because it focuses on the severity of existing conditions rather than considering the potential for improvement. As a result, our new method of prioritization is based on the benefits from the proposed signal retiming projects. Estimation of benefits in delay, fuel consumption as well as emissions is possible using before and after studies. Corridor benefits can be estimated before implementation through a model, which includes various corridor characteristics related to the physical structure and traffic flow. This model can be used in the future to estimate the benefits associated with any signal retiming project. An overall benefit score is calculated using dollar rates and weighting for each type of benefit.

ACKNOWLEDGEMENTS

The authors thank Mr. Alauddin Khan and Ms. Natalie Bettger, NCTCOG for providing the data and explaining the existing method.

REFERENCES

American Automobile Association (2006). "Today's Regional Gasoline Averages", http://www.fuelcostcalculator.com/, Accessed on February 18, 2006.

Institute of Transportation Engineers. "Traffic Signal Timing", http://www.ite.org/signal/index.asp, Accessed on February 16, 2006.

Jamar Technologies Inc. (2004). *PC-Travel for Windows Manual*.

Mattingly, S. P., A. Upayokin, and J. Li (2004). "A Driver's Dilemma: Main Lane or HOT Lane." *Proceedings of the 4th International Conference on Decision Making in Urban and Civil Engineering,* CD.

Sunkuri, Srinivasa (2004). "The Benefits of Retiming Traffic Signals", *ITE Journal*, April 26-29.

Tindale, Steven A., and Peter Hsu (2005), "Crash Data and Signal Coordination: a One-Way Pair Study", *Journal of Safety Research- Traffic Records Forum Proceedings,* 36 (5) 481-482.

Witkowski, James M. (1992). "Prioritizing signalized intersection operational deficiencies", *Transportation Research Record*, 1360, 4-12.

Zabrowsky, Peter, Evolution Markets LLC (2006). *E-mail Response*. http://www.evomarkets.com/, Accessed on February 15, 2006.