FUND 87 PERFORMANCE MEASURES OF EFFECTIVENESS

I. BACKGROUND

The Maryland State Highway Administration established the Fund 87 Program for the specific purpose of addressing "capacity improvements at failing intersections." Each year, Maryland's Assistant District Engineers – Traffic (ADE-T's) present candidate intersections to be selected for funding under Fund 87. The candidate intersections compete for funding within their district and statewide. The current methodology for determining whether an intersection improvement meets the requirements of Fund 87 is based on the premise that the improved Level of Service (LOS) should improve from F by one or more letter grade, or the v/c ratio by 20-percent or more. This method of analysis, which has primarily been used by SHA to quantify Fund 87 intersection improvements, is based on the Critical Lane Volume (CLV) method. The CLV method is primarily a planning tool and not an operational tool, whose specific purpose is to analyze forecasted traffic volumes for long-range planning studies in order to determine the number of through and turning lanes at signalized intersections.

In recent years and during the course of the Fund 87 Program, several candidate intersections were often presented by ADE-T's that did not meet these criteria. The ADE-T's felt that many of these intersections suffered a capacity deficiency, and that they should qualify for funding under the Fund 87 Program. Because of this shortcoming, SHA decided that the existing criteria should be reviewed and possibly revised, and that the total intersection LOS or v/c ratio should not solely describe the overall intersection operations. The SHA's goals are to: **a)** identify better measures of effectiveness (MOEs) for evaluating whether or not an intersection qualifies for the Fund 87 Program; **b)** determine credible and cost-effective MOEs to conduct "before and after improvement" studies; **c)** establish a procedure to predict whether or not the candidate improvement will result in a benefit that exceeds the cost of construction; and **d)** develop a method to rank candidate intersections.

The University of Maryland, in conjunction with the work presented here, is investigating better method(s) to rank and prioritize candidate intersections under the SHA Fund 87 Program, i.e. addressing item (d) of the SHA's goals identified above. Therefore, the discussion presented here focuses only on the remaining goals, which deal with measures of effectiveness and models that SHA may choose in the future to quantify the effectiveness of intersection improvements. The success of this work will provide SHA offices better means to assess the effectiveness and benefits of the Fund 87 Program. This discussion presented in this paper is organized as follows:

Goal and Objectives

- i) Criteria for Selection of Measures of Effectiveness (MOEs)
- ii) Criteria for Validation of MOE's from Field Measurements

Work Plan

- i) Selection of Measures of Effectiveness
- ii) Validation of MOE's from Field Measurements
- iii) Comparing MOE's

II. GOAL AND OBJECTIVES

The goal of this paper is to present a work plan for evaluating the transportation effectiveness of alternatives for capacity improvement at candidate intersections. The specific focus is on the Maryland State Highway Administration's Fund 87 program, which seeks to provide capacity improvements for failing intersections. It should be noted that the work plan does not address financial/economic performance, social impacts, land use/economic development impacts, or environmental impacts of the proposed improvements. These issues are not addressed in this paper since they are outside of its scope, and because the preliminary nature of studies typically conducted at these intersections. The focus of these preliminary studies is on transportation impacts with a cursory attention to the other types of impacts.

The objectives of this paper are to develop a set of MOE's that may be used to rank the selected intersections in terms of transportation effectiveness and to establish a procedure to validate these MOE's for use in alternatives analysis. Several objectives and criteria were defined for this goal, as presented in **Figure 1**, in a hierarchical order. This section of the paper presents the criteria used to determine which MOE's should be used. The actual selection of MOE's is discussed in the following section.

GOAL:
Develop A Work Plan To Evaluate The Transportation Effectiveness Of Alternatives For Capacity Improvement At Candidate Intersections

A. Determination of Appropriate Measures of Effectiveness (MOE's)

   Criteria
   1. Understandable
   2. Measurable
   3. Labor Intensiveness
   4. Consistent with State-of-the-Practice
   5. Reliable
   6. Sensitive
   7. Congestion-Based
   8. Can be Validated in a Model

B. Validation of MOE's Using Field Measurements in the Model

   Criteria
   1. Accuracy and Precision
   2. Cost
   3. Comparison of MOE's (Significance)

Figure 1. Hierarchical Order of Objectives and Criteria

i) Criteria for Selection of Measures of Effectiveness

The selection process for which Measures of Effectiveness (MOE's) to be used is guided by the criteria listed in **Figure 1**. These criteria can serve as a framework for defining MOE's in operations evaluations[i].

1. Understandable

The MOE's should define the problem so that it is *understandable* to the decision-makers and the general public. However, each MOE does not need to be understandable by the public. Some of the scientific congestion indicators that are important to traffic engineers don't necessarily need to be understood by the public. However, the public should be able to *understand the problem* in layman terms.

2. Measurable

Each MOE should be *measurable* using standard traffic engineering practices, such as those presented in the ITE's *Manual on Transportation Engineering Studies*.

3. Labor-Intensiveness

Furthermore, the MOE's should not be excessively *labor-intensive*. For example, total intersection delay satisfies all of the criteria (easy to understand by the public, sensitive to geometric changes, congestion-based, reliably reflects different congestion levels and is easily validated in a model), except that it is very difficult and cost prohibitive to collect in the field, especially at intersections that experience queues that can't be seen from the best vantage point at an intersection. The MOE's should also be obtained using standard, state-of-the-practice traffic engineering methods.

4. Reliable

The MOE's should *reliably* reflect changes in congestion levels[ii]. Results should be consistent and predictable.

5. Congestion-Based

The MOE's should also be *congestion-based*. MOE's such as emissions and fuel consumption are derived from congestion-based MOE's, but are not inherently congestion-based. However, the degree of saturation MOE is a direct reflection of a movement's operation.

6. Sensitive

The MOE's should be *sensitive* so that they vary among alternatives. The MOE's should be sensitive to traffic volume, traffic control, and geometric changes. Not all of the congestion indicators are sensitive to the impact of geometry changes on the congestion level. For example, queues and stops are not necessarily sensitive to changes in geometrics, but they are considered as good congestion indicators.

7. Can Be Validated in a Traffic Model

Finally, the MOE's selected should be able to be measured in the field and *validated* in a traffic model. The purpose of validation is to be able to use the validated model to analyze various alternatives. Once the model accurately reflects real-world conditions, the analyst can assume that the alternatives analyzed will be accurate as well.

ii) Criteria for Validation of MOE's from Field Measurements

The purpose of this section is to define the criteria for how MOE's should be validated in the traffic model.

1. Validation

The Highway Capacity Manual (HCM) defines validation as "determining whether the selected model is appropriate for the given conditions and for the given task; it compares model prediction with measurements of observations." The HCM provides guidelines for calibrating and validating traffic models so that they reflect actual conditions. The goal of model validation is to confirm that "the model does in fact provide a reasonable approximation of reality." Furthermore, the HCM notes "validation occurs when the output of the model is statistically compared with the baseline case observed in the field. Typical baseline case parameters are speed, delay, and queue length."[iii]

2. Accuracy and Precision

The HCM states that "inputs [to traffic models, such as volume, lane width, signing timings, etc.] Can only be expected to be accurate to within 5 or 10 percent of the true value. Thus, the computations performed cannot be expected to be extremely accurate, and the final results must be considered as estimates that are accurate and precise only within the limits of the input values used." The HCM also notes that prediction errors may increase when the default parameters are used. Therefore, the traffic engineer should recognize the inherit limitations of traffic models to interpret the results accordingly. For example, if the difference in performance measures between alternatives is less than the prediction error, the traffic engineer should not assume that there are in fact real (statistically significant) differences. At times, it may be that the difference in performance measures between alternatives shows a positive benefit, whereas the real benefit may be negative.[iv]

Figure 2 shows Trafficware's, the developer of the traffic models "Synchro and SimTraffic", assumptions relative to the accuracy of Synchro's estimated travel-time delay. Trafficware states that field data that matches Synchro's output within a 30% range is normal and acceptable. The differences that one might except between Synchro-derived measures and actual field measures are influenced by Synchro's default parameters such as phase lost time, saturation flow rate of 1900 passenger cars per hour per lane, peak hour factor, and traffic composition. Also considered should be driver types and headways, vehicle turning speeds, the compounding affect of oversaturated traffic conditions, unaccounted overflow of traffic in turning lanes, and fluctuation of midblock traffic volumes. Therefore, by no means should anyone expect to exactly match Synchro's signal delays and travel time with actual field measurements. There should be, however, consistency in the differences between both measurements, i.e. Synchro and field.

Accuracy	Delay Computation Variable
+- 5%	Typical accuracy of volume counts
+- 5%	Typical accuracy of saturation flows calibration (+-100vph)
∑ 7%	**Total = Combined v/c error**
* 2	Magnification of v/c error in delay calculations, when v/c is >= 0.9
∑ +- 14%	**Total = raw delay error**
+- 5%	Uncertainties about signal timings
+- 5%	Uncertainties about lost time
∑ +- 21%	**Expected Accuracy in Delay Calculations**

Figure 2. Expected Accuracy in Delays Calculation in Synchro

3. Cost

Model validation and calibration can be a tedious and hence time-consuming task due to the large amount of data, the availability of the data, and the cost to obtain the data. The accuracy to which the model is calibrated is inter-related to the time required to obtain an acceptable accurate model. The cost incurred in model calibration should be relatively small compared to the total cost of the study. The issue is how extensively does the model need to be calibrated? The following work plan recommends the MOE's that should be validated, and the accuracy to which they should be validated.

III. WORK PLAN

This section presents a recommended plan for evaluating the transportation effectiveness of alternatives for capacity improvement at candidate intersections. It begins by presenting the selected proposed measures of effectiveness (MOE's) based on the criteria described above, defines each MOE, and then explains how these MOE's can be validated in a traffic model. Finally, recommendations are presented for comparing the MOE's between alternatives.

i) Selection of Measures of Effectiveness

1. Evaluation of Measures of Effectiveness Based on Criteria

Table 1 summarizes the MOE's, and evaluates them based on the criteria listed above. The ratings for 'understandable' and 'measurable' were adapted from *Measures of Effectiveness for Major Investment Studies*.[v] The ratings are based on a scale of 1.0 to 0.0 where 1.0 is an ideally suited MOE, and 0.0 is only partially suited MOE. The 'can be validated' column is rated based on the output from one example model, i.e. Synchro.

Table 1. Conformity with Criteria

MOE	***Understandable***	***Measurable***	***Reliable***	***Sensitive***	***Congestion-Based***	***Can be Validated***	**Total Score**
Peak Hour Volumes	1.0	1.0	0.0	0.0 Not sensitive to compare between alternatives	0.0	0.0 Only with microscopic model	**2.0**
Delay	1.0	0.5	1.0	1.0	1.0	0.5 Units of measurement may be different	**5.0**
Percent (%) of Vehicles Stopped	0.5	0.5	1.0	0.0 Not sensitive to compare between intersections	1.0	0.5 Units of measurement may be different	**3.5**
Queue Length	0.5	1.0	1.0	0.5 Not sensitive to geometry	1.0	1.0	**5.0**
Travel Time	0.5	1.0	1.0	1.0	1.0	1.0	**5.5**
V/c ratio	0.0	0.0 Only measurable with a model	1.0	1.0	1.0	0.0 Model-only measurement	**3.0**

MOE	*Understandable*	*Measurable*	*Reliable*	*Sensitive*	*Congestion-Based*	*Can be Validated*	**Total Score**
LOS	0.5	0.0 Only measurable with a model	1.0	1.0	1.0	0.0 Model-only measurement	**3.5**
% Failing approaches	0.0	0.0 Only measurable with a model	0.0 May not reflect improvement	0.0 Approaches may still be failing under an alternative that offers improvement	1.0	0.0 Model-only measurement	**1.0**

2. Definition of Measures of Effectiveness

Two types of MOE's are recommended for use, those that can be measured in the field and those that can only be determined in a traffic model.

Field Measured MOE's

Peak Hour Volumes: Peak hour traffic volume data is the basic data needed to conduct a capacity analysis. The sampling interval should be in 5-minute intervals rather than 15 or 60 minutes. A shorter sampling interval will provide better means to determine the field data collection periods within the peak hours. With computer programs to reduce data, shorter intervals require no more effort. Raw peak hour volumes can also be used as an MOE to rank intersections. For example, intersections with higher traffic volumes would receive a higher ranking.

Stopped Delays and % of Vehicles Stopped: Delay is the additional travel time experienced by a vehicle. Average stopped delay per vehicle should be measured by lane-group. The lane-groups to measure should be determined based on observed congestion or local knowledge. The data collection process may be overly labor-intensive to collect movement delays for all lane groups at the intersection. Movement delays can be collected manually using the standard forms in the ITE's *Manual of Transportation Engineering Studies*, or using a handheld computer, such as Jamar's TDC-8®. These methods will also provide a percent (%) of vehicles stopped MOE as well. This MOE is only significant on through movements, since nearly 100% of controlled turning movements stop at congested, signalized intersections.

Queues: A queue is a line of vehicles waiting to be served by a system (traffic signal). Slowly moving vehicles, and vehicles joining the rear of the queue are usually considered as part of the queue. One of the easiest, and most reliable ways of validating traffic models is to compare field-measured queues with the queues reported in the model. The following information should be field-measured, by lane-group, on a cycle-per-cycle basis:

- Maximum queue at the beginning of the green interval
- Number of vehicles arriving during the green period
- Maximum queue at the end of the red interval
- Maximum back-of-queue at any time in the cycle due to a red signal. This includes vehicles stopped at the back of the queue while the front of the queue started to move.
- Number of residual vehicles in queue and cycle failure (if there are residuals, then the cycle failed)

It is preferable to measure queues in each lane group at the intersection. They should be measured several times during the peak hour. When traffic volumes are measured in 5-minute intervals, a determination can be made of how long the queuing study should last. If traffic has little variation (Peak Hour Factor greater than 0.85) during the peak hour for the movement, the queuing study may be performed for 3 to 5 signal cycles, 3 to 4 times during the peak hour.

Travel Time and Delay: Travel time and delay studies are typically performed for system or corridor analyses. Even though the focus of the Fund 87 Program is on individual intersection improvements, the overall benefits of improvements, or lack of it, on the overall roadway systems should not be ignored. Improvement at individual intersections could also affect the overall operations at upstream and downstream intersections, especially when the arterial system operates in a coordinated mode. This is especially true of closely spaced intersections. When improvements at an intersection(s) require additional through travel lanes on the mainline, travel time and delays studies should be performed for the entire affected arterial. These types of studies may also need to be performed in other situations, depending upon site-specific characteristics. Travel time and delays studies measure the following MOE's:[vi]

- Travel time – the time taken by a vehicle to traverse a given segment of a roadway
- Travel-time delay – the difference between the actual travel time and the travel time based on a vehicle traversing the study segment at the prevailing speed of that segment.
- Stopped-time delay – the part of a delay when the vehicle is not moving (or moving slower than a pre-designated speed such as 5 mph or less)

Model Measured MOE's

V/c Ratio: The volume-to-capacity ratio is the degree of saturation of an intersection or roadway; it is the ratio of flow rate to capacity (maximum sustainable flow rate which vehicles can reasonably be expected to traverse a point of a lane or roadway under a specified time period). Capacity of a movement or a lane group is measured based on the green period-to-cycle length ratio multiplied by the saturation flow rate for the movement or a lane group. When the v/c ratio exceeds 1.0, the intersection is operating over capacity, i.e., oversaturated. V/c ratios are computed by lane group and by the overall intersection. The HCM states that the critical v/c ratio is an approximate indicator of the overall sufficiency of an intersection, and that any v/c ratio greater than 1.0 is an indicator of an actual or a potential breakdown.

The HCM notes that at lane-groups where the v/c ratio exceeds 1.0, the following may be considered for improvements:

- Changes in intersection geometry to increase the number of lanes
- Increase the green period-to-cycle length ratio
- Reduce the number of signal phases

Level of Service: Level of Service (LOS) is defined as a qualitative measure describing operational conditions within a traffic stream, based on service measures such as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience. Signalized intersection LOS is determined based on control delay. It should be noted that control delay includes initial deceleration delay, queue move-up time, stopped delay, and final deceleration delay.[vii]

It should be noted that v/c and LOS are not directly related. LOS is computed based on control delay. For example, intersections delays within the LOS F range could result in a v/c ratio of less than 1.0. The opposite could also be true; the LOS may compute to be E with a v/c ratio greater than 1.0. Therefore, LOS F does not necessarily mean that the intersection is over capacity, and LOS E does not necessarily mean that there is reserve capacity. The HCM states that both capacity and LOS analyses are required to fully evaluate the operation of a signalized intersection.

The CLV method of analysis assumes a direct correlation between LOS and v/c ratios. In the CLV method of analysis, the v/c ratio and LOS are interdependent, and are therefore the same MOE. In order to use a v/c as an MOE for operational analyses, it must be determined based on the HCM methods of analysis.

ii) Validation of MOE's from Field Measurements

When validating a model, it is important that the analyst understands the theory behind the model, the model's limitations and assumptions, how the model derives MOE's, and be able to interpret it's results and determine whether the results of the model are consistent with the field observed measurements. For example, Synchro calculates queues (measured in feet) based on a 25-foot vehicle, and SimTraffic based on a 19.5-foot vehicle. The analyst must understand this before attempting to compare field-measured queues with model-derived queues. Additionally, SimTraffic (the animation software companion to Synchro) should always be run to identify any anomalies in the Synchro model.

Chapter 31 of the HCM 2000 provides guidance on when to use deterministic (Synchro) versus stochastic (SimTraffic) models. Simulation models may more effectively address the following:[viii]

- Effects of signal coordination
- Queue spillback (residuals)

- Cycle failures
- Geometrically offset intersections
- Mix of signalized and unsignalized intersections
- Unbalanced lane use
- Complex weaving areas

The HCM notes that signalized intersection capacity analyses, both undersaturated and oversaturated can adequately be performed without a simulation model.

For the purposes of this report, we have assumed that the Synchro and SimTraffic models would be used for analysis. The reason for this assumption is that 1) the Maryland State Highway Administration has purchased this software for use in it's District offices and at its Office of Traffic and Safety, 2) many of the SHA staff at these offices have received training on the software, 3) the majority of SHA's consultants use the software for intersection analysis and simulation, and 4) because these models are nationally accepted by DOTs and consulting agencies. It should be noted that Synchro implements the HCM 2000 methodology for signalized, unsignalized intersections, and arterials. Also, the Synchro model serves as the input for the SimTraffic model. Synchro is a deterministic, macroscopic program; SimTraffic is a stochastic, microscopic simulation and animation program.

The following describes a procedure for validating each MOE in either the Synchro or SimTraffic models. As noted in Table 1, only the field-measured MOE's can be validated in a traffic model, and hence the v/c ratio, LOS and % of failing approaches MOE's are not described.

It should be noted that the errors between field-measured MOE's and model-derived MOE's may be up to 30%, and the model would still be considered adequately validated. However, the error should be consistent within the model over several corridors (for travel time and delay studies) or movements (for intersections studies). When this occurs, the MOEs for the alternatives analyses should be based on the validated model, and should emphasize the relative change between alternatives. Therefore, the setting s of the validated model becomes the base condition for the analysis.

1. Peak Hour Volumes

Volumes can be validated only within SimTraffic. SimTraffic seeds, or places vehicles, into the network before the simulation begins. During the seeding and recording process, SimTraffic executes several microscopic logics such as gap acceptance, car following, lane changing, acceleration and deceleration rates, start-up times, driver type, vehicle paths, etc. which will ultimately determine delays, queues, stops, and several other MOEs. If one or more movements are above capacity, the number of entering vehicles will always exceed the number of exiting vehicles, and equilibrium will not be achieved. In other words, at times, the signal network will be oversaturated and will accept any more vehicles into the system. This also occurs in real-world conditions when a signal can't process the demand. Peak hour volumes by movement, can be validated by comparing the *vehicles entered* and *vehicles exited* MOE's within SimTraffic. These MOE's should match the peak hour field collected data to within 5%. If they do not match, there may be a coding error, or the default parameters in model cannot accurately represent real-world conditions (such as the capacity constraining effect of numerous low-volume driveways on an arterial) unless they are adjusted to replicate the field conditions.

2. Delay

Field-measurements of delay at signalized intersections typically measure stopped-delay. Synchro reports control delays at signalized intersections. Control delay is approximately equal to 1.3 times stopped delay.[ix] In order to validate field-measured delays in Synchro, the field-measurements must first be increased by 30%. SimTraffic considers a vehicle to be stopped when it is traveling less than 10 feet per second (6 mph). In order to validate field-measured stopped-delays in SimTraffic, the field-measurements must also consider a vehicle stopped when it is traveling less than 10 feet per second.

3. Percent (%) Of Vehicles Stopped

Validation of the Percent (%) of Vehicles Stopped MOE in Synchro can be determined by dividing the number of stops by the hourly traffic volume. In Synchro, vehicles being delayed for less than 10 seconds do not make a full stop. Vehicles delayed less than 10 seconds are considered partially delayed.

Since this MOE is determined using the same field study as delay, the definitions of delay in the field study (discussed above) must be the same as the SimTraffic definition. The SimTraffic MOE to be compared with the field-measured MOE is *stops/vehicle*.

4. Queues

Synchro provides two queuing measurements: 50th percentile and 95th percentile queues. In Synchro, the vehicle length and space between vehicles is 25 feet. The 50th percentile queue is the average back-of-queue during a typical signal cycle. Field-measured back-of-queues should be compared to the 50th percentile MOE.

SimTraffic reports several types of queues as well. For purposes of validation, the maximum queue should be compared with the field-measured queues. **Figure 3** summarizes the different queuing calculations within SimTraffic.

The **Maximum Queue** is the maximum back of queue observed for the entire analysis interval. This is a simple maximum, no averaging is performed. The maximum queue is calculated independently for each lane. The queue reported is the maximum queue for each individual lane, NOT the sum of all lanes' queues.

SimTraffic records the maximum back of queue observed for every two-minute period. The **Average Queue** is average of all the 2-minute maximum queues.

A standard deviation is also calculated using the sum of squares for each 2-minute interval. The 95th Queue is equal to the Average Queue plus 1.65 standard deviations of the average queue. The 95th Queue is not necessarily ever observed, it is simply based on statistical calculations.

Figure 3. SimTraffic Queuing Methodology

5. Travel Time

Travel time measurements in the field can be directly validated with the Arterial Travel Time report in Synchro. In Synchro, travel time is equal to running time plus signal delay, where running time is the link distance divided by the flow speed, and signal delay is the percentile delay for the through lane group.

iii) Comparing MOE's

The HCM states "when satisfactory simulation model results are obtained from the baseline case, the user can prepare data sets for alternative cases by varying geometry, controls, and traffic demand. If the model is calibrated and validated on the basis of the observed data, values of the calibrated parameters should also be used in the alternatives analysis, assuming that driver behavior and vehicle characteristics in the baseline case are the same as those in the alternative cases."[x]

Once the MOE's are compared and tabulated among the alternatives, ranking may occur. Using a utility index could aggregate the MOE's. A Utility Index (UI) assigns predetermined weights to each MOE with the purpose of calculating a weighted numerical value (for example a scale of 10 or 100 points) for each intersection or project. This single numerical value can be compared between different projects for ranking and prioritizing alternatives.

The governing office of the SHA such as ADE-Traffic should select the assignment of "weights" to various variables of the Utility Index. Such weights should vary by project on a case-by-case basis. Weights should be assigned, but not limited, to MOEs such as traffic volumes, Stops, Delays, Queues, LOS, V/C ratio of mainline and side streets, Movement Failure, Travel time, and Cost. These weights should be assigned base on the significance of the MOE to the prospect improvements.

IV. SUMMARY

Based on the above, the most appropriates measures of effectiveness to conduct before and after studies and evaluate alternative improvements are listed as follows in a hierarchical order: travel time (when applicable), delay, queue, stops, level of service, V/C ratio, traffic volumes, and lastly Percent of Failing Approaches. Of those MOEs, a traffic model should be validated based on queue lengths, delay and travel time.

Collecting accurate traffic data for the Base Condition and conducting "before and after improvement" studies is very important for the success of the Fund 87 Program. At a minimum, the field measured traffic data for the "before and after improvement" conditions should include traffic volumes, delays, travel time and queues. Without accurate and complete objective data, monetary funds could be expanded at locations of less significance than others, and the net benefits of the Program could potentially be underestimated.

The Synchro and SimTraffic models are acceptable tools and better than the CLV method to use for the Fund 87 Program. Both models are currently in use by SHA and consultants and meet all of the criteria discussed in this paper. Both models have been validated by SHA and used for numerous intersections and arterials in the state. All of the SHA District Traffic staff have been trained to use both models and, therefore, should be able to use it as well as review consultants' work.

ENDNOTES

[i] Joseph L. Schofer, "Emerging Methods in Transportation Evaluation," n.p, (n.d): 77

[ii] Schofer, 78

[iii] Transportation Research Board, Highway Capacity Manual (Washington D.C.: Transportation Research Board, 2000) 31-23

[iv] Transportation Research Board, 9-3

[v] Shawn M. Turner, Matthew E. Best, and David L. Schrank, "Measures of Effectiveness for Major Investment Studies" (Texas Transportation Institute, 1996), 71-74

[vi] H. Douglas Robertson, Joseph E. Hummer, and Donna C. Nelson, Manual of Transportation Engineering Studies (Englewood Cliffs, NJ: Prentice Hall, 1994), 53

[vii] Transportation Research Board, 16-1

[viii] Transportation Research Board, 31-2 and 31-16

[ix] Trafficware Corporation, Synchro on-line help, Build 321, computer software, 2002.

[x] Transportation Research Board, 31-24