Framework to Consider the Effect of Uncertainty in Forecasting the Level of Service of Signalized and Unsignalized Intersections

ZAHER KHATIB
MICHAEL KYTE
University of Idaho, USA

ABSTRACT

One question that is not often considered in highway capacity analysis is the effect that uncertainty in the input parameters has on the output results. Typically, analysts produce a single number that represents the performance of the facility, with no statement of a likely range of variation in the result.

And yet we know that there is variability in our input data. What is the effect, for example, of not knowing if the demand on a given intersection approach, is 2700 veh/h or 3000 veh/h? What is the effect of knowing that the range of truck percentage is between 5 percent and 10 percent? It is interesting to note that modelers of future traffic demand often say that their forecasts are within 25 percent of the value cited; some say that this forecast error is even higher!

What is the impact of this uncertainty on capacity analysis? It depends on the kind of problem that we are trying to solve: do we want to know how many lanes are required for a given approach? Do we want to know whether stop control or signal control is most appropriate for a given intersection? Do we want a precise estimate of the timing for a signalized intersection?

We believe that it is the responsibility of the analyst to report this uncertainty with his or her estimate of level of service and how it will affect the problem or decision under consideration. The purpose of this paper is to consider which variables have a significant effect on level of service and to suggest a framework for considering this issue in the analysis of signalized and unsignalized intersections.

1. INTRODUCTION

The primary purpose in applying the procedures of the *Highway Capacity Manual* (HCM) is to produce information that is useful in making a decision about a transportation facility or system. The various HCM procedures produce forecasts of one or more performance measures, one of which is tied to a level of service grade.

The nature of the decision under consideration helps to identify one of the three analytical procedures most appropriate for use for a given problem: operational analysis, design analysis, or planning analysis.

An *operational analysis* is used to identify a potential problem in a given facility or system and how it might be remedied. The HCM 2000 notes that

> . . . decisions that can be made, using the results from the HCM, include a choice among alternative intersection controls, a choice among alternative signal phasing and timing arrangements, a choice among alternative minor changes to control and marking . . . , and a choice among a combination of actions.

A *design analysis* is most commonly used to determine the number of lanes needed to operate a facility at a desired level of service.

A *planning analysis* is often used to determine the feasibility of a new development. Again, from the HCM 2000:

> For example, if a shopping center is proposed for a location, the HCM analyses may be used to decide if the traffic generated by the development will result in an undesirable quality of service. . . . Thus the HCM can be used in the process of deciding on what should be required of a new commercial or residential development as well as cost-sharing for any public improvements to be made in conjunction with the development. For example, the developer might be required to change the location, number, or geometrics of access points based upon tests made using the HCM.

The HCM 2000 notes the importance of the role of sensitivity analysis:

> Once one or more performance measures have been selected for use in reporting analysis results, decision making can be improved by showing how the numerical values (or the letter grade for LOS) change when one or more of the assumed input values changes. For the decision maker, it may be quite important to know how an assumed increase of 15 percent in future traffic volume (compared with the standard forecast volume) will affect delay and level of service at a signalized intersection. By providing a central value along with values based on upward and downward assumptions on key input variables (especially volume), the analyst can ensure that decision-making is based on a full understanding of sensitivities.

Each type of analysis requires a different level of accuracy. The role of accuracy in capacity analysis is noted in the HCM 2000:

> The limitations on accuracy and validity of predictions for performance measures should be recognized when applying the results of the analysis. For instance, small differences between the values of performance measures for alternative designs should not be assumed to be real (statistically significant) differences. Furthermore, if the predicted value for an MOE is near, but below, a critical threshold, it should be recognized that there is some probability that it will in fact be higher than predicted, and may exceed the critical threshold. The HCM user should recognize,

> therefore, that judgment is required when applying the results of HCM analyses. One basis for judgment should be a good understanding of the structure and basis of the models that are used in this manual.

The HCM 2000 includes a discussion of the quality of the results as they relate to the quality of the input variables:

> The analyst should recognize that the quality of the results is dependent on the quality of the input data. Default values will produce less accurate results than field measured data. Generic default values suggested in this manual will produce less accurate results than locally developed default values.

So, how do we deal with these concerns that are raised in the HCM? We know, for example, that there are two ways in which uncertainty emerges in our results. First, there can be uncertainty in our input data that is propagated through to the final results and calculations. Second, there can be uncertainty in the nature or quality of the forecasting model itself that again generates uncertainty in our results.

Next, we present a discussion on how the uncertainty in various categories of input data affects the results of a capacity analysis.

2. GENERIC ANALYSIS FRAMEWORK

2.1 Unsignalized Intersections

Let's consider the unsignalized intersection capacity analysis procedure. Suppose that we need to assess the performance of a two-way stop-controlled intersection to determine whether signal control is needed or if a change to the intersection geometry might better solve a problem. What are the factors that we know will influence our decision? When we are using the HCM as the analysis tool, these factors are simply the input variables for the unsignalized intersection capacity analysis procedure:

- Vehicles flow rates by direction and movement
- Proportion of heavy vehicles in the traffic stream
- Pedestrian flow rates
- Critical gap
- Follow up time
- Intersection geometry: number and configuration of lanes
- Presence of upstream signals on the major street
- Presence of a flare on the minor street approaches
- Median storage on the major street
- Grades on the approaches

How does each factor affect delay and level of service? How can we best account for the uncertainty that we identify in these variables? Let's first consider grouping these variables into three categories, each representing a different kind of uncertainty.

- The flow rate data, and related traffic stream characteristics, must be forecasted, often with a high level of uncertainty. Transportation planners often place errors of plus or minus 25 percent on their traffic demand forecasts.
- The critical gap and follow up time data included in the HCM are average values representing a range of field data and site characteristics. Kyte and others (1996) found that site-specific data always yield superior forecasts compared to the forecasts using general values. Thus, the level of uncertainty created by the critical gap and follow up time may be high.
- The intersection geometry data is usually known to a high degree of certainty. While some may argue this point, even when considering a future project, a specific design is usually developed to the point that the geometric parameters (number of lanes, lane configuration, etc.) are known. For one variable (upstream signals), however, the quality of the model may be poor since it represents a stochastic process in a deterministic manner.

Next, let's consider how the level of service of the intersection under consideration might itself affect the range of variation in the forecast. Consider two extreme cases of traffic demand for an intersection with all other factors remaining constant. Under low volume conditions, the traffic volume forecasts can vary considerably with very little effect on the performance of the intersection. However, at high volume conditions, even a small variation in the volume forecast may have a large effect on the performance of the intersection. We may see a high uncertainty in the level of service forecast over a relatively small variation in the input volume.

So, we must consider two issues here:

- Certain input variables, such as traffic forecasts and driver behavior, have an inherently high degree of variability and may cause a high degree of uncertainty in the results.
- The volume level itself introduces another source of uncertainty.

Both issues must be considered in our analysis.

A discussion on how this variation might affect our forecasts is presented in Section 3 of this paper.

2.2 Signalized Intersections

Let's now consider the more complex situation of a signalized intersection. The more common kinds of decisions that are made using the signalized intersection capacity analysis module of the HCM include:

- The number of lanes required to accommodate the given traffic demand
- The signal timing and phasing plan required to serve a given traffic volume

The signalized intersection procedure requires the following input data:

- The traffic volumes by approach and movement
- The ideal saturation flow rate

- The intersection geometry, including number and configuration of lanes
- The signal timing and phasing plan
- The proportion of heavy vehicles in the traffic stream
- The grades on the intersection approaches
- The number of parking maneuvers

Which of these values do we know precisely and which can we only forecast with some level of uncertainty? As before, the traffic volume forecast is subject to a high degree of uncertainty. Driver behavior, as measured by the saturation headway, is site specific, similar to the critical gap at unsignalized intersections. There is some degree of uncertainty introduced by some of the model components, maybe greatest with the left turn permitted movement model. But the intersection geometry and the signal timing plan are both fixed by the design parameters that we are considering. The signal timing plan, for example, can be developed or synthesized so that for a given design and traffic volume, the intersection will operate in a near optimal manner.

So our uncertainty lies primarily in the following areas:

- Traffic volume forecast
- Driver behavior at a particular site
- Model inadequacies

And, as with the earlier discussion on unsignalized intersections, the level of service of the intersection itself helps to determine the range of uncertainty or variability that we can expect in our results.

Uncertainty might be generated due to volume fluctuation, changes in one or more parameters that affect capacity analysis. For instance, the volume might fluctuate from season to season, the conflicting pedestrian flows might change from peak versus non-peak periods, or the lane width might change due to new stripping.

The question here is: if one parameter has changed, how much will this affect the overall operational level of performance for a signalized intersection. Are the signalized capacity analysis and the level of service modules sensitive to small changes in the input parameters? These questions will be answered in the next section of this paper.

3. CASE STUDIES

In the previous section, we discussed two concepts:

- There are three classes of input variables, each of which we may know with a different level of uncertainty.
- The level of service itself affects the degree of certainty with which we may know the level of service.

3.1 Unsignalized Intersections

We will first consider a two-way stop-controlled intersection with three approaches, a standard T-intersection. Case 1, in Table 1, has low volumes on the approaches; the total intersection volume is 900 veh/h. Cases 2 and 3 show levels of service C and E, respectively, with intersection volumes of 1200 and 1400 veh/h.

The forecasted level of service for the minor street approach for Case 1 is B. If we consider a variation in both the flow rate and the critical gap, the demand forecast and driver behavior variables that we discussed earlier, the effect on level of service is minimal. Figure 1 shows the effect of a variation in the flow and critical gap on delay, as a function of the volume level. When level of service is low, as demonstrated by Case 1, a 10 percent change in the volume or the critical gap (both increase and decrease) shows little effect on the overall level of service. Decisions made about intersection performance in this range can be made with a higher level of confidence.

But now consider Case 3, with a base forecast of level of service E. Here, variation in either the flow rate or the critical gap produces a wide range in level of service. A 10 percent volume variation shows a wide range in the level of service forecast, from level of service D (acceptable) to level of service F (not acceptable). Similar changes in critical gap produce similar effects on level of service. Decisions about intersection design, then, must be made more carefully since a change in the input conditions have a much larger effect at this level of service range.

TABLE 1 Unsignalized Intersection Volumes

Volumes (veh/h)		**Case 1 - LOS A**			**Case 2 - LOS C**			**Case 3 - LOS E**		
		NB	**EB**	**WB**	**NB**	**EB**	**WB**	**NB**	**EB**	**WB**
LT movement		40		150	50		200	60		250
TH movement			250	300		350	400		400	450
RT movement		120	40		150	50		180	60	
Minor (NB) movement	v/c	0.30			0.50			0.77		
	delay	14.4			23.0			46.2		
	LOS	B			C			E		

3.2 Signalized Intersections

Let's now consider a case study using the signalized intersection methodology. This intersection is located in northern Idaho, along U.S. 95, a signalized arterial, and is now two-way stop-controlled. Plans are now underway to install a signal at the intersection. The volume forecast is 3000 veh/h on the major street and 450 veh/h on the minor street.

For a base analysis, the present intersection geometry is assumed and an optimal phasing and timing plan was developed. The HCM signalized intersection model forecasts 25.8 sec/veh for the intersection, or level of service C. This forecast assumes 12-foot lanes, no grade, and no heavy vehicles.

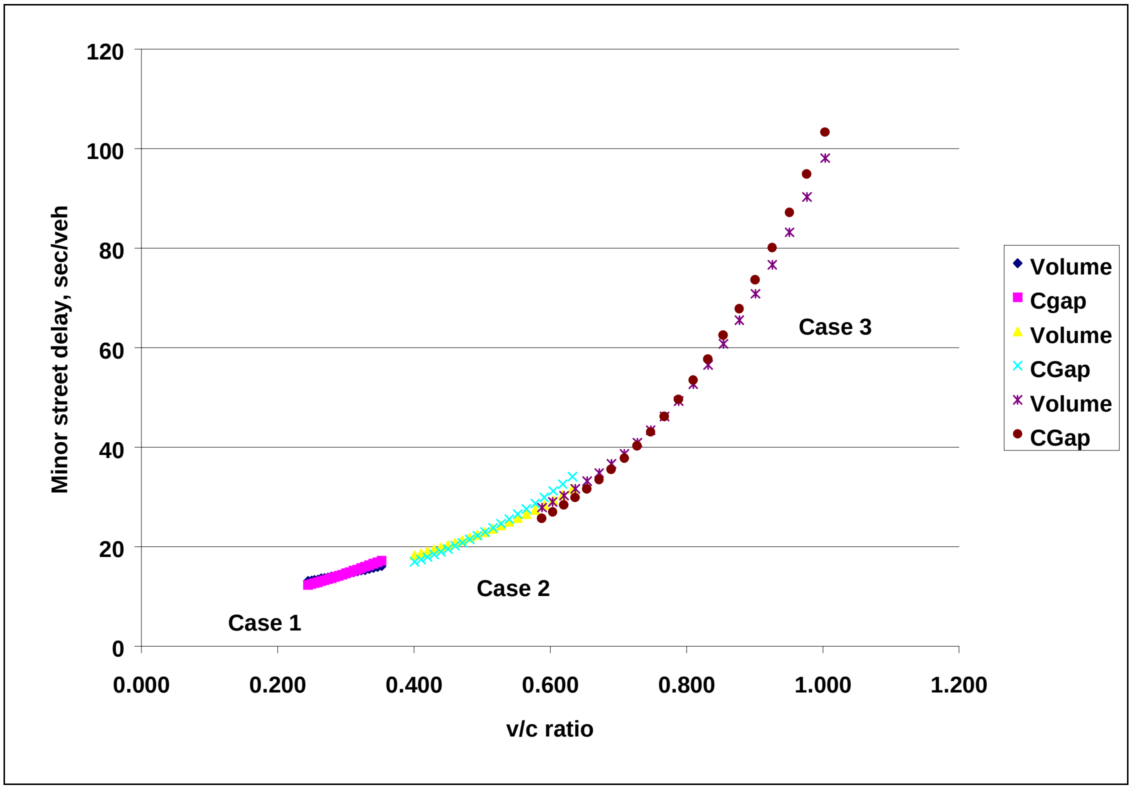

FIGURE 1 TWSC intersection delay sensitivity.

We completed a number of calculations for level of service for this intersection, varying several input variables. The results are shown in Figure 2. While we don't claim that the results here are general, the figure does show three important points:

- The geometric factors such as lane width or grade have some effect on the level of service, but the effect is small.
- The volume forecasts have a significant effect. Figure 2 shows that a range of –20 percent to +20 percent would change the level of service from B to E, nearly the entire range of level of service grades.
- Varying the saturation headway shows that driver behavior also has a significant effect. Figure 2 shows that aggressive drivers (*h* = 1.6) have a minor affect on delay. The delay has increased from 15 sec/veh to 25 sec/veh as volume increases from –20% to +20% of the base volume. But non-aggressive drivers (*h* = 2.4) have a major effect on delay as traffic volume increases. The delay increased fivefold from 27 sec/veh to 150 sec/veh. The corresponding level of service for the aggressive driver ranged between B and C, whereas for the non-aggressive driver the LOS has ranged from C to F as traffic volume increases. Another perspective on this variation in the saturation headway is that if we only know the value to within 10 percent, we may find a large variation in our results.

The delays represented here are based on changing one parameter at a time. However, the impact of changing more than one parameter in one specific run will have a compound

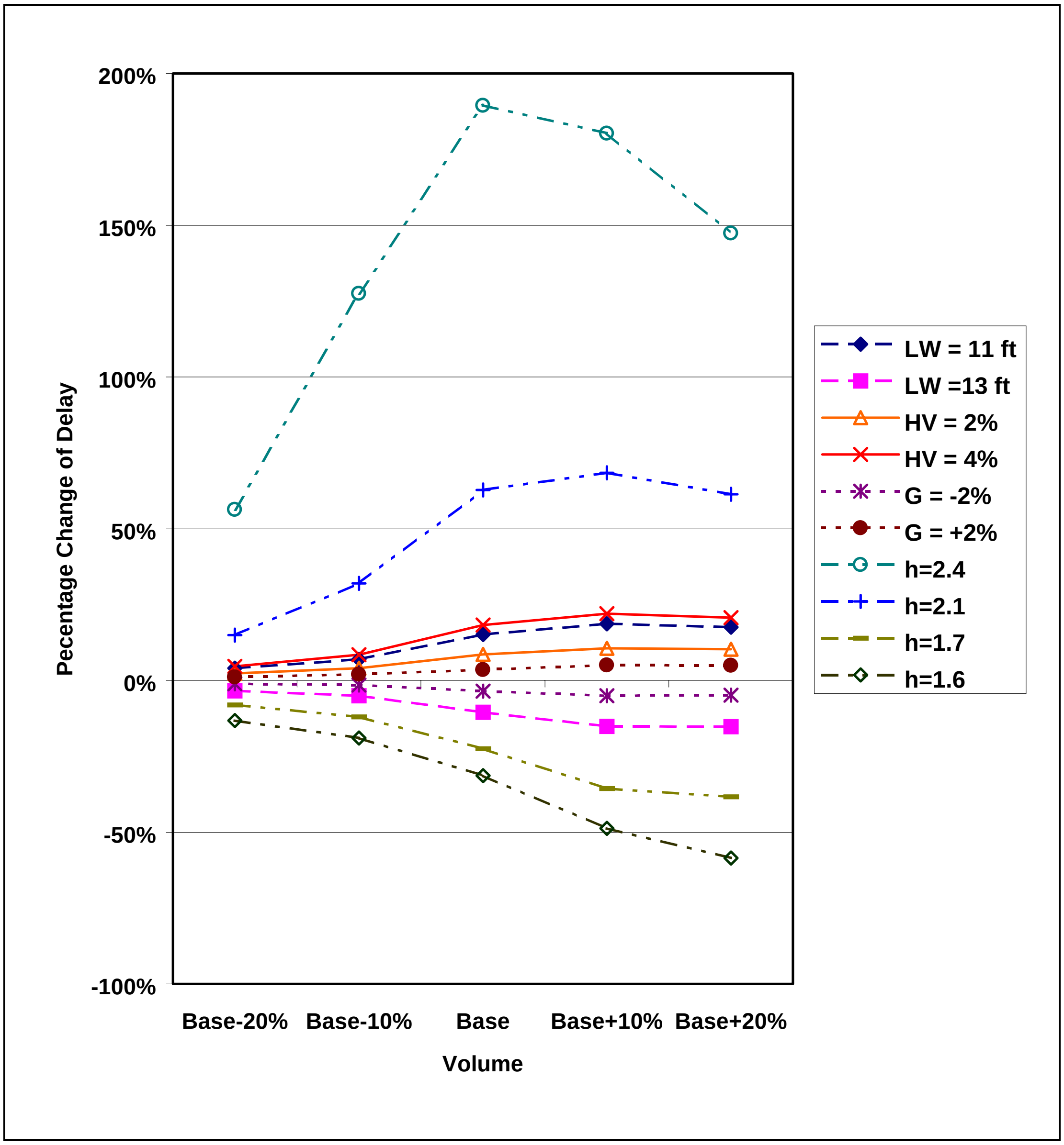

FIGURE 2 Signalized intersection delay sensitivity.

effect on the delay unless changes are made in such a way that one parameter is increasing while the other is decreasing the delay.

4. DISCUSSION

Let's now consider some of the key issues that we have discussed, and determine what additional work is needed.

- The volume level is important. Intersections with average to poor levels of service (higher volume levels) make the analysts' job more difficult in that a variation in the volume forecast results in a potentially wide variation in the range of the level of service forecast. Variations in any input variable have a higher effect in these cases than for intersections with good levels of service. The analyst should treat cases with average to poor levels of service carefully.

- Driver behavior variables (saturation headway, critical gap) also cause a high degree of uncertainty in the results. The analyst can reduce this uncertainty by using site specific data, if such data are available.
- Even a reasonable level of volume uncertainty, within the range of likely error of most travel demand forecasting models, can produce large variation in the level of service.
- Other factors, such as intersection geometry and signal timing, have some effect. But these variables are known to a high degree of specificity so uncertainty effects are minimized.

One possible area of additional work is to study specific cases in greater depth. In this way, the analyst can have available guidelines that can help determine which input variables are likely to have the greatest effect on the final result and how this variation will affect the decision at hand.

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