

CHAPTER 3

RESEARCH METHODOLOGY

This research effort is conducted to assess the consistency of delay, number of stops and queue size estimates among various existing analytical and simulation approaches for both undersaturated and oversaturated signalized intersections. To perform this assessment, the various estimation models are thoroughly investigated by identifying their assumptions, limitations and strengths. The analytical model estimates are compared to the results of the INTEGRATION microscopic traffic simulation model in order to demonstrate the consistency between macroscopic analytical and car-following approaches. Having demonstrated the validity of the INTEGRATION model for conditions where analytical solutions are available, the INTEGRATION model is used to evaluate conditions that are extremely difficult to compute analytically. For specifically, the number of vehicle stops for oversaturated signalized intersections and delay for mixed flow arrivals are evaluated. This chapter describes the research methodology to assess the consistency of the various analytical and simulation methods considered.

3.1 LIMITATIONS OF ANALYTICAL DELAY MODELS

Essentially, all analytical delay models of traffic systems are structured in a demand-supply framework. The demand-supply framework can be defined at the microscopic analysis level, in which individual traffic units are studied, or at the macroscopic analysis level, in which attention is given to groups of traffic units in aggregate form instead of individual vehicles. Most analytical models deal with the macroscopic models to estimate delay measurements. In this particular research, six analytical delay models have been selected for analysis. These models are the queue-based models used in the 1994 and 2000 versions of the Highway Capacity Manual and in the 1995 Canadian Capacity Guide for Signalized Intersections, as these three models are among the most widely used in North America, a theoretical vertical queuing analysis model and

a theoretical horizontal queuing model derived from shock wave analysis. The above analytical delay models were described in some detail in Chapter 2.

The most important limitation that is inherent to all analytical delay models for signalized intersections is their inability to predict delay for traffic conditions that are different than those assumed in the models. In particular, because they were designed to evaluate flow patterns from a macroscopic point of view, that is, by considering only hourly flows and average traffic behavior, these models cannot be used to analyze the delay incurred by individual vehicles. The following is a list of the major limitations currently attributed to the analytical delay models:

- The existing analytical models cannot handle interacting queuing process.
- Residual queues at the end of a control period cannot be transferred to another control period. This could lead to a significant underestimation of delays in congested periods.
- The variability of traffic demand within a given control period cannot be fully considered. Analyses are typically done using the average demand within a period.
- Unusual arrival and service patterns that do not follow traditional statistical distributions cannot be modeled.
- Alternative scenarios such as those analyzing the impact of additional traffic lanes or alternative lane stripping cannot be considered, as analytical models do not track the progression of individual vehicles.
- The models cannot be used to experiment with situations that do not exist today.
- The models cannot be used to analyze real-time traffic operations, as such operations are typically concerned with instantaneous and cyclic flows rather than average flows.
- The model fail to model mixed approach flow signalized intersections.

In addition, the existing analytical models were primarily designed to perform operational traffic analyses. While some practitioners use analytical delay models such as the HCM models to generate signal timing at signalized intersections, these models were not designed to directly perform design procedures.

3.2 BENEFITS OF COMPUTER SIMULATION AS AN EVALUATION TOOL

This section provides a brief introduction into computer simulation as an alternative approach to the analysis of traffic and transportation problems. The early development in computer traffic simulation technology dates back to the 1950's (May, 1990). By about 1960 it became generally accepted that traffic simulation was possible and feasible (Gerlough, 1975) and since then this powerful technique has found a wide range of applications in many transportation and traffic engineering fields.

Computer simulation has been defined in several ways as simulation means different things to different people. In the broader sense, computer simulation is defined as a "logical-mathematical representation of a concept, system, or operation programmed for solution on a high speed electronic computer" (Martin, 1968). Drew (1968) defined simulation as "a working analogy that involves the construction of a working model presenting similarity of properties or relationships to the real problem under study". However, in transportation-related applications, May (1990) defined computer simulation using more specific terms as "a numerical technique for conducting experiments on a digital computer, which may include stochastic characteristics, be microscopic or macroscopic in nature, and involve mathematical models that describe the behavior of a transportation system over extended periods of real time".

Macroscopic traffic simulation models incorporate analytic models that deal with the average traffic stream characteristics, such as flow, speed, density, etc. On the other hand, microscopic models consider the characteristics of individual vehicles, and their interactions with other vehicles in the traffic stream (Scabardonis, 1988). Nonetheless, some microscopic traffic simulation models are able to produce macroscopic statistics of the transportation system.

Traffic simulation models also differ in their scope and applications. Some models are designed exclusively to deal with individual components of the highway system, such as isolated signalized/unsignalized intersections, bridges, linear or corridor freeway systems, etc. Other

simulation models have the ability to deal with complex highway networks that could integrate most highway system components.

Historically, vehicle delay at signalized intersections has been studied through the use of analytical techniques and field data. In fact, all analysis procedures for delay estimates were developed based on simple queuing theory. However, these theoretical approaches were shown to be limited in many aspects and this fact affected the efficiency and accuracy of both the design and evaluation processes of traffic operations at signalized intersection. This is true despite the fact that significant research efforts have been devoted in the past four decades to develop reasonably reliable models. These inherent limitations to analytical techniques were described in section 3.1 and are mainly attributed to the practical difficulties of analytical modeling traffic behavior at signalized intersections. Another limitation source is the considerable amount of field data that is required to capture all aspects of traffic behavior. For example, data is typically required on vehicle flows, lane changing behavior, transit operations, vehicle occupancy, etc.

Traffic operations represent the final outcome of a complex interaction between transportation system components, i.e., vehicles, network, and control strategies. Also, driver characteristics and environmental conditions are part of this interaction and they have their impacts on traffic operations. Numerous theories and mathematical models have been developed to address individual aspects of traffic operations. No single theory or model has been developed so far which applies to all aspects of traffic operations. Examples of these individual theories and models are queuing theory and shock wave theory. These theories and models were initially intended to analyze specific aspects of traffic operations in an isolated fashion. While the analyses that are based on these well-accepted theories and models may represent reasonable and effective analytical tools at the component level, they can not predict traffic operations at the more general network level. With this regard, the most important benefit to computer traffic simulation is the ability to integrate different analytical tools into one model and to dynamically represent their interaction on a network. This ability, which is not provided by conventional analytical techniques, is needed by engineers and professionals.

Besides the ability to model complex systems such as traffic operations at the network level, there are many advantages and strengths associated with simulation as related to traffic and transportation applications. In many cases, computer simulation offers opportunities that are simply not feasible using field data. Specifically, traffic simulation enables traffic and transportation analysts to test the effectiveness of alternative design and traffic management schemes before their field implementation. In this regard, many innovative Intelligent Transportation System (ITS) projects and strategies are being typically investigated using computer simulation techniques at their early conceptual stages.

Another important benefit of computer simulation is that it offers an alternative approach to investigate traffic operations when empirical data is unavailable or very difficult to obtain due to practical or technical reasons. In particular, this lack of empirical data has caused what appeared to be a change in the general attitude towards the use of computer simulation in developing new analytical models. This change in attitude can be observed from many of the now active NCHRP (National Co-operative Highway Research Program) research projects to develop the new version for the HCM 2000.

Moreover, the state-of-the-art traffic simulation models provide users with the ability to perform sophisticated experiments on various highway systems and to get the most desirable statistics and measures of performance. This is not normally possible using conventional analytical technique. Another important issue which is critical to many users and applications, is that the resources required for traffic simulation modeling are much less than those required by studies that utilize analytical techniques and field data. In this sense, computer simulation seems to offer an affordable and feasible tool for traffic analysis on highway system components.

In summary, the severe limitations of analytical techniques for signalized intersections, and the tremendous amount of field data required to exhaustively model traffic behavior using analytical technique, were behind the selection of computer traffic simulation as the most appropriate technique to conduct this research.

3.3 SIMULATED VERSUS REAL LIFE TRAFFIC BEHAVIOR

An important issue to be considered in the selection of a technique or tool is the ability to model the main aspects of traffic behavior as they exist in real life. Normally, graphical or mathematical models that are developed from some theories are viewed as the most reliable means of describing this traffic behavior. In this regard, most analysis and design models included in the different versions of the HCM (and other analytical models) were developed based on some sort of theories and/or empirical data. However, the numerous factors that affect many aspects of traffic behavior, as well as the inherent limitations of analytical have raised questions concerning the reliability and accuracy of these analytical procedures in evaluating traffic operations, particularly at signalized intersections. In many cases, the analytical procedures are insensitive to some traffic variables that are known to have significant impacts on traffic operation, e.g., impact of mixed traffic, and do not always produce logical sensitivities.

In practice, many professionals and specialists are inclined to deal with models that are based on some sort of theories and empirical data with higher level confidence than models based on simulated data. However, being established on analytical techniques based on theories is not enough for a model to predict accurate and reliable traffic performance measures. On the other hand, predicted performance measures from microscopic simulation models were often found to be considerably closer to the field data than the estimated values from all analytical models.

In summary, models that are based on theories and empirical data are not always predicting good estimations. On the other hand, the state-of-the-art computer traffic simulation models can reasonably be used for identifying key operation and traffic performance measures. In particular, the use of simulation models can be justified by two main factors. The first factor is the need expressed by transportation professionals for better understanding of complicated traffic behavior at highway facilities and the relationships that lie behind this behavior. These relationships can not be reasonably explored using most existing analytical models. The second reason, which is equally important, is the significant developments in computer technology and traffic simulation

models in the last two decades. This has led to a consensus in the field on the promising potential of computer simulation in developing new improved and robust analytical techniques. Examples of this new attitude is the significant research on traffic simulation modeling during the last decade and the plan to use simulated data in some new analysis procedures in the HCM 2000.

3.4 METHODOLOGY

Having decided on the analytical technique to use, the natural step was to formulate a methodology to perform the analyses that would explore the consistency of delay estimates from various models at signalized intersections. This methodology is best presented by describing its main features as discussed in the following sections.

3.4.1 COMPARISON WITH THE STATE OF PRACTICE

In order to assess the contribution of any innovative research, there must be standards against which any improvement in the state of knowledge can be identified. Normally, these standards should represent the existing state of knowledge at the time of development. Currently, the delay estimates and Level Of Service (LOS) procedures of the HCM are the principal means to investigate delay estimates and traffic performance at signalized intersections on highway sections. Highway systems, at different levels, are being planned, designed and operated using these procedures. Therefore, it was felt that the HCM delay and LOS procedures are an important reference against which any progress in the current state of knowledge should be evaluated. Consequently, traffic performance behavior as predicted by these analytical models will be thoroughly investigated and then compared to the corresponding behavior from computer simulation prior to establishing the proposed patterns of traffic performance behavior under the influence of different traffic variables.

3.4.2 STUDY APPROACH TO MEASURE DELAY ESTIMATES

The delay that a particular vehicle experiences when it travels through a signalized intersection approach depends on a number of factors such as the arrival flow rate and distribution, the signal

timings. In a real application environment, many of these factors are random variables, which makes the accurate prediction of delay a very complicated process. As an initial research effort, this research considers the following idealized road traffic, signal control and prediction conditions:

- (a) Initially, the intersection approach consists of a single through lane controlled by an isolated fixed-time signal. Later, the lane will be extended to two lanes to compare the delay estimates between single-lane and two-lane scenarios.
- (b) The approach has limited space for queue and has a constant saturation flow rate.
- (c) To cover a range of scenarios, delay estimations will be carried out for scenarios considering uniform and random arrivals as well as undersaturated and oversaturated conditions.
- (d) The headways of vehicle arrivals at on an intersection approach are assumed to follow a shifted negative exponential distribution.
- (e) No overflow queue is present at the time when a prediction is performed.
- (f) Initially, this research assumes that the traffic stream consists only of passenger car units. Later, the traffic stream is expanded to comprise both passenger cars and buses to enable delay measurements in mixed traffic flow conditions.

3.4.3 STUDY APPROACH TO EVALUATE TRAFFIC PERFORMANCE MEASURES

The proposed approach uses state-of-the-practice analytical procedures for computing delay at isolated signalized approaches in conjunction with the INTEGRATION model. Comparisons are made for simplified scenarios in order to demonstrate the validity of the INTEGRATION logic. Subsequently, the INTEGRATION model is utilized to compute the queue length and number of stops for over-saturation signalized approaches, which is beyond the scope of current state-of-the-art analytical approaches. Finally, the INTEGRATION model is utilized to compute the delay associated with mixed flow approaches.

The INTEGRATION model provides six outputs for delay estimates. These are outputs in Files 10, 11, 12, 15, 16 and the Summary File. The reader may consult the user's guide for more information on the INTEGRATION output. For example, File 10 produces an average trip time, while File 11 produces an average link travel time. This means that the INTEGRATION model

can find not only the total and average delay estimates, but also the delay estimates of individual vehicles for each link. This research effort ensures that the INTEGRATION delay estimates are consistent for the different output files.