

**DELAY, STOP AND QUEUE ESTIMATION FOR
UNIFORM AND RANDOM TRAFFIC ARRIVALS
AT FIXED-TIME SIGNALIZED INTERSECTIONS**

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**Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of**

**Doctor of Philosophy
in
Civil and Environmental Engineering**

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**April, 2000
Blacksburg, Virginia**

**Keywords: ITS, ATMS, Delay Models, HCM, CCG, Queue, Deterministic,
Stochastic, Signalized Intersection, Shock Wave, INTEGRATION**

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ABSTRACT

With the introduction of different forms of adaptive and actuated signal control, there is a need for effective evaluation tools that can capture the intricacies of real-life applications. While the current state-of-the-art analytical procedures provide simple approaches for estimating delay, queue length and stops at signalized intersections, they are limited in scope. Alternatively, several microscopic simulation softwares are currently available for the evaluation of signalized intersections. The objective of this dissertation is fourfold. First, it evaluates the consistency, accuracy, limitations and scope of the alternative analytical models. Second, it evaluates the validity of micro simulation results that evolve as an outcome of the car-following relationships. The validity of these models is demonstrated for idealized hypothetical examples where analytical solutions can be derived. Third, the dissertation expands the scope of current analytical models for the evaluation of oversaturated signalized intersections. Finally, the dissertation demonstrates the implications of using analytical models for the evaluation of real-life network and traffic configurations.

This dissertation compared the delay estimates from numerous models for an undersaturated and oversaturated signalized intersection considering uniform and random arrivals in an attempt to systematically evaluate and demonstrate the assumptions and limitations of different delay estimation approaches. Specifically, the dissertation compared a theoretical vertical queuing analysis model, the queue-based models used in the 1994 and 2000 versions of the Highway Capacity Manual, the queue-based model in the 1995 Canadian Capacity Guide for Signalized Intersections, a theoretical horizontal queuing model derived from shock wave analysis, and the delay estimates produced by the INTEGRATION microscopic traffic simulation software. The results of the comparisons for uniform arrivals indicated that all delay models produced identical results under such traffic conditions, except for the estimates produced by the INTEGRATION software, which tended to estimate slightly higher delays than the other approaches. For the random arrivals, the results of the comparisons indicated that the delay estimates obtained by a micro-simulation model like INTEGRATION were consistent with the delay estimates computed by the analytical approaches.

In addition, this dissertation compared the number of stops and the maximum extent of queue estimates using analytical procedures and the INTEGRATION simulation model for both undersaturated and oversaturated signalized intersections to assess their consistency and to analyze their applicability. For the number of stops estimates, it is found that there is a general agreement between the INTEGRATION microscopic simulation model and the analytical models for undersaturated signalized intersections. Both uniform and random arrivals demonstrated consistency between the INTEGRATION model and the analytical procedures; however, at a v/c ratio of 1.0 the analytical models underestimate the number of stops. The research developed an

upper limit and a proposed model for estimating the number of vehicle stops for oversaturated conditions. It was demonstrated that the current state-of-the-practice analytical models can provide stop estimates that far exceed the upper bound. On the other hand, the INTEGRATION model was found to be consistent with the upper bound and demonstrated that the number of stops converge to 2.3 as the v/c ratio tends to 2.0. For the maximum extent of queue estimates, the estimated maximum extent of queue predicted from horizontal shock wave analysis was higher than the predictions from vertical deterministic queuing analysis. The horizontal shock wave model predicted lower maximum extent of queue than the CCG 1995 model. For oversaturated conditions, the vertical deterministic queuing model underestimated the maximum queue length. It was found that the CCG 1995 predictions were lower than those from the horizontal shock wave model. These differences were attributed to the fact that the CCG 1995 model estimates the remaining residual queue at the end of evaluation time. A consistency was found between the INTEGRATION model and the horizontal shock wave model predictions with respect to the maximum extent of queue for both undersaturated and oversaturated signalized intersections.

Finally, the dissertation analyzed the impact of mixed traffic condition on the vehicle delay, person delay, and number of vehicle stops at a signalized intersection. The analysis considered approximating the mixed flow for equivalent homogeneous flows using two potential conversion factors. The first of these conversion factors was based on relative vehicle lengths while the second was based on relative vehicle riderships. The main conclusion of the analysis was that the optimum vehicle equivalency was dependent on the background level of congestion, the transit vehicle demand, and the Measure of Effectiveness (MOE) being considered. Consequently, explicit simulation of mixed flow is required in order to capture the unique vehicle interactions that result from mixed flow. Furthermore, while homogeneous flow approximations might be effective for some demand levels, these approximations are not consistently effective.

ACKNOWLEDGEMENT

Special thanks to my previous advisor, *Dr. Michel W. Van Aerde*, who passed away last year. You, Michel, are an important part of my life and I had many fond memories with you. I will not forget you and you are always in my heart, Michel.

I owe much gratitude to the many people who generously supported me, both directly and indirectly, throughout the process of completing this dissertation.

The members of my dissertation committee warrant special mention. I would like to express my sincere appreciation to Dr. Hesham Rakha, Dr. John Collura, Dr. Antonio Trani, Dr. Wei Lin and Dr. Francois Dion for their insight, guidance and patience throughout my studies and in the preparation of the dissertation. I owe my most heartfelt thank to Dr. Hesham Rakha, my principal advisor and dissertation committee chairman, for the friendship, for the assistance and for the guidance and financial support in the preparation of my dissertation, for without his help I would not be where I am today. He has consistently encouraged me to persist in an area of inquiry which he graciously assured me would be an important contribution to the body of knowledge. I am also particularly grateful to Dr. Francois Dion for his kindness, helpful guidance and discussions. He caused me to explore important but less obvious dimensions of my study, posing questions for reflection which caused me to stretch my thinking in directions I had not previously considered. In addition, I thank my committee member Dr. John Collura for valuable comments and suggestions. I also thank my committee member Dr. Antonio Trani and Dr. Wei Lin for a helpful suggestion.

My special thanks to my friend Hojong Baik for his friendship, support and assistance over the years of my stay in Blacksburg. I would not have survived the last two years of my life without his support. He witnessed my graduate studies, comforted me when I was depressed, and continues to encourage me everyday. I also thank to my friends, Gyuhae Park, Heung Gweon Sin, Sang-Ouk Ryu, Kyoungho Ahn, Vijay, Casturi, Josh Diekman and Yonglin Ding for their support and friendship. I would like to thank to many close friends and colleagues, to numerous to list but you know who you are.

Finally, to my family, I dedicate this dissertation to my loving parents, Sun-Keun Kang and Hyo-Sook Rho. They have always believed in me and encouraged me to achieve with great love and patience. Every time I hear their voice, I know I am loved. I would also like to thank my brothers and sister-in-laws. In addition, a special thanks goes to sisters, Yeon-Hwa Kang, Yeon-Kyung Kang and brother-in-laws who made this dissertation successfully.

To My Parents:

Sun-Keun Kang

and

Hyo-Sook Rho

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GLOSSARY OF TERMS

Arterial – Signalized streets that serve primarily through traffic and provide access to abutting properties as a secondary function, having signal spacings of 2 miles or less and turn movements at intersections that usually do not exceed 20 percent of total traffic.

Arterial segment – A one-way length of arterial from one signal to the next, including the downstream signalized intersection but not the upstream signalized intersection.

Average approach delay – Average stopped-time delay at a signalized intersection plus average time lost because of deceleration to and acceleration from a stop, generally estimated as 1.3 times the average stopped time delay.

Average running speed – The average speed of a traffic stream computed as the length of a highway segment divided by the average running time of vehicles traversing the segment, in kilometers per hour.

Average running time – The average time vehicles are in motion while traversing a highway segment of given length, excluding stopped-time delay, in seconds per vehicle or minutes per vehicle.

Average stopped-time delay – The total time vehicles are stopped in an intersection approach or lane group during a specified time interval divided by the volume departing from the approach or lane group during the same time period, in seconds per vehicle.

Average total delay – The total additional travel time experienced by drivers, passengers, or pedestrians as a result of control measures and interaction with other users of the facility divided by the volume departing from the corresponding cross section of the facility.

Average travel speed – The average speed of a traffic stream computed as the length of a highway segment divided by the average travel time of vehicles traversing the segment, in kilometers per hour.

Average travel time – The average time spent by vehicles traversing a highway segment of given length, including all stopped-time delay, in seconds per vehicle or minutes per vehicle.

Capacity – The maximum rate of flow at which persons or vehicles can be reasonably expected to traverse a point or uniform segment of a lane or roadway during a specified time period

under prevailing roadway, traffic, and control conditions, usually expressed as vehicles per hour or persons per hour.

Critical density – The density at which capacity occurs for a given facility, usually expressed as vehicles per kilometer per lane.

Critical speed – The speed at which capacity occurs for a given facility, usually expressed as kilometers per hour.

Critical v/c ratio – The proportion of available intersection capacity used by vehicles in critical lane groups.

Cycle – Any complete sequence of signal indications.

Cycle length – The total time for a signal to complete one cycle.

Delay – Additional travel time experienced by a driver, passenger, or pedestrian beyond what would reasonably be desired for a given trip.

Demand volume – The traffic volume expected to desire service past a point or segment of the highway system at some future time, or the traffic currently arriving or desiring service past such a point, usually expressed as vehicles per hour.

Density – The number of vehicles occupying a given length of lane or roadway averaged over time, usually expressed as vehicles per kilometer or vehicles per kilometer per lane.

Effective green time – The time allocated for a given traffic movement (green plus yellow) at a signalized intersection less the start-up and clearance lost times for the movement.

Effective red time – The time during which a given traffic movement or set of movements is directed to stop; cycle length minus effective green times.

Free-flow speed – (1) The theoretical speed of traffic when density is zero, that is, when no vehicles are present; (2) the average speed of vehicles over an arterial segment not close to signalized intersections under conditions of low volume.

Green ratio – The ratio of the effective green time for a given movement at a signalized intersection to the cycle length.

Green time – The actual length of the green indication for a given movement at a signalized intersection.

Headway – The time between two successive vehicles in a traffic lane as they pass a point on the roadway, measured from front bumper to front bumper, in seconds.

Interrupted flow – A category of traffic facilities having traffic signals, STOP signs, or other fixed causes of periodic delay or interruption to the traffic stream; examples include intersections and arterials.

Interval – A period of time in a signal cycle during which all signal indications remain constant.

Jam density – The density at which congestion becomes so severe that all movement of persons or vehicles stops, usually expressed as vehicles per kilometer (per lane) or pedestrians per square meters.

Lane group – A set of lanes on an intersection approach that has been established for separate capacity and level-of-service analysis.

Level of service – A qualitative measure describing operational conditions within a traffic stream, generally described in terms of such factors as speed and travel time, freedom to maneuver, traffic interruptions, comfort and convenience, and safety.

Measures of effectiveness – Parameters describing the quality of service provided by a traffic facility to drivers, passengers, or pedestrians; examples include speed, density, delay, and similar measures.

Platoon – A group of vehicles or pedestrians traveling together as a group, either voluntarily or involuntarily because of signal control, geometrics, or other factors.

Platoon flow rate – The rate of flow of vehicles or pedestrians within a platoon.

Queue – A line of vehicles or persons waiting to be served by the system in which the rate of flow from the front of the queue determines the average speed within the queue. Slowly moving vehicles or people joining the rear of the queue are usually considered a part of the queue. The internal queue dynamics may involve a series of starts and stops. A faster-moving line of vehicles is often referred to as a *moving queue* or a *platoon*.

Rate of flow – The equivalent hourly rate at which vehicles or persons pass a point on a lane, roadway, or other trafficway for a period of time less than 1 hr; computed as the number of persons or vehicles passing the point divided by the time interval in which they pass (in hours); expressed as vehicles or persons per hour.

Saturation flow rate – The equivalent hourly rate at which vehicles can traverse an intersection approach under prevailing conditions, assuming that the green signal is available at all times

and no lost times are experienced, in vehicles per hour of green or vehicles per hour of green per lane.

Space mean speed – The average speed of the traffic stream computed as the length of the highway segment divided by the average travel time of vehicles to traverse the segment; average travel speed; in kilometers per hour.

Spacing – The distance between two successive vehicles in a traffic lane measured from front bumper to front bumper, in meters.

Speed – A rate of motion expressed as distance per unit time.

Time mean speed – The arithmetic average of individual vehicle speeds passing a point on a roadway or lane, in kilometers per hour.

Uninterrupted flow – A category of facilities having no fixed causes of delay or interruption external to the traffic stream; examples of such facilities include freeways and unsignalized sections of multilane and two-lane rural highways.

v/c ratio – The ratio of demand flow rate to capacity for a traffic facility.

Volume – The number of persons or vehicles passing a point on a lane, roadway, or other traffic way during some time interval, often taken to be 1 hr, expressed in vehicles.