# CHAPTER 1. Introduction

### Models

The models that are used to study the operation of an intersection must account for this driver behavior and judgement, and in the case of signalized intersections, the interaction of the user and the technology of the traffic control system.

Before we discuss the specific elements of the HCM methods, let’s provide a framework for classifying traffic models. Six categories are often used (cite Courage and Wallace):

* Scope: point, linear, network.
* Computational or simulation.
* Empirical or analytical.
* Deterministic or stochastic.
* Microscopic or macroscopic (or mesoscopic).
* Evaluation or optimization.

The HCM intersection models typically fit into the following categories:

* They focus on a single point, or possibly two. So they are either point, or linear.
* They are computational.
* The can be either empirical or analytical.
* They are deterministic.
* They are macroscopic.
* They are evaluation.

The HCM intersection models also fit into a category known as queuing models. Queuing models consider lines of users waiting to pass through a point with limited capacity. Queuing theory is often called the science of waiting lines, since users are waiting to be served.

A queuing system has three primary components as shown in Figure 1, the nature of the input process, the manner of service, and the nature of the output process.

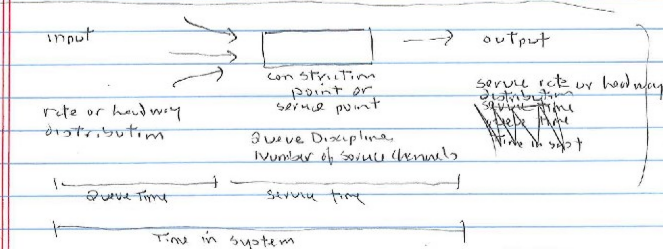


Figure 1. Queuing system

* The input process is defined by the arrival rate of users into the queuing system, as well as the distribution that represents how users arrive. Common arrival distributions are random and deterministic.
* The manner of service is based on how the queue is served, or what is often called queue discipline. For an intersection, the queue discipline is first-in, first-out.
* The output process is defined by the service rate of users leaving the system as well as the distribution that represents how users are service. Common distributions are random and deterministic.

Figure 1 also shows three performance measures produced by a queuing analysis. The queue time is the time spent in the queue, waiting for service. The service time at an intersection is the time spent waiting at the stop bar to enter the intersection. The time in the system is the sum of the queue time and the service time. The time in the system is essentially the average delay, a parameter that will be discussed later in this book for each intersection type.

Table 1 shows more detail on the type of queuing model appropriate for each intersection type. A signalized intersection, for example, is represented by a deterministic model, as both the arrival and service patterns are deterministic. For stop-controlled intersections or roundabouts, the arrival and service process are random, usually represented by a negative exponential distribution.

Table 1

|  |  |  |  |
| --- | --- | --- | --- |
|  | **AWSC Intersections** | **TWSC Intersections/Roundabouts** | **Signalized Intersections** |
| Arrival distribution | Random/Negative exponential | Random/Negative exponential | Deterministic |
| Service distribution | Random/General | Random/Negative exponential | Deterministic |
| Number of service channels | n | n | n |
| Notation | M/G/n | M/M/1 | D/D/1 |

**Other text to be added in the preface:**

Common traffic analysis problems:

* Analyze existing systems – how well is it doing?
* Analyze and compare design options
* Compare control types at intersections…change control?
* Systems of intersections
* Congested conditions-one intersection affects another

### The HCM Methods

The first edition of the HCM was published in 1950 and included a total of xx pages devoted to xx. The sixth edition, published in 2016, includes xx pages in three hard copy volumes as well as significant online supplementary material. The methods addressing both interrupted and uninterrupted flow facilities have grown more complex as traffic science has grown more capable, the data describing traffic systems has become more detailed and ubiquitous, and the nature of transportation problems has become more challenging.

The 1950 HCM covered only signalized intersections, and not other types of intersections. The 1965 HCM included xx. The 1985 HCM included a method for TWSC intersections adapting methods developed in Germany and Australia. The 1997 HCM included new methods for AWSC and TWSC intersections based on the first comprehensive study of U.S. conditions. The HCM 2000 first included a method to analyze roundabouts.

The signalized intersection method is the most widely used of the various analysis methods of the Highway Capacity Manual (HCM). The signalized intersection method has evolved significantly since the publication of the first HCM sixty years ago with the number of pages devoted to the method growing from 39 in 1950 to 206 in 2010.

* The 1950 HCM method (*1*) was based on a capacity model that has persisted through four subsequent editions of the HCM: capacity is the product of the maximum flow rate (as it was called then) and the green ratio. The saturation flow rate (as it is called now) was calculated as a function of the approach width and other adjustment factors.
* The 1965 HCM method (*2*) added the concept of level of service, based on load factor: the ratio of the number of loaded phases to the total number of phases during the hour. The 1950 capacity model was modified to include additional adjustments to the saturation flow rate based on conditions found in the field.
* The 1985 HCM method (*3*) included a new performance measure from which to determine level of service: delay. Consideration was also given to the pattern in which vehicles arrive at the intersection and additional adjustments were made to the saturation flow rate. The capacity model remained unchanged, and signal control was still assumed to be pretimed. The concept of effective green time was introduced to clarify how much of the yellow time could be used by vehicles entering the intersection and the amount of the green interval that was lost due to vehicles starting up at the beginning of green. The lane group, rather than the intersection approach, became the basic unit of analysis.
* The 2000 HCM method (*4*) introduced a model to calculate green time based on actuated control, though pretimed control remained the default condition. Multiple analysis periods were introduced to accommodate oversaturated conditions.
* The 2010 HCM method (*5*) is based on actuated signal control as the default condition, with a complex method to estimate green time. The arrival flow rate is predicted based on conditions at an upstream signalized intersection, allowing for a more precise estimate of the proportion of vehicles arriving during green. The queue accumulation polygon is now directly used to estimate delay for all situations including complex arrival and signal phasing patterns. Level of service measures were added for two new modes (pedestrians and bicyclists) allowing for a multimodal level of service analysis.

The method has evolved into a rich representation or model of a very complex system. Both the complexity and the richness provide challenges for instructors who teach the method and students who try to master it. The system includes:

* A variety of users arriving at the intersection in different and sometimes changing patterns,
* Detectors sensing when these users arrive,
* Complex intersection geometries accommodating various user movements, and
* A traffic controller determining both the sequence and the duration of the various signal indications to serve the users.

#### HCM Signalized intersection models: persistent Principles from 1950 to 2010

What are the traffic flow and control principles that are important for a student to understand as he or she learns the signalized intersection method of the HCM? To help answer this question, the methods from the five editions of the HCM were reviewed, and the results are summarized here. The methods have become increasingly complex during this sixty year period as traffic control systems have improved, understanding of traffic flow principles has deepened, and computing capabilities have expanded. Seven principles relating to the analysis of signalized intersections have persisted through the five editions of the HCM:

* Capacity: how is capacity modeled?
* Saturation flow rate: what factors affect the saturation flow rate?
* Signal control system: how is the signal control system, including the duration of green, modeled?
* Left turns: how are left turns modeled?
* Arrival flow: How is the flow modeled as it arrives during each cycle and how does it vary during the hour?
* Analysis unit: What is the unit of analysis by which the intersection is modeled?
* Performance: how is the performance of the intersection perceived by the user and how is it modeled?

#### Capacity

The basic capacity model has remained unchanged since the 1950 HCM. The model recognizes that there is a maximum flow rate (now called the saturation flow rate) that exists for the proportion of the hour that is green for the approach under study. This proportion is represented by the green ratio, the ratio of the green time to the cycle length. The manner in which the green time is determined has changed from the actual duration of the green display (as seen by motorists) to the effective green time, which accounts for the time lost at the beginning of the green interval when the queue begins to move and the time gained during a portion of the yellow interval when vehicles still enter the intersection. The model assumes that conditions found during an average cycle are representative of conditions found during an entire hour.

#### Saturation Flow Rate

While it didn’t use the term saturation flow rate, the 1950 HCM did propose a maximum flow rate during the green period that varied with the width of the intersection approach. Factors lowering the ideal or base saturation flow rate have been added in subsequent editions of the HCM to account for the number of lanes (not width of the approach), driver characteristics (size of the urban area, location of the intersection within the urban area), and traffic stream turbulence (due to parking maneuvers, turning movements, pedestrians, heavy vehicles, and bicycles).

#### Signal Control

The model of signal control has evolved considerably over the past sixty years, recognizing the evolution from pretimed operation at an isolated intersection to actuated control in which the signal timing is coordinated between intersections. Regardless of the kind of signal control, the model is based on the green duration. For pretimed control, the green duration is either measured in the field or estimated by a model. For actuated control, the green time estimation model includes components for the time for the initial standing queue to clear and for the additional time that green is extended based on the arrival flow rate on the approach and the signal timing settings.

#### Left Turns

The operation of left turn movements is a special consideration in the model of signal control. The 1950 HCM included different maximum flow rates (what we now call saturation flow rate) for exclusive left turn lanes and lanes shared by both left turns and through vehicles, and for permitted and protected left turn phasing. The modeling of left turn operation has evolved considerably with more complex representations of left turn operation in the 1985, 2000, and 2010 HCMs. The queue accumulation polygons presented in the 2010 HCM allow representations of the evolution of the queue even when signal phasing and lane configurations are complex.

#### Arrival Flow Pattern and Variation

The pattern of arrivals at the intersection was originally assumed to be at a uniform rate, with all vehicles arriving continuously throughout the cycle. An adjustment factor (called the progression factor) was applied based on the proportion of vehicles that arrive during green. In the 2010 HCM, arrival flow rates are specified by time interval and/or by a flow profile forecasted by a platoon dispersion model based on the flow profile of vehicles leaving an upstream signalized intersection.

The arrival pattern is also adjusted for the variation of flow during the hour (using the peak hour factor) and the flow rates over several time periods, particularly if the arrival flow during one of these time periods exceeds the capacity of the lane group or approach. Consideration of oversaturation results in a more complex queue accumulation polygon but a more realistic assessment of the delay that results from the presence of a queue at the initial part of the analysis period.

#### Unit of Analysis

In the 1950 HCM, each approach of the intersection was analyzed separately, based on the width of the approach. The concept of the lane group, a group of lanes with common demand and geometric characteristics, was first introduced as the unit of analysis in 1985. Performance data for lane groups can be aggregated by intersection approach, and then for the entire intersection.

#### Performance

Performance was not specifically included in the 1950 HCM. But since 1965, the objective of the signalized intersection method has remained unchanged: to determine the performance of the intersection from the perspective of the user based on the concept of level of service. The 1965 HCM used load factor to determine level of service, where load factor is the ratio of the number of loaded phases to the total number of phases in an hour for an intersection approach. In the 1985 HCM, delay replaced load factor as the primary measure of intersection performance. Delay is calculated based on up to three terms: uniform delay, incremental delay, and overflow delay. A factor representing the quality of progression is applied to recognize the pattern of arrivals in relation to green and its effect on delay. In the 2010 HCM, delay is computed directly from the queue accumulation polygon, a graphical representation of the evolution of the queue length over the cycle.