CHAPTER 3. ALL-WAY STOP-CONTROLLED INTERSECTIONS

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1. Introduction/Overview

An all-way stop-controlled (AWSC) intersection requires that all vehicles stop before proceeding into and clearing the intersection. In this chapter we will explore the models on which the HCM operational analysis method for AWSC intersections is based. The chapter begins with a discussion of two simplified scenarios of an AWSC intersection so that you can more clearly see that theory on which the HCM operational analysis method is based. The first scenario is the intersection of two one-way streets, with one lane on each approach. The second scenario is based on a four-leg intersection, again with one lane on each approach. In both of these scenarios, the concept of the degree of conflict faced by vehicles on each approach is described. To understand the workings of the HCM method under these scenarios, you will build and validate a computational engine, a spreadsheet tool that will allow you to quickly see the results of various traffic flow conditions on intersection operation. This will allow you to see how an AWSC intersection is predicted to perform and under what conditions it will reach capacity. [Delay?] Finally, we will introduce the components of the full HCM method to account for turning movements and multilane approaches.

2. Simplified Scenario #1: Intersection of Two One-Way Streets

Let's consider an intersection of two one-way streets, with through movements only, which we'll call simplified scenario #1. We will study the conditions on one of the two approaches to this intersection, which we'll call the subject approach. Drivers on this approach face two different cases, one in which there are vehicles on the other (conflicting) approach and the other in which there are no vehicles on the conflicting approach.

[Figure showing this scenario]

There are six concepts to be considered in the development of the model that represents this scenario:

- The analysis is based on analyzing one approach at a time. The approach being analyzed is called the subject approach. The other approach is called the conflicting approach.
- The headway between consecutive departures on the subject approach depends on the "degree of conflict" experienced by vehicles on this approach.
- There are two degree of conflict cases. In the first case, each vehicle arrives at the stop line, stops, judges that there are no vehicles on the conflicting approach, and enters the intersection. In the other case, the subject vehicle waits for the vehicle on the conflicting approach to enter and clear the intersection before it can proceed. There is some degree of conflict in the latter case, but no conflict in the first case.
- Research has shown that the headway between vehicles under these two cases is different and is a function of this degree of conflict experienced by vehicles on the subject approach. The saturation headway (the headway between successive vehicles departing from one approach under conditions of a continuous queue on that approach) between vehicles departing on the subject approach for the first case is 3.9 sec. However, if there are vehicles on the conflicting approach, the degree of conflict is higher for subject approach vehicles. The saturation headway for subject approach

vehicles is also higher: 5.8 sec. For reasons that we will discuss shortly, we call this case 3.

- Terms:
    - Departure headway: the time between consecutive departures of two vehicles.
    - Service time: the time that a vehicle spends in the first position (server) at the stop line.
    - Move up time: the time for a second vehicle to move from the second position to the server after the first vehicle leaves the server and enters the intersection. [hd = ST +MT]
- The degree of utilization, traffic intensity, or likelihood of observing a vehicle in the server on either approach is the ratio of the volume to the capacity.

[Figure x shows cases 1 and 3]. For case 1, the pattern of service is simple: vehicles on the subject approach depart one after the other. For case 3, vehicles on the two approaches enter the intersection in turns, one approach followed by the other approach.

Figure x illustrates the definition of three important terms using a time space diagram. The departure headway is defined as the time between the departures of two consecutive vehicles on one approach. The service time is the duration of time that a vehicle spends at the stop bar (in the server position). The move-up time is the time that it takes a vehicle in the second position to "move up" to the server or first in line position after the preceding vehicle enters the intersection. The sum of the service time and move up time is equal to the departure headway.

[TSD illustrating above]

The mean departure headway for vehicles on the subject approach is a function of the traffic flow rate on the conflicting approach. Specifically the departure headway is the expected value of a bimodal distribution, with h_{s1} and h_{s3} as the two modes.

Equation 1

$$h_{ds} = h_{s1}(1 - X_c) + h_{s3}(X_c)$$

X_c is the degree of saturation on the conflicting approach, the ratio of the volume on that approach to its capacity. We can also think of the degree of saturation as the probability that a vehicle is present on that approach at any given time.

Let's now consider our simplified scenario. For two intersection one-way streets (with NB and WB traffic), the mean departure headway for each approach can be written as follows:

Equation 2

$$h_{d,NB} = h_{s1}(1 - X_{WB}) + h_{s3}(X_{WB})$$

Equation 3

$$h_{d,WB} = h_{s1}(1 - X_{NB}) + h_{s3}(X_{NB})$$

There is clearly an interaction between the flows on the two approaches. The higher the flow rate on the NB approach, and thus the more likely that a vehicle will be present on that approach, the higher the departure headway on the WB approach.

We can write equations x and x in a form in which we can more directly calculate the departure headways on each approach. Since X can also be written as the product of the arrival rate λ and the departure headway h_d. Another way of thinking about this relationship is as the product of the number of vehicles that arrive and the time between departing vehicles. [Or, the proportion of time that the stop line is occupied.[]

[add some of the algebra]

Equation 4

$$h_{d,NB} = \frac{h_{s1}[1 + \lambda_{WB}(h_{s3} - h_{s1})]}{1 - \lambda_{NB}\lambda_{WB}(h_{s3} - h_{s1})^2}$$

Equation 5

$$h_{d,WB} = \frac{h_{s1}[1 + \lambda_{NB}(h_{s3} - h_{s1})]}{1 - \lambda_{NB}\lambda_{WB}(h_{s3} - h_{s1})^2}$$

Since h_{s1} = 3.9 sec and h_{s3} = 5.8 sec, these equations can be simplified to:
[Simplification of model that could be used in above and subsequent calculations:]

$$h_d = \frac{h_{s1}[1 + \lambda_{CON}(h_{s3} - h_{s1})]}{1 - \lambda_{SUB}\lambda_{CON}(h_{s3} - h_{s1})^2}$$

$$h_d = \frac{(3.9)[1 + \lambda_{CON}(5.8 - 3.9)]}{1 - \lambda_{SUB}\lambda_{CON}(5.8 - 3.9)^2}$$

$$h_d = \frac{(3.9)[1 + \lambda_{CON}(1.9)]}{1 - \lambda_{SUB}\lambda_{CON}(1.9)^2}$$

$$h_d = \frac{3.9 + 7.41\lambda_{CON}]}{1 - 3.61\lambda_{SUB}\lambda_{CON}}$$

Equation 6

$$h_{d,NB} = \frac{3.9 + 7.41\lambda_{WB}]}{1 - 3.61\lambda_{NB}\lambda_{WB}}$$

Equation 7

$$h_{d,WB} = \frac{3.9 + 7.41\lambda_{NB}]}{1 - 3.61\lambda_{NB}\lambda_{WB}}$$

Example Calculation #1

Let's consider an example in which the volumes are 300 veh/hr on the NB approach and 200 veh/hr on the WB approach. What are the mean departure headways for vehicles on each approach and what is the degree of saturation X for each approach?

Solution steps:

1. Calculate λ
2. Calculate h_d
3. Calculate X
4. Check that X < 1.0

Step 1. Calculate λ.

$$\lambda_{NB} = \frac{300}{3600} = .083\ veh/sec$$

$$\lambda_{WB} = \frac{200}{3600} = .056\ veh/sec$$

Step 2. Calculate h_d.

For the NB approach:

$$h_{d,NB} = \frac{h_{s1}[1 + \lambda_{WB}(h_{s3} - h_{s1})]}{1 - \lambda_{NB}\lambda_{WB}(h_{s3} - h_{s1})^2}$$

$$h_{d,NB} = \frac{(3.9)[1 + .056(5.8 - 3.9)]}{1 - (.083)(.056)(5.8 - 3.9)^2}$$

$$h_{d,NB} = 4.4\ sec$$

For the WB approach:

$$h_{d,WB} = \frac{h_{s1}[1 + \lambda_{NB}(h_{s3} - h_{s1})]}{1 - \lambda_{NB}\lambda_{WB}(h_{s3} - h_{s1})^2}$$

$$h_{d,WB} = \frac{(3.9)[1 + .083(5.8 - 3.9)]}{1 - (.083)(.056)(5.8 - 3.9)^2}$$

$$h_{d,WB} = 4.6\ sec$$

Step 3. Calculate X.

$$X = \lambda h_d$$

For the NB approach:

$$X_{NB} = \lambda_{NB} h_{d,NB}$$

$$X_{NB} = (.083)(4.4) = .365$$

For the WB approach:

$$X_{WB} = \lambda_{WB} h_{d,WB}$$

$$X_{WB} = (.056)(4.6) = .255$$

[Note: other interpretation of X: likelihood of vehicle presence.]
[Show v/c = X using these same data…]

Step 4. Check that X < 1.0.
Yes; undersaturated, so model assumptions hold. [Discuss results from steps 3 and 4 in more detail here, as well as a final conclusion on what was learned in the example calculation.]