# Definitions and governing equations

The parameters that were used throughout our lab are defined in the below section, for they will be later used in our calculations and analysis.

## Headway and saturation flow rate

The time elapsed between successive vehicles as front bumper pass a designated point is the **headway**. The headway measured when the saturation flow rate is reached is called the **saturation headway** and is noted by hs.

In fact, the **saturation flow rate** is the maximum flow that could pass through an intersection if 100% effective green time was allocated to that movement for a whole hour. Typical saturation flows have a maximum value of 1900 pc/h/lane. It is given by the below Eq. 3.1:

|  |  |  |
| --- | --- | --- |
|  |  | (3.1) |

Where is the saturation flow rate and is the mean saturation headway expressed in .

## Lost time

Stopping and starting means a portion of the cycle length is not being completely utilized/ This time not effectively serving any movement is the lost time. The total lost time is the sum of the **start-up lost time** and the **clearance lost time**.

The start up lost time is the time lost when the signal changes from red to green: the drivers do not instantly start moving at saturation flow rate. It is the time used by the first vehicles in the queue while reacting to the initiation of green phase and accelerating. For this lab experiment, we assumed that the start-up period ends when the 3rd car clears the intersection. Hence, it can be expressed in Eq. 3.2:

|  |  |  |
| --- | --- | --- |
|  |  | (3.2) |

Where is the time at which the rear bumper of the 3rd vehicle passes the reference point and is the mean saturation headway. As for the average start-up lost time, it will be calculated ignoring the negative lost times in Eq. 3.3:

|  |  |  |
| --- | --- | --- |
|  |  | (3.3) |

Where is as defined in Eq. 3.2

## Effective green

The **effective green time** is the time during the cycle that is effectively utilized by traffic movement. The effective green g is the summation of the displayed green time G (sec), the displayed yellow Y, and the all red time AR minus the total lost time tl (sec). It is given by the following Eq. 3.4;

|  |  |  |
| --- | --- | --- |
|  |  | (3.4) |

The time not effectively serving any movement is the **lost time**. The total lost time is the sum of the start-up lost time and the clearance lost time.

For this experiment, we will consider that the clearance lost time is equal to the sum of the last second of yellow time and the all-red time as shown below:

|  |  |  |
| --- | --- | --- |
|  |  | (3.5) |

## Control delay

**Control delay** is an average delay per lane group due to the signal. The total delay is usually experienced by drivers due to deceleration and acceleration time, stop time, and queue move up time. It is calculated using Eq. 3.6 below:

|  |  |  |
| --- | --- | --- |
|  |  | (3.6) |

is the delay calculated assuming uniform arrivals. Uniform delay is most affected by progression quality. It is therefore adjusted for signal progression: level of coordination of 2 signals depends on travel speed, cycle length and distance between intersections. The adjustment progression PF factor will be taken as 1. And d1 is given by Eq. 3.7:

|  |  |  |
| --- | --- | --- |
|  |  | (3.7) |

Where:

* is the cycle length (sec)
* is the effective green time for the lane group studied (sec)
* is the volume-to-capacity ratio v/c for the lane group studied. It can be calculated using Eq. 3.8

|  |  |  |
| --- | --- | --- |
|  |  | (3.8) |

( being the hourly volume, and being the saturation flow rate.

As traffic nears its capacity, the probabillty of signal failures increases. is given by Eq. 3.9:

|  |  |  |
| --- | --- | --- |
|  |  | (3.9) |

Where:

* is the duration of the analysis period (hr). Hence, in our case,
* is a delay adjustment factor that depends on the signal controller mode. In this experiment, we will be dealing with a pre-timed intersection and hence
* is an upstream filtering/metering adjustment factor. Taken as
* is the capacity of the lane group studied (veh/hr). It can be calculated using the following expression:

|  |  |  |
| --- | --- | --- |
|  |  | (3.10) |

where and are as defined previously, and is the saturation flow rate at the lane group studied (veh/hr).

# Data and Calculations

There are two parts for this experiment each tackling a different direction bound: both data collected and calculations for each part will be presented in this section. The saturation flow rate, start-up lost time, effective green time, and control delay of two chosen lanes are calculated for both the NBT and SBT movements.

## Calculations for NBT lane

### Saturation flow rate

The **saturation headway** is calculated in order to determine the saturation flow rate.

In our 1st observation: times of both the 3rd and the 7th car passing a reference line were obtained: and . Hence,

Based on the results found for the other observations represented in Table 1, we can calculate the mean saturation headway as follows:

Therefore, based on Eq. 3.1, we get the mean saturation flow rate to be:

Table 1 - Data obtained for the WBT lane, saturation headway, and start-up lost time

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **WBT** | Time (s) from start of green till… | | | | | (s/veh) | Start – Up Lost Time  (s) |
| Observation Number | 3rd veh  (T3) | 7th veh  (T7-T3) | 8th veh  (T8-T3) | 9th veh  (T9-T3) | 10th veh  (T10-T3) |
| 1 | 3.23 | 6.3 |  |  |  | 1.575 | -1.21 |
| 2 | 3.16 |  |  |  | 9.45 | 1.35 | -1.28 |
| 3 | 4.22 |  | 5.98 |  |  | 1.196 | -0.22 |
| 4 | 3.68 |  | 7.7 |  |  | 1.54 | -0.76 |
| 5 | 2.74 | 4.98 |  |  |  | 1.245 | -1.7 |
| 6 | 3.61 |  |  | 8.08 |  | 1.347 | -0.83 |
| 7 | 4.71 |  | 10.1 |  |  | 2.02 | 0.27 |
| 8 | 2.88 |  | 6.47 |  |  | 1.294 | -1.56 |
| 9 | 3.35 | 6.73 |  |  |  | 1.6825 | -1.09 |
| 10 | 3.89 |  |  | 8.4 |  | 1.4 | -0.55 |
| 11 | 3.02 | 4.65 |  |  |  | 1.1625 | -1.42 |
| 12 | 3.44 | 5.18 |  |  |  | 1.295 | -1 |
| 13 | 4.61 |  | 8.26 |  |  | 1.652 | 0.17 |
| 14 | 3.17 |  |  |  | 8.28 | 1.183 | -1.27 |
| 15 | 2.91 | 5.45 |  |  |  | 1.3625 | -1.53 |
| 16 | 3.49 | 6.53 |  |  |  | 1.6325 | -0.95 |
| 17 | 4.12 |  |  | 8.24 |  | 1.373 | -0.32 |
| 18 | 3.05 |  | 7.88 |  |  | 1.576 | -1.39 |
| 19 | 3.66 | 5.93 |  |  |  | 1.4825 | -0.78 |
| 20 | 4.44 |  | 9.17 |  |  | 1.834 | 0 |
| 21 | 2.98 |  |  | 9.38 |  | 1.563 | -1.46 |
| 22 | 3.12 | 6.23 |  |  |  | 1.5575 | -1.32 |
| 23 | 2.78 |  | 9.28 |  |  | 1.856 | -1.66 |
| 24 | 3.35 | 6.35 |  |  |  | 1.5875 | -1.09 |
| 25 | 2.67 |  |  | 7.82 |  | 1.3033 | -1.77 |

### Start-up lost time

Based on Eq. 3.2 and on the calculated value of the average saturation headway, the start-up lost time can now be found. For example, for the 1st observation where , we get:

The results obtained for the other observations are represented in Table 1. Therefore, ignoring the negative lost times obtained, and based on Eq. 3.3, the average start-up lost time is calculated to be:

### Effective green

As mentioned in the experimental procedure, one part of the experiment consisted of measuring the displayed green, yellow, and red times. The data recorded in the field is represented in Table 2.

Table 2 - Recorded and average measurements of displayed red, green, and yellow times

|  |  |  |  |
| --- | --- | --- | --- |
| **Reading** | **R** | **G** | **Y** |
| **1** | 42 | 30 | 3 |

As for the all-red time, it was measured to be:

Hence, based on Eq. 3.5 and on the average start-up lost time calculated in the previous section, the total lost time is calculated below:

Therefore, based on Eq. 3.4, the effective green time for this lane group is obtained as follows:

### Delay at the intersection

To be able to determine the delay at the intersection using Eq. 3.6, we first need to determine several parameters. First of all, based on the average values of and represented in Table 2, the cycle length is obtained as follows:

Moreover, the 15-minute volume was found to be 150 vehicles; hence, extrapolating to an hour, we get:

Therefore, replacing the obtained values into Eq. 3.8, we get the volume-to-capacity ratio to be:

All the parameters needed to evaluate have been found. Hence, using Eq. 3.7, we obtain

On the other hand, to determine , we will first have to find the capacity of the lane studied using Eq. 3.10. For this case,

Therefore, replacing the obtained value of into Eq. 3.9 and based on the assumptions listed in part 3.4, we get:

As a result, according to Eq. 3.6, the total delay per vehicle for the WBT lane is:

Which corresponds to LOS **B** based Table A1 in Appendix A.

## Calculations for NBT lane

### Saturation flow rate

To find the saturation flow rate, we first need to calculate the saturation headway for each observation. For example, for the 1st observation, we recorded the times at which the 3rd and the 7th car passed the reference line and obtained: and . Hence,

Table 3 - Data obtained for the WBT lane (1st trials), saturation headway, and start-up lost time

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **WBT** | Time (s) from start of green till… | | | | | (s/veh) | Start – Up Lost Time  (s) |
| Observation Number | 3rd veh  (T3) | 7th veh  (T7-T3) | 8th veh  (T8-T3) | 9th veh  (T9-T3) | 10th veh  (T10-T3) |
| 1 | 4.62 |  | 10.72 |  |  | 2.144 | -2.410 |
| 2 | 5.05 | 10 |  |  |  | 2.5 | -1.980 |
| 3 | 6.51 |  | 10.53 |  |  | 2.106 | -0.520 |
| 4 | 7 |  |  |  | 13.72 | 1.96 | -0.0305 |
| 5 | 5.08 |  |  | 11.83 |  | 1.972 | -1.950 |
| 6 | 5.56 | 9.7 |  |  |  | 2.425 | -1.470 |
| 7 | 5.83 |  | 11.57 |  |  | 2.314 | -1.200 |
| 8 | 5.12 |  |  | 12.13 |  | 2.022 | -1.910 |
| 9 | 5.63 | 8.77 |  |  |  | 2.1925 | -1.400 |
| 10 | 8.23 |  | 10.88 |  |  | 2.176 | 1.199 |
| 11 | 6.45 | 8.05 |  |  |  | 2.0125 | -0.580 |
| 12 | 5.15 | 10.22 |  |  |  | 2.555 | -1.880 |
| 13 | 5.42 |  |  |  | 14.72 | 2.103 | -1.610 |
| 14 | 5.31 |  |  | 12.95 |  | 2.158 | -1.720 |
| 15 | 4.82 | 9.91 |  |  |  | 2.4775 | -2.210 |
| 16 | 5.18 |  |  | 13.05 |  | 2.175 | -1.850 |
| 17 | 6.02 |  |  |  | 13.42 | 1.917 | -1.010 |
| 18 | 6.88 |  | 11.97 |  |  | 2.394 | -0.150 |
| 19 | 6.12 |  | 13.17 |  |  | 2.634 | -0.910 |
| 20 | 6.63 | 12.82 |  |  |  | 3.205 | -0.400 |
| 21 | 5.61 | 9.81 |  |  |  | 2.4525 | -1.420 |
| 22 | 6.45 | 11.93 |  |  |  | 2.9825 | -0.580 |
| 23 | 5.21 | 11.81 |  |  |  | 2.9525 | -1.820 |
| 24 | 5.32 |  | 12.84 |  |  | 2.568 | -1.710 |
| 25 | 4.63 |  | 10.95 |  |  | 2.19 | -2.400 |

Based on the results found for the other observations represented in Table 3, we can calculate the mean saturation headway as follows:

Therefore, based on Eq. 3.1, we get the mean saturation flow rate to be:

### Start-up lost time

Based on the calculated value of the average saturation headway, and on Eq. 3.2, the start-up lost time can now be found. For example, for the 1st observation where, we get:

The results obtained for the other observations are represented in Table 3. Ignoring the negative lost times obtained, and based on Eq. 3.3, the average start-up lost time is then calculated to be:

### Effective green

As mentioned in the experimental procedure, one part of the experiment consisted of measuring the displayed green, yellow, and red times. The data recorded in the field is represented in Table 4.

Table 4 - Recorded and average measurements of displayed red, green, and yellow times for WBT

|  |  |  |  |
| --- | --- | --- | --- |
| **Reading** | **R** | **G** | **Y** |
| **1** | 52 | 20 | 3 |

As for the all-red time, it was measured to be:

Hence, based on Eq. 3.5 and on the average start-up lost time calculated in the previous section, the total lost time is found to be:

Therefore, based on Eq. 3.4, the effective green time for this lane group is obtained as follows:

### Delay at the intersection

To be able to determine the delay at the intersection using Eq. 3.6, we first need to determine several parameters. First of all, based on the average values of and represented in Table 4, the cycle length is obtained as follows:

Moreover, the 15-minute volume was found to be 80 vehicles; hence, extrapolating to an hour, we get:

Therefore, replacing the obtained values into Eq. 3.8, we get the volume-to-capacity ratio to be:

All the parameters needed to evaluate have been found. Hence, using Eq. 3.7, we obtain

On the other hand, to determine, we will first have to find the capacity of the lane studied using Eq. 3.10. Hence,

Therefore, replacing the obtained value of into Eq. 3.9 and based on the assumptions listed in part 3.4, we get:

As a result, according to Eq. 3.6, the total delay per vehicle for the WBT lane is:

Hence, based on Table A1 in the Appendix A, this value of stopped delay per vehicle corresponds to LOS **D.**

# Appendix

Table A1 - Stopped delay per vehicle and corresponding LOS

|  |  |
| --- | --- |
| **Level of Service** | **Stopped delay per vehicle (s/veh)** |
| **A** |  |
| **B** |  |
| **C** |  |
| **D** |  |
| **E** |  |
| **F** |  |