TRAFFIC FLOW FUNDAMENTALS

Time-Space Diagram

The time-space diagram is a graph that describes the relationship between the location of vehicles in a traffic stream and the time as the vehicles progress along the highway.

1. **Flow and Volume:**

Volume and rate of flow are two different measures. Volume is the actual number of vehicles observed or predicted to be passing a point during a given time interval. The rate of flow \( q \) represents the number of vehicles passing a point during a time interval less than 1 hour, but expressed as an equivalent hourly rate.

\[
q = \frac{n \times 3600}{T} \quad \text{Veh/hr}
\]

- \( n \): the number of vehicles passing a point in the roadway in \( T \) sec
- \( q \): the equivalent hourly flow

Thus, a volume of 200 vehicles observed in a 10-minute period implies a rate of flow of \( (200 \times 60)/10 = 1200 \) veh/hr. Note that 1200 vehicles do not pass the point of observation during the study hour, but they do pass the point at that rate for 10 minutes.
Example:
Calculate the volume and rate of flow of vehicles from the following data:

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Volume (vehicles)</th>
<th>Flow rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>4:00-4:15</td>
<td>700</td>
<td>2800</td>
</tr>
<tr>
<td>4:16-4:30</td>
<td>812</td>
<td>1624</td>
</tr>
<tr>
<td>4:31-5:00</td>
<td>1635</td>
<td>3270</td>
</tr>
</tbody>
</table>

2. Density or concentration:
The number of vehicles occupying a given length of lane or roadway, averaged over time, usually expressed as vehicles per mile (vpm). Direct measurement of density can be obtained through aerial photography, but more commonly it is calculated from Eq. 5 if speed and rate of flow are known.

\[ q = v \times k \text{ (Veh/mi)} \]

where
\( q \) = rate of flow (veh/hr)
\( v \) = average travel speed (mph)
\( k \) = average density (veh/mi)

Example:
Calculate the density of a highway segment with a rate of flow of 1350 veh/hr and an average travel speed of 45 mph. (1350) veh/mi.

3. Speed:
Rate of motion, as distance per unit time. There are two types of mean speeds: time mean speed and space mean speed:

Thus, if travel times \( t_1, t_2, t_3, \ldots, t_n \) are observed for \( n \) vehicles traversing a segment of length \( L \), the average travel speed is:

\[ v_s = \frac{L}{\frac{1}{n} \sum_{i=1}^{n} t_i} = \frac{nL}{\sum_{i=1}^{n} t_i} \]

where
\( v_s \) = average travel speed or space mean speed (mph)
\( L \) = length of the highway segment (miles)
\( t_i \) = travel time of the \( i \)th vehicle to traverse the section (hours)
\( n \) = number of travel times observed
Three vehicles are traversing a 1-mile segment of a highway and the following observation is made:
Vehicle A : 1.2 min
Vehicle B : 1.5 min
Vehicle C : 1.7 min

What is the average travel speed of the three vehicles?

Average travel time = (0.0200 + 0.0250 + 0.0283) / 3 = 0.0244 hr
The average travel speed = 1/0.0244 = 40.91 mph.

**Time mean speed** ($\bar{u}_i$) is the arithmetic mean of the speeds of vehicles passing a point on a highway during an interval of time. The time mean speed is found by:

$$\bar{u}_i = \frac{1}{n} \sum_{i=1}^{n} u_i$$

$n$ -number of vehicles passing a point on the highway
$u_i$ - speed of the $i$th vehicle

**Example 2**
Three vehicles pass a mile post at 50, 40, and 35.3 mph, respectively. What is the time mean speed of the three vehicles? (41.77).

It can be shown that whereas the time mean speed is the arithmetic mean of the spot speeds, the space mean speed is their harmonic mean. Time mean speed is always greater than space mean speed except in the situation where all vehicles travel at the same speed. it can be shown that an approximate relationship between the two mean speeds is:
Example 1: Time-Space diagram:

According to the figure below:

1. Calculate the flow rate (in vehicle/hr) for vehicles that are crossing line A-A' within 25 sec.
2. What are the individual headways and the average headway?
3. Assuming that the distance between AA-BB, find the average speed (in mile/hour) of vehicles 4, 5, 6, 7, 8, and 9. (Time mean speed and space mean speed)
4. At the time of observation, calculate the density (k) (in vehicle/mile).
1. \( q = \frac{n}{T} = \frac{6}{25} = 0.24 \text{ vehicle/sec} = 864 \text{ veh/h} \)

2. 

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Time of passing (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>5.2</td>
</tr>
<tr>
<td>6</td>
<td>8.2</td>
</tr>
<tr>
<td>7</td>
<td>12.1</td>
</tr>
<tr>
<td>8</td>
<td>15.5</td>
</tr>
<tr>
<td>9</td>
<td>18.2</td>
</tr>
</tbody>
</table>

What are the individual headways and the average headway? Because there are six vehicles, only the first five headways can be determined directly.

\[
\begin{align*}
    h_{4,5} &= 2.2 \\
    h_{5,6} &= 3 \\
    h_{6,7} &= 3.9 \\
    h_{7,8} &= 3.4 \\
    h_{8,9} &= 2.7 \\
    h_{9,4} &= 9.8 
\end{align*}
\]
Average headway = 4.17 sec

3.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Time passing AA'</th>
<th>Time passing BB'</th>
<th>Trap time (sec)</th>
<th>Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3.0</td>
<td>11.5</td>
<td>8.5</td>
<td>19.25</td>
</tr>
<tr>
<td>5</td>
<td>5.2</td>
<td>13.1</td>
<td>7.9</td>
<td>20.71</td>
</tr>
<tr>
<td>6</td>
<td>8.2</td>
<td>15.2</td>
<td>7.0</td>
<td>23.38</td>
</tr>
<tr>
<td>7</td>
<td>12.1</td>
<td>18.1</td>
<td>6.0</td>
<td>27.27</td>
</tr>
<tr>
<td>8</td>
<td>15.5</td>
<td>20.7</td>
<td>5.2</td>
<td>31.46</td>
</tr>
<tr>
<td>9</td>
<td>18.2</td>
<td>22.4</td>
<td>4.2</td>
<td>38.96</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>38.8</td>
<td>161.03</td>
</tr>
</tbody>
</table>

Time-mean speed \( ut = \frac{161.3}{6} = 26.84 \text{ mph} \)
Space mean speed = \( \frac{6 \times 240}{38.8} = 25.3 \text{ mph} \)

4. Density = \( \frac{7 \times 5280}{1000} = 36.96 \text{ veh/mile} \)
Ex 2: Greenberg model:

The volume-density relationship of traffic on a section of a heavily used road was estimated to be:

\[ q = 18.2k(\ln 220 - \ln k) \]

where \( q \) is in vehicle/hour and \( k \) is in vehicle/kilometer.

1. Calculate the maximum flow \( (q_{\text{max}}) \), and jam density \( (K_j) \)?

\[ (q/k) = \frac{18.2k(\ln 220 - \ln k)}{k} \]

\[ u = 18.2 \ln \frac{\ln 220}{\ln k} \]  \hspace{1cm} (1)

According to Greenberg

\[ u_s = c \ln \frac{\ln k_j}{\ln k} \]

\( k_j = 220 \) veh/km

at \( q_{\text{max}} \) \hspace{1cm} \frac{dq}{dk} = 0

so \( \frac{dq}{dk} = \frac{18.2 \ln 220}{\ln k} - 18.2 \)

\[ \ln 220/\ln k = 1 \] \hspace{1cm} \ln 220 - \ln k_{\text{opt}} = 5.39 - 1 = \ln k_{\text{opt}} \] \hspace{1cm} k_{\text{opt}} = 80.94 \) veh/km

Substituting 1 for \( (k_j/k_o) \) in equation 1 \hspace{1cm} u_{\text{opt}} = 18.2 \text{ km/hr}

\[ q_{\text{max}} = k_{\text{opt}} \times u_{\text{opt}} = 18.2 \times 80.94 = 1473.1 \text{ veh/hr} \]
**EX3 : Greenshields model:**

According to the collected data from freeway segment (off rush hour) the relationship between speed and density was found to be:

\[ u = 120 - 0.77k \] (km/hr)

Where:   
- \( u \): speed  
- \( k \): density.

According to above equation, compute the followings:

1. **Free speed.**  
   At free speed \( k = 0 \)  
   so \( u = 120 - 0(0) \). \( u_f = 120 \) km/hr.

2. **Optimum speed:**  
   \[ u_{opt} = \frac{u_f}{2} \]  
   \[ = \frac{120}{2} = 60 \] (km/hr)

3. **Jam density.**  
   At jam density speed =0.  
   So \( 0 = 120 - 70(k_j) \). \( k_j = 156 \) (veh/km)  
   \[ k_{opt} = k_j/2 = 156/2 = 78 \] (veh/km)

4. **Maximum flow rate:**  
   \[ q_{max} = \frac{u_f k_j}{4} \]  
   \[ = \frac{(60*78)}{2} = 4680 \] (veh/hr)

5. **\( u = 120 - 0.77k \)**  
   \[ u \cdot k = 120k - 0.77k^2 \]  
   \[ q = 120k - 0.77k^2 \]

For \( k = 30 \), \( q = 120*30 - 0.77(30)^2 = 2907 \) veh/hr
Space mean speed and Time mean speed:

Ex:

Figure 1 shows vehicles traveling at constant speeds on a two-lane highway between sections X and Y with their positions and speeds obtained at an instant of time by photography. An observer located at point X observes the four vehicles passing point X during a period of $T$ sec. The velocities of the vehicles are measured as 45, 45, 40, and 30 mi/h, respectively. Calculate the flow, density, time mean speed, and space mean speed.

Solution:
**INTERSECTIONS**

An intersection: is the area where two or more streets join or cross at-grade. The intersection includes the areas needed for all modes of travel: pedestrian, bicycle, motor vehicle, and transit. Intersections are a key feature of street design in four respects:

1.1. **Focus of activity** - The land near intersections often contains a concentration of travel destinations.

2.1. **Conflicting movements** - Pedestrian crossings and motor vehicle and bicycle turning and crossing movements are typically concentrated at intersections.

3.1. **Traffic control** - At intersections, movement of users is assigned by traffic control devices such as yield signs, stop signs, and traffic signals. Traffic control often results in delay to users traveling along the intersecting roadways, but helps to organize traffic and decrease the potential for conflict.

4.1. **Capacity** - In many cases, traffic control at intersections limits the capacity of the intersecting roadways, defined as the number of users that can be accommodated within a given time period.

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**INTERSECTIONS**

Definitions and key elements

*Gray area = FUNCTION AREA OF INTERSECTION*

Sidewalks, crosswalks and pedestrian curb cut ramps are considered to be within the intersection.

The pavement edge corner is the curve connecting the edges of pavement of the intersecting streets.
INTERSECTIONS

Basic types of maneuvers within intersections
Typical maneuvers are:

- Crossing
- Merging
- Diverging
- Weaving

Basic types of maneuvers within intersections:

Crossings may be direct, if the angle of skew is between 75 and 105 degrees, or oblique if the angle is in the range of below 75 or above 105 degrees. (Oblique skews should be voided if at all possible).

Diverging is a traffic operation when the vehicles moving in one direction is separated into different streams according to their destinations.

Merging is the opposite of diverging. Merging is referred to as the process of joining the traffic coming from different approaches and going to a common destination into a single stream.

Weaving is the combined movement of both merging and diverging movements in the same direction.

All maneuvers within intersection result in conflicts

Basic types of conflict points within intersections
- Crossing conflicts (through traffic, left turns with through traffic)
- Merging conflicts
- Diverging conflicts
CROSS INTERSECTION
- 32 conflict points – 8 merging + 8 diverging + 16 crossing

ROUNDABOUT
- 8 conflict points – 4 diverging + 4 merging

Total = 32 Conflicts
pedestrians not included
Degree of Complexity: \( (P) \)

\[
P = P_1 + 3P_2 + 5P_3
\]

\( P_1 = \) total # of diverging movements
\( P_2 = \) total # of merging movements
\( P_3 = \) total # of crossing movements

\( P < 9 \) » intersection is very simple
\( 10 < P \leq 25 \) » intersection is simple
\( 25 < P \leq 55 \) » intersection is medium complex
\( 55 < P \) » intersection is complex

EX:
Show the total number of conflict points on this intersection by classification. Give your opinion to reduce this number of conflict points.
Total number of conflict points is 18 points