

Moving Observer Method

Lecture Notes in Transportation Systems Engineering

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1 Overview

For a complete description of traffic stream modeling, one would require flow, speed, and density. Obtaining these parameters simultaneously is a difficult task if we use separate techniques. Since we have a fundamental equation of traffic flow, which gives the flow as the product of density and space mean speed, if we knew any two parameters, the third can be computed. Moving car or moving observer method of traffic stream measurement has been developed to provide simultaneous measurement of traffic stream variables. It has the advantage of obtaining the complete state with just three observers, and a vehicle. Determination of any of the two parameters of the traffic flow will provide the third one by the equation $q = u.k$. Thus, moving observer method

is the most commonly used method to get the relationship between the fundamental stream characteristics. In this method, the observer moves in the traffic stream unlike all other previous methods.

2 Theory

Consider a stream of vehicles moving in the north bound direction. Two different cases of motion can be considered. The first case considers the traffic stream to be moving and the observer to be stationary. If n_o is the number of vehicles overtaking the

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Figure 1: Illustration of moving observer method

observer during a period, t , then flow q is $\frac{n_o}{t}$, or

$$n_o = q \times t \tag{1}$$

The second case assumes that the stream is stationary and the observer moves with speed v_o . If n_p is the number of vehicles overtaken by observer over a length l , then by definition, density k is $\frac{n_p}{l}$, or

$$n_p = k \times l \tag{2}$$

or

$$n_p = k.v_o.t \tag{3}$$

where v_o is the speed of the observer and t is the time taken for the observer to cover the road stretch. Now consider the case when the observer is moving within the stream. In that case m_o vehicles will overtake the observer and m_p vehicles will be overtaken by the observer in the test vehicle. Let the difference m is given by $m_o - m_p$, then from equation 1 and equation 3,

$$m = m_o - m_p = q t - k v_o t \tag{4}$$

This equation is the basic equation of moving observer method, which relates q, k to the counts m, t and v_o that can be obtained from the test. However, we have two unknowns,

q and k , but only one equation. For generating another equation, the test vehicle is run twice once with the traffic stream and another one against traffic stream, i.e.

$$\begin{aligned} m_w &= q t_w - k v_w t_w \\ m_a &= q t_a + k v_a t_a \\ &= q t_a + k l \end{aligned}$$

where, a, w denotes against and with traffic flow. Thus:

$$m_w = q t_w - k l \quad (5)$$

$$m_a = q t_a + k l \quad (6)$$

It may be noted that the sign of equation 6 is negative, because test vehicle moving in the opposite direction can be considered as a case when the test vehicle is moving in the stream with negative velocity. Further, in this case, all the vehicles will be overtaking, since it is moving with negative speed. In other words, when the test vehicle moves in the opposite direction, the observer simply counts the number of vehicles in the opposite direction. Adding equation 5 and 6, we will get the first parameter of the stream, namely the flow(q) as:

$$q = \frac{m_w + m_a}{t_w + t_a} \quad (7)$$

Now calculating space mean speed from equation 5,

$$\begin{aligned} \frac{m_w}{t_w} &= q - k v_w \\ &= q - \frac{q}{v} v_w \\ &= q - \frac{q}{v} \left[\frac{l}{t_w} \right] \\ &= q \left(1 - \frac{l}{v} \times \frac{1}{t_w} \right) \\ &= q \left(1 - \frac{t_{avg}}{t_w} \right) \end{aligned}$$

If v_s is the mean stream speed, then average travel time is given by $t_{avg} = \frac{l}{v_s}$. Therefore,

$$\begin{aligned} \frac{m_w}{q} &= t_w \left(1 - \frac{t_{avg}}{t_w} \right) = t_w - t_{avg} \\ t_{avg} &= t_w - \frac{m_w}{q} = \frac{l}{v}, \end{aligned}$$

Rewriting the above equation, we get the second parameter of the traffic flow, namely the mean speed v_s and can be written as,

$$v_s = \frac{l}{t_w - \frac{m_w}{q}} \quad (8)$$

Thus two parameters of the stream can be determined. Knowing the two parameters the third parameter of traffic flow density (k) can be found out as

$$k = \frac{q}{v_s} \quad (9)$$

For increase accuracy and reliability, the test is performed a number of times and the average results are to be taken.

3 Proof

4 Assumptions

4.0.1 Numerical Example 1

The length of a road stretch used for conducting the moving observer test is 0.5 km and the speed with which the test vehicle moved is 20 km/hr. Given that the number of vehicles encountered in the stream while the test vehicle was moving against the traffic stream is 107, number of vehicles that had overtaken the test vehicle is 10, and the number of vehicles overtaken by the test vehicle is 74, find the flow, density and average speed of the stream.

Solution

1. Time taken by the test vehicle to reach the other end of the stream while it is moving along with the traffic is $t_w = \frac{0.5}{20} = 0.025$ hr
2. Time taken by the observer to reach the other end of the stream while it is moving against the traffic is $t_a = t_w = 0.025$ hr
3. Flow is computed from equation 7 as,

$$q = \frac{107 + (10 - 74)}{0.025 + 0.025} = 860 \text{ veh/hr}$$

Table 1: Solution to the numerical example 2

No	m_a	m_o	m_p	$m_w = (m_o - m_p)$	t_a	t_w	$q = \frac{m_a + m_w}{t_a + t_w}$	$u = \frac{l}{t_w - \frac{m_w}{q}}$	k
1	107	10	74	-64	0.025	0.025	860	5.03	
2	113	25	41	-16	0.025	0.025	1940	15.04	
3	30	15	5	10	0.025	0.025	800	40	
4	79	18	9	9	0.025	0.025	1760	25.14	

4. Stream speed v_s is computed from equation 8 as

$$v_s = \frac{0.5}{0.025 - \frac{10.74}{860}} = 5 \text{ km/hr}$$

5. Density can be computed from the fundamental relation as

$$k = \frac{q}{v_s} = \frac{860}{5} = 172 \text{ veh/km}$$

4.0.2 Numerical Example 2

The data from four moving observer test methods are shown in the table. Column 1 gives the sample number, column 2 gives the number of vehicles moving against the stream, column 3 gives the number of vehicles that had overtaken the test vehicle, and last column gives the number of vehicles overtaken by the test vehicle. Find the three fundamental stream parameters for each set of data. Also plot the fundamental diagrams of traffic flow.

No	1	2	3
1	107	10	74
2	113	25	41
3	30	15	5
4	79	18	9

Solution From the calculated values of flow, density and speed, the three fundamental diagrams can be plotted as shown in figure 2.

Figure 2: Fundamental diagrams of traffic flow

5 Summary

Traffic engineering studies differ from other studies in the fact that they require extensive data from the field which cannot be exactly created in any laboratory. Speed data are collected from measurements at a point or over a short section or over an area. Traffic flow data are collected at a point. Moving observer method is one in which both speed and traffic flow data are obtained by a single experiment.

Exercises

1. Derive the expression for flow across a section of road by moving car method. Prove that this formulae actually estimates the stream flow.

Solution:

- (a) Refer notes
- (b) Proof

Assume that the test vehicle begins its run against traffic at time zero. At the same time an independent observer located at point A begins to count the vehicles passing that point and continues to do so until the test vehicle crosses the same point going north. The test vehicle reaches the end of the run against traffic T_a units of time after the start of the test. It then turns around instantaneously and begins the test run with traffic, which takes T_w units of time. The total number of vehicles that would cross line A during the total time $(T_a + T_w)$ is equal to the number of vehicles M_a that the test vehicle encounters during its run against traffic plus the number of vehicles that overtake the test vehicle during its run with traffic - any vehicles that the test vehicle overtakes during its run with traffic. The difference between the latter two counts taken during the run in the direction of the stream is simply equal to N_w , as defined before. The sum of M_a and M_w is exactly the number of vehicles that the independent observer at point A will be able to count during the time $(T_w + T_a)$. Consequently the computation of flow equation $q = \frac{M_w + M_a}{T_w + T_a}$ yields the required stream flow q .

2. In a traffic stream, 30% of the vehicles travel at a constant speed of 60km/h, 30% at a constant speed of 80km/h, and the remaining vehicles at a constant

speed of 100km/h. An observer travelling at a constant speed of 70km/h with the stream over a length of 5km is overtaken by 17 vehicles more than what he has overtaken. The observer met 303 vehicles while traveling against the stream at the same speed and over the same length of highway. What is the mean speed and flow of the traffic stream?

Solution: From the moving observer method, (b) mean speed = $\frac{5}{(5/70) - (17/2240)} = 78.3$ kmph or

(a) $Q = (x + y) / (t_a + t_w) = (303 + 17) / (5/70 + 5/70) = 2240$ veh per hour

(b) mean speed = $\frac{5}{(5/70) - (17/2240)} = 78.3$ kmph or

mean speed = $100 / ((30/60) + (30/80) + (40/100)) = 78.43$ kmph

3. Two friends were traveling from Mumbai to Pune and have decided to count the vehicles on a short stretch of 5 km. The first one sat on the left side and counted vehicles passed by him. The second sat on the right side and counted vehicles overtaken him. They counted 20 and 60 respectively while traveling at 30 kmph. They did the same exercise on the next day about same time and counted 25 and 40 respectively and were traveling at 35 kmph. Assuming same traffic conditions on both days, compute the density, mean speed, and flow on that stretch.

Solution: From the moving observer method,

$$m = m_0 - m_p = qt - kv_o t. \quad (10)$$

$$(11)$$

where m_o is number of vehicles overtaken the test vehicle,
and m_p is number of vehicles passed by the test vehicle.

In the first trial, $m = 60 - 20 = 40$, and

time taken by test vehicle to complete the stretch $t_1 = \frac{5}{30} = 0.1666$. Therefore
 $40 = 0.1666(q - 30k)$

In the second trial, $m = 40 - 25 = 15$, and

time taken by test vehicle to complete the stretch $t_2 = \frac{5}{35} = 0.1428$.

Therefore $15 = 0.1428(q - 35k)$

Solving the two equations for q and k , $k = 27 \text{ veh/km}$ and $q = 1050 \text{ veh/hr}$.

$v_o = 38.89 \text{ m/s}$.

Alternatively mean speed can be obtained from ,

$$v_o = \frac{l}{t_w - \frac{m_w}{q}} = \frac{5}{0.1667 - \frac{40}{1050}} = 38.88 \text{ m/s}.$$

4. The observations from a moving car method are given in the table below. The column (1) shows the number of vehicles overtaken by the test vehicle, (2) show

the number overtaking the test vehicle, (3) shows the number of vehicles moving against traffic stream, (4) is the travel time with the traffic (s), and (4) is the travel time against the traffic (s). Assuming linear speed-density relation, what is the maximum flow, speed, and density the following following stretch can take. Show the details of the calculation.

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(1)	(2)	(3)	(4)	(5)
5	119	618	422	268
26	12	389	213	188
24	9	401	226	396
2	55	410	274	255
26	9	374	226	396

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Solution:

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M_w	M_a	q	u	l	k
114	618	3819	53	4.66	71.61
-14	389	3367	48	3.06	69.67
-15	401	2234	44	3.06	50.74
53	410	3151	52	3.06	61.05
-17	374	2066	43	3.06	47.95

$v_f = 80kmph$

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$$\frac{v_f}{k_j} = \frac{80}{140}$$

$$k_j = 140veh/km$$

$q_{max} = \frac{80*140}{4} = 2800veh/hr$

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5. A moving vehicle experiment was conducted on a 2.5 km section of a highway. Two trials were conducted in the direction of dominant traffic flow. In the first trial, number of vehicles that had overtaken the test vehicle is 30, number of vehicles overtaken by the test vehicle is 6, and test vehicle speed is 30 kmph. In the second trial, number of vehicles that had overtaken the test vehicle is 20, number of vehicles overtaken by the test vehicle 26, and test vehicle speed is 35 kmph. Calculate the fundamental parameters of traffic flow and the average headway and spacing.

Solution: The basic equation of moving observer method is

$$m = m_o - m_p = qt - kv_ot \tag{12}$$

where m_o is the number of vehicles that had overtaken the test vehicle and m_p is number of vehicles overtaken by the test vehicle. v_o is test vehicle speed. In the first trial, $v_1 = 30\text{kmph}$, $t_1 = 2.5/30 = 0.0833$ hr.

$$m_1 = 30 - 6 = 24.$$

Substituting in equation 12,

$$288.11 = q - 30k. \quad (13)$$

In the second trial, $v_2 = 35\text{kmph}$, $t_2 = 2.5/35 = 0.0714$ hr.

$$m_2 = 20 - 26 = -6. \text{ Substituting in equation 12,}$$

$$-84.033 = q - 35k. \quad (14)$$

Equation 13 - 14 implies,

$$\begin{aligned} 288.11 + 84.033 &= 5k, \\ k &= 74.42\text{veh/km}, \\ q &= 2520\text{veh/hr}, \\ v &= q/k = 33.88\text{kmph}. \end{aligned}$$

Average headway = $1/q = 1.42$ seconds.

Average spacing = $1/k = 13.44$ m.

6. A person walking from office on a one-way street takes 60 min to get home, of which 12 min was taken talking to the driver of a stalled vehicle. He counted 52 vehicles while he was walking and 25 vehicles while he stopped. What are the travel time and flow of the vehicle stream?

Solution: Flow of the stream = $\frac{\text{No of vehicles counted}}{\text{Duration of count}}$

$$Q = \frac{25}{12} = 2.1 \text{ veh/min} = 125 \text{ veh/hr}$$

Travel time of stream = $\frac{\text{Travel time of test vehicle} - \text{no of vehicles overtaken test vehicle}}{\text{no of vehicles overtaken by test vehicle}}$

$$T = T_w - \frac{n_w}{q} = 60 - \frac{52+25}{2.1} = 60 - 12 = 23.3 \text{ min}$$

7. A student riding his bicycle from campus on a one-way street takes 50 min to get home, of which 10 min was taken talking to the driver of a stalled vehicle. He counted 42 vehicles while he rode his bicycle and 35 vehicles while he stopped. What are the travel time and flow of the vehicle stream? (6)

Solution: Flow of the stream = $\frac{\text{No of vehicles counted}}{\text{Duration of count}}$

$$Q = \frac{35}{10} = 3.5 \text{ veh/min} = 210 \text{ veh/hr}$$

Travel time of stream = $\frac{\text{Travel time of test vehicle} - \text{no of vehicles overtaken test vehicle}}{\text{flow of stream}}$

$$T = T_w - \frac{n_w}{q} = 50 - \frac{42+35}{3.5} = 50 - 12 = 28 \text{ min}$$

References

1. L R Kadiyali. *Traffic Engineering and Transportation Planning*. Khanna Publishers, New Delhi, 1987.
2. C. S Papacostas. *Fundamentals of Transportation Engineering*. Prentice-Hall, New Delhi, 1987.

Web links

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