Uncertainty in Traffic Flow Estimation Using the Moving-Observer Method

Ann-Marie Mulligan
B.E. (Hons)
Graduate Engineer, Beca Carter Hollings and Ferner Ltd

Alan Nicholson
B.E. (Hons), M.E., M.Sc., Ph.D.
Assoc. Professor in Civil Engineering, University of Canterbury

Abstract

Traffic flow rate estimation is very important in the planning and design process for all aspects of the road network. Flow rates are most commonly estimated using a 'stationary count' that requires specialised equipment and is expensive to set up. In the 1950's a method utilising a moving observer was suggested. Basically, it involves an observer in a moving vehicle counting the number of oncoming vehicles passed in a specified length of road. If the average speed of the moving vehicle, length of road and trip time is known, then the flow rate can be calculated. This study investigated the feasibility and accuracy of using this method for rural roads in New Zealand, many of which have low flow rates. A risk analysis approach was used to simulate moving observer surveys on roads with low flow rates. Results show that this method does not give accurate flow estimates for roads with a balanced two-way flow rate less than about 1000 veh/h, unless one undertakes an impracticably large number of moving observer runs.

1. Introduction

Traffic flow rate estimation is very important in the planning and design process for all aspects of the road network. However, since flow rates vary by day, week and month, and flow rate estimation generally involves sampling in time, it is important to take account of the consequent uncertainty when estimating the flow rate.

2. Risk Analysis

Practitioners are becoming increasingly aware of the need to estimate and take account of the uncertainty (or risk) in a project evaluation. Hence, there is an increasing emphasis on using risk analysis techniques in the Project Evaluation Manual (Transfund NZ, 1997).

One way of assessing the risk in a project is to model it using software such as @RISK, which is an advanced computer modelling system used in conjunction with Microsoft Excel or Lotus 1-2-3 to analyse any situation (from business to science to engineering) that has an element of risk. Traditionally, analyses combined single point estimates of a model's variables to predict a single result or outcome. @RISK allows the uncertainty in the estimates of those variables to be used to generate information on the probability of all the possible outcomes.

The risk analysis process involves the following steps:

- A model is developed by defining a problem and its associated variables;
- The uncertainty in the variables is identified and a suitable probability distribution assigned;
- The model is analysed by simulation to determine the range and probability of all outcomes.

@RISK works in a spreadsheet that has been defined in Excel (or Lotus 1-2-3) with some or all of the variables having special @RISK functions assigned to them. Each variable is described using its full range of possible values and a measure of the likelihood of occurrence for each possible value. @RISK has 32 built in probability distributions (e.g. the Normal, Binomial and Poisson distributions), which allow specification of nearly any type of uncertainty for the input variables.

Simulation involving a certain number of iterations is then carried out and results generated for output cells in the spreadsheet. @RISK executes simulations by randomly sampling from the input probability distributions. As the number of iterations increases, the sampled values become distributed so that they approximate the specified input probability distribution. Finally, taking all the generated output values and calculating statistics on how they are distributed, a distribution of outcomes is created.

3. Parameters Subject to Uncertainty

When discussing risk one usually thinks of a classic example such as the chance of a bridge being carried away in a flood. However, nearly all parameters used in a project evaluation are in fact subject to some uncertainty, with some being more uncertain than others (Travers Morgan, 1992).

The average annual daily traffic volume (AADT) is one of the most important parameters in an economic evaluation of a roading project. Therefore, reducing the error in the estimation of the traffic volume is beneficial in reducing the uncertainty in the overall analysis.

The AADT is usually estimated using short-term counts (e.g. weekly) and applying adjustment factors to take into account seasonal variations.

Traffic flow rates can be measured in various ways, the most common being a stationary count. However, stationary counts have disadvantages, such as the requirement for specialist equipment, which is expensive to install and operate, and the limited coverage. An alternative method is to use moving observers.

4. The Moving Observer Method

Although there are many variations to the moving observer method, it basically involves the use of an observer (or observers) in a moving vehicle travelling along a section of road. The observer records the number of oncoming vehicles met, the number of vehicles overtaken by the observer, and the number of times the observer is overtaken by other vehicles. If this and additional information, such as the average speed of the vehicles, the observer speed and the length of the road section are known, then the flow rate can be estimated. In order to obtain a more accurate estimate of the flow rate a number of trips down the same section of road is carried out.

The method is currently little (if at all) used in New Zealand for estimating flow rates. However, another 'moving observer' method, frequently known as the 'floating car' method, is commonly used to obtain a speed-distance profile for a route.

The moving observer method was developed in the UK by the Road Research Laboratory (Traffic and Safety Division) and was first described in a paper by Wardrop and Charlesworth (1954). Their method involved a series of runs in a test vehicle made travelling 'with' and 'against' a one-way traffic stream. The observers in the test vehicles record the following information for each run:

- The number of opposing vehicles met;
- The number of vehicles overtaking the test vehicle while it was travelling;
- The number of vehicles the test vehicle overtook;
- The average speed of the test vehicle and the distance of the run (or alternatively the journey times of the observer, with and against the stream).

These observations form the basis for the estimate of the traffic flow rate. Equations were derived enabling the traffic flow rate to be calculated from the collected information.

Several advantages of using the moving observer method were recognised by Wardrop and Charlesworth (1954). These include the following:

- Information on flow and speed can be collected at the same time (this can be particularly useful when studying the relationship between the two parameters).
- Travel time along a length of road can be measured as well as the flow rate and average speed of vehicles.
- It is economical when the number of person-hours required to achieve a desired level of accuracy is smaller for the moving observer method than for stationary counts.
- Vehicles can be classified and flow rates found for the different classifications.
- Additional information (such as the locations and causes of delays) can be recorded if required.

The disadvantages of the moving observer method as stated by O'Flaherty and Simons (1970) are:

- The method is very sensitive to the amount of intersecting traffic from side streets joining the flow on the main route.
- The accuracy of the method is very sensitive to fluctuations in the traffic stream.
- For low traffic flows a large number of test runs is required to achieve a given degree of accuracy, and this may prove impractical.

Limited research has been carried out on the effectiveness of the moving observer method for rural roads.

Previous research has focussed on comparing the moving observer method with stationary counts, but stationary counts have their own errors. This desktop study, however, investigated the theoretical errors in estimating the flow rate using the moving observer method.

5. Study Method

5.1 Research Undertaken

For this study, the moving observer method was simplified to better model a traffic survey on a rural road. Only the flow rate in the opposing direction to the moving observer was taken into account, with the number of vehicles that overtake the observer or are overtaken by the observer being ignored.

Wardrop and Charlesworth stated that trips would be taken in two vehicles travelling in opposite directions on the same section of road at the same time (alternatively, one vehicle travelling up and down a section of road so that it travels along the section in both directions at approximately the same time would be used). However, these methods would not work in the New Zealand context, if the observer were collecting the traffic flow data on a section of road while travelling to a job. It is unlikely that the vehicle would make the same trip in the opposite direction immediately following the first trip, or two vehicles would travel in opposing directions at the same time. Therefore, trips are defined as one-way journeys, independent of other trips undertaken on the same section of road.

5.2 Theory

The one-way flow rate of vehicles in the opposite direction to the observer, q_1, can be calculated using the following equation (refer to the Appendix for the derivation):

$$q_1 = \frac{x}{l} \frac{1}{\left(\frac{1}{v_1} + \frac{1}{v_0}\right)}$$

where x = the number of oncoming vehicles met by the observer during the observation time
l = the length of the surveyed section of road
v_1 = the speed of oncoming vehicles (km/h)
v_o = the speed of the observer (km/h)

For a particular combination of flow rate, section length, oncoming vehicle speed and observer speed, one can determine the expected number of oncoming vehicles met by the observer as shown in the rearranged equation below.

$$x = q_1 l \left(\frac{1}{v_1} + \frac{1}{v_o}\right)$$

Given the randomness of traffic, one would expect some variation (about the expected value) in the number of oncoming vehicles met.

The study involved controlling the three variables q_1, l and v_o, and allowing v_1 and x to vary according to specified probability distributions. For a chosen combination of the controlled variables (q_1, l and v_o) and a particular value of v_1 (taken from a probability distribution), the expected value of x was determined and a value of x was generated (from a probability distribution with the appropriate expectation). Using the chosen values for l and v_o, and the randomly generated values for v_1 and x, a value of q_1 was then determined. This was compared to the chosen value of q_1, to identify the error that may arise in the estimation of q_1 when x and v_1 vary randomly.

5.3 Variables

The values of the three controlled variables, namely the actual flow rate, the section length and the observer speed, were varied as indicated in Table 1. All combinations of values were simulated giving a total of 36 (or 6x3x2) combinations or scenarios.

Table 1: Values of Controlled Variables Used in Simulations

Oncoming flow rate, q_1 (veh/h)	Section Length, l (km)	Observer vehicle speed, v_o (km/h)
10	5	50
25	10	100
50	15	
100		
200		
500		

The flow rates were initially chosen to reflect rural roads with low flow rates. However considering these are hourly one-way flow rates, these flows actually equate to two-way AADTs of 200 – 10,000 veh/d, which are not really low flow rates in the New Zealand context.

The three section lengths and two observer speeds were chosen to identify the effect of variations in the section length and the observer speed on the precision of the estimate of the flow rate.

In addition the speed of the oncoming vehicles was required. The mean speed on an open rural road in New Zealand based on speed surveys conducted by the LTSA is 102.4 km/h, with a standard deviation of 10.4 km/h (Phipps, 1999). There was no significant correlation between the mean speeds and the standard deviations of the speeds. Comparing the 85^{th} percentile speeds with the mean speeds indicated that the speeds are approximately Normally distributed. Therefore a mean speed of 100 km/h with a standard deviation of 10.4 km/h was utilised.

The number of vehicles that the moving observer meets in each trip was assumed to be governed by a Poisson process. In such a process, events occur at random and independently, two events cannot occur simultaneously, the events occupy a negligible amount of time, and they occur at a constant average rate per unit of time.

For each of the thirty-six scenarios 10,000 Monte Carlo simulations were performed. The standard deviation of the calculated flow rate, q_1, was examined for each of the scenarios. The standard error in the estimated flow rate (equal to the standard deviation divided by the square root of the number of observations or trips), plus upper and lower bounds, were then calculated. It was assumed that a 5% ‘proportional error’ (i.e. the standard error being 5% of the flow rate) would be acceptable. Assuming errors are Normally distributed, this means that there is only a 2.3% probability of the error being 10% (of the flow rate) or more. This is consistent with the suggestion of Walker (1957) that a maximum acceptable error is 10%.

The number of trips required for the proportional error to be no more than 5% was calculated for each scenario. The number of trips was then multiplied by the time for each observer trip (based on the speed and length of section) to obtain the total observation time. The total observation time is an indication of the resource cost of estimating the traffic flow using the moving observer method (the lower the time and therefore the resources required the better). The results are shown in Table 2.

6. Results

Table 2: Summary of Scenario Results

Scenario	Flow Rate, q_1 (veh/h)	Observer Speed, v_o (km/h)	Distance, l (km)	Trip Time, t (min)	Required Number of Trips	Total Observation Time, T (hours)
1	10	50	5	6	165	16.5
2		100		3	245	12.25
3		50	10	12	82	16.4
4		100		6	123	12.3
5		50	15	18	55	16.5
6		100		9	83	12.45
7	25	50	5	6	84	8.4
8		100		3	127	6.35
9		50	10	12	43	8.6
10		100		6	64	6.4
11		50	15	18	29	8.7
12		100		9	43	6.45
13	50	50	5	6	47	4.7
14		100		3	70	3.5
15		50	10	12	24	4.8
16		100		6	35	3.5
17		50	15	18	16	4.8
18		100		9	24	3.6
19	100	50	5	6	25	2.5
20		100		3	37	1.85
21		50	10	12	13	2.6
22		100		6	19	1.9
23		50	15	18	9	2.7
24		100		9	13	1.95
25	200	50	5	6	13	1.3
26		100		3	19	0.95
27		50	10	12	7	1.4
28		100		6	10	1.0
29		50	15	18	5	1.5
30		100		9	7	1.05
31	500	50	5	6	6	0.6
32		100		3	8	0.4
33		50	10	12	3	0.6
34		100		6	4	0.4
35		50	15	18	2	0.6
36		100		9	3	0.45

These results indicate that the degree of accuracy increases as the number of runs increases, but the accuracy depends heavily on the flow rate. In other words, the flow rate has a strong and direct effect on the number of trips required to achieve a specified degree of accuracy.

Figure 1 shows the effect the number of trips has on the proportional error in the estimate of the flow rate. The smaller the desired error in the flow rate, the more the number of trips that need to be made. For example, if the actual flow rate for a 5 km section of road is 500 veh/h and an observer is travelling at 100 km/h. Then approximately 8 trips are required to achieve a proportional error of 0.05 (or 5%). For flow rates of 100 veh/h a very large number of runs are required to achieve the target.

Figure 1 shows clearly how the estimation error initially reduces quickly as the number of trips increases from one, with the rate of error reduction becoming quite small as the number of trips increases beyond the value corresponding to the 'knee' of the curve.

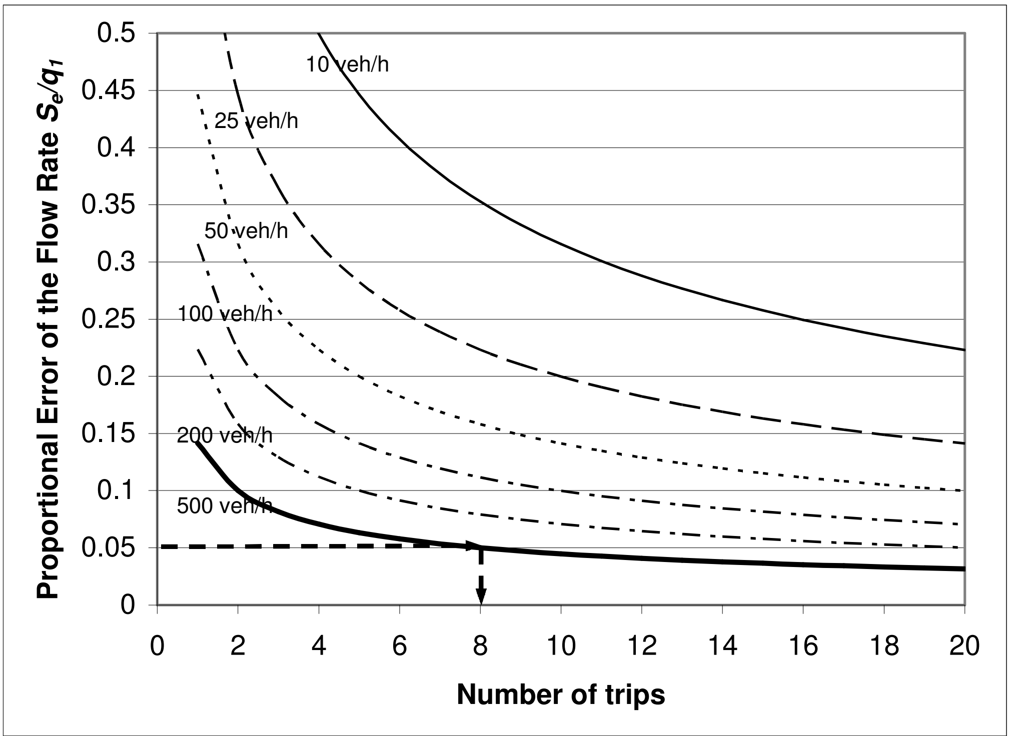

Figure 3: Flow rate estimation error versus number of trips (observer speed = 100 km/h, section length = 5 km)

A faster observer speed results in a larger error in the flow rate. This arises because the surveys with faster observer speeds have shorter trip times and therefore observe for a shorter length of time.

The length of the surveyed section of road directly affects the number of trips required but makes little difference to the total observation time. For example, if six trips are required to achieve a certain accuracy for a 5 km section then three trips will be required for a section twice as long (i.e. 10 km). However, the trips on the 10 km section take twice as long so the total observation time between the two sections is very similar. The results indicate that it is better to carry out more trips at a faster observer speed than fewer trips at a slower speed. This requires a smaller total observation time and therefore fewer resources.

The most important observation, however, is that the method requires a very large number of trips and therefore large total observation times for low flow rates. It is only at a flow rate of 500 veh/h on a long section of road (10-15 km) that the number of trips becomes practical. A flow rate of 500 veh/h equates to approximately 10,000 veh/day, and this is not a low flow rate in New Zealand.

7. Conclusion

The moving observer method might appear to be a sound method for estimating flow rates, especially on low flow roads where the cost of laying down a tube count is too expensive. However, in order to achieve an acceptable level of accuracy for low flow rural roads, the number of trips required will be too large to be practical. The method would better suit a high volume urban road, although if there are a large number of side roads (causing the flow rate on the main road to change) there may well be substantial inaccuracies in the estimates of the flow rate.

References

O'Flaherty, C.A and Simons F. (1970). An Evaluation of the Moving Observer Method of Measuring Traffic Speeds and Flows. *Australian Road Research Board Proceedings*, 5, Part 3, 40-54.

Wardrop, B.A. and Charlesworth G. (1954). A Method of Estimating Speed and Flow of Traffic from a Moving Vehicle. *Proceedings of the Institution of Civil Engineers*, 3, Part II, 158-169.

Chapman, R.A. (1971). *Some Relationships Between Road Accident Frequencies and Measures of Exposure to Risk*. PhD Thesis, University College, University of London, London.

Phipps, P. (1999). *Rural Speed Measurements*. Land Transport Safety Authority, Wellington.

Travers Morgan NZ (1992). *Evaluation Sensitivity Analysis*. Research Report 13, Transit NZ, Wellington.

Walker, W.P. (1957). Speed and Travel Time Measurements in Urban Areas. *Highway Research Board Bulletin 156*, 27-36.

Appendix

Consider a constant stream of vehicles travelling along a section of road in one direction. The stream can be regarded as the sum of several streams of vehicles travelling at v_a, v_b, etc. with flow rates of q_a, q_b, etc. and concentrations k_a, k_b, etc. respectively.

The general traffic equation is:

$$q = kv \qquad (1)$$

where q is the flow rate (veh/h), k is the concentration (veh/km), and v is the space mean speed (km/h).

Now:

$$q=q_a+q_b+\ldots \qquad (2)$$

$$k=k_a+k_b+\ldots \qquad (3)$$

$$v = \frac{q_a + q_b + \ldots}{\sum\left(\frac{q_a}{v_a} + \frac{q_b}{v_b} + \ldots\right)} \qquad (4)$$

Rearranging eq. (1) gives:

$$k = \frac{q}{v} \qquad (5)$$

The number of vehicles in a specified length of the road l is:

$$kl = \frac{ql}{v} \qquad (6)$$

Chapman (1971) noted that the number of vehicles observed (x) equals the number of vehicles already present in the section when the observer enters the test section (x_a), plus the number of vehicles that enter the section while the observer is within the section (x_b). That is:

$$x = x_a + x_b \qquad (7)$$

For a traffic stream with a flow rate q_1, and an average speed of v_1 then from eq. (6):

$$x_a = \frac{q_1 l}{v_1} \qquad (8)$$

If the observer travels at a speed v_o with a trip time of t_o then the number of vehicles that enter the section while the observer is observing is the flow rate multiplied by the time the observer is in the section. That is:

$$x_b = q_1 t_o \tag{9}$$

Wardrop and Charlesworth developed the following expression for the flow rate:

$$q = \frac{(x + y)}{(t_a + t_w)} \tag{10}$$

In this equation, x is the number of vehicles met while travelling against the flow, y is the number of vehicles that overtake or are overtaken while travelling with the flow, and t_a and t_w are the observer trip times when travelling 'against' and 'with' the traffic stream respectively. Equation (9) is a special case of equation (10) when an observer trip is only done one way (against the flow) so that y and t_w are effectively zero, and t_a equals t_o .

Obviously:

$$t_o = \frac{l}{v_o} \tag{11}$$

and substituting eq. (11) into eq.(9) gives:

$$x_b = \frac{q_1 l}{v_o} \tag{12}$$

Finally, combining eqs. (7), (8) and (12) gives:

$$x = \frac{q_1 l}{v_1} + \frac{q_1 l}{v_o} \tag{13}$$

Simplifying eq. (13) gives:

$$x = q_1 l \left(\frac{1}{v_1} + \frac{1}{v_o} \right) \tag{14}$$

Rearranging eq. (14) gives:

$$q_1 = \frac{x}{l} \frac{1}{\left(\frac{1}{v_1} + \frac{1}{v_o} \right)} \tag{15}$$

Hence, by measuring v_1, v_o, x and l, one can estimate the actual flow rate of the oncoming vehicles.