Use of Probe Vehicles to Increase Traffic Estimation Accuracy in Brisbane

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Abstract

Traffic congestion is an increasing problem with high costs in financial, social and personal terms. These costs include psychological and physiological stress, aggressivity and fatigue caused by lengthy delays, and increased likelihood of road crashes.

Reliable and accurate traffic information is essential for the development of traffic control and management strategies. Traffic information is mostly gathered from in-road vehicle detectors such as induction loops. Traffic Message Channel (TMC) service is a popular service which wirelessly sends traffic information to drivers. Traffic probes have been used in many cities to increase traffic information accuracy.

A simulation to estimate the number of probe vehicles required to increase the accuracy of traffic information in Brisbane is proposed. A meso level traffic simulator has been developed to facilitate the identification of the optimal number of probe vehicles required to achieve an acceptable level of traffic reporting accuracy. Our approach to determine the optimal number of probe vehicles required to meet quality of service requirements, is to simulate runs with varying numbers of traffic probes. The simulated traffic represents Brisbane's typical morning traffic. The road maps used in simulation are Brisbane's TMC maps complete with speed limits and traffic lights.

Experimental results show that that the optimal number of probe vehicles required for providing a useful supplement to TMC (induction loop) data lies between 0.5% and 2.5% of vehicles on the road. With less probes than 0.25%, little additional information is provided, while for more probes than 5%, there is only a negligible affect on accuracy for increasingly many probes on the road. Our findings are consistent with on-going research work on traffic probes, and show the effectiveness of using probe vehicles to supplement induction loops for accurate and timely traffic information.

Keywords

Probe Vehicles, Induction Loops, Traffic Estimation, Traffic Management Channel

Body of Paper

Introduction

Traffic on city roads is continually increasing, while road infrastructure is unable to keep up with demand, resulting in increasing levels of congestion.

Traffic congestion is considered to be a major transportation issue, having significant costs to individuals, community, industry and environment. These costs include psychological and physiological stress, aggressivity and fatigue caused by lengthy delays, lost economic productivity, environmental impacts from increased emissions and increased likelihood of road crashes (VCEC, 2005). Traffic congestion is estimated to cost approximately $100 billion annually in the U.S., and has comparable costs in other countries (VTPI, 2007).

There are several different ways of reducing congestion, such as optimizing traffic signal timing, increasing public transport coverage, and introducing road tolls. One attractive means of reducing congestion is to provide timely traffic information that allows drivers to make informed traffic route decisions. For example, Google maps is able provide traffic information in some locations. Reliable and accurate traffic information is also essential for the development of traffic control and management strategies.

The Traffic management channel (TMC) is a service provided in many countries around the world that delivers traffic and travel information to drivers. It is generally encoded within conventional FM radio broadcasts using the Radio Data System (RDS), which allows digital messages to be received silently, without interrupting normal broadcast services, or even allow radio and CD play to be suspended for important alerts. In the TMC scheme, each traffic incident is broadcast as a TMC message containing an event code, location code, and time and other details (such as alternate routes). Furthermore, TMC information is often incorporated into a GPS guidance system, to assist drivers in avoiding congested routes to their destination.

The sources of traffic information typically include inductor loops embedded in the road network, traffic cameras, police, and probe vehicle (also known as floating car) data. Unfortunately, TMC services commonly suffer from problems of latency (data may be out of date by the time it is transmitted) and accuracy (inductor loop faults are well known to cause erroneous traffic data). Traffic probes have been used in many cities to increase traffic information accuracy, and decrease latency.

In this paper we investigate the number of probe vehicles (market penetration) required to achieve an acceptable level of traffic reporting accuracy. This is done using a Matlab based meso-level traffic simulator, we have developed. This simulates vehicles (both probe and normal traffic), induction loops, and a TMC service on an actual road map (in this case Brisbane).

Simulator

Traffic simulation models can be classified based on the level of detail simulated. At the lowest (microscopic) level, the physics of each vehicle is simulated, providing realistic individual vehicle models at the cost of limiting the number of vehicles that can be simulated at any time. Macroscopic-level simulators, whereby vehicles are aggregated so that only traffic flow itself is modelled, lie at the other end of the spectrum. Mesoscale simulators lie between these two extremes, modelling only those aspects of individual vehicle dynamics (speed, direction and location) required to determine the interactions between vehicles that constitute traffic flow.

Commercially available simulators were unable to match all our requirements for this and parallel projects, so a meso level simulator was developed in Matlab for traffic and TMC modelling on any given TMC map (which contains all the major roads for a given region and their intersections with minor roads). This allows us to identify the optimal number of probe vehicles required to achieve an acceptable level of traffic reporting accuracy. Traffic is simulated as individual vehicles, with a pre-specified percentage being equipped with technology for transmitting traffic information back to the TMC service. Vehicles appear randomly on traffic network gates and move towards their destination gatex by following deterministic behavioural laws. Induction loops and a TMC service are also simulated.

Each vehicle is implemented with individual driving styles based on randomized parameters that model driver aggressiveness, maximum vehicle acceleration, vehicle length, safe inter-vehicular distance, vehicle age and breaking abilities. Additionally, cars follow road rules, consider speed limits, and perform overtaking when possible. We are also able to randomly insert accidents at intersections and vehicle break downs on roads to realistically simulate normal (peak) traffic conditions.

Simulation Parameters

Simulation runs starts by loading simulation parameters, such as TMC map, number of vehicles, rate (flow) of entry into the network, network and TMC update rates, etc. The road maps used in simulation are actual TMC maps (for Brisbane), complete with speed limits, but with all TMC links being 2 lanes. TMC links are directional, so this means roads may be 2 or 4 lanes wide.

All vehicles travel from their starting sector to their destination, with the flow of traffic being determined prior to the start of simulation. Vehicles may enter and exit the map (and hence simulation) during the course of simulation. Vehicles travel at the speed limit, but maintain safe distances between each other. Traffic lights and vehicle behaviour at intersections are simulated, as are break downs and accidents (which occur randomly) – the probabilities of which are specified prior to simulation. Probe vehicles transmit back to base when the TMC reported speed differs from the actual average speed across a TMC link by a given threshold. A pre-specified percentage of vehicles on the road are equipped for transmitting speed data back to the TMC server. Induction loops transmit back average speeds over a TMC link segment periodically. For realism, a small amount of noise (2.5%) is added to the reported speed (which is 100% accurate as it comes directly from the simulator), also a pre-specified percentage of loops are dysfunctional.

The map used in all simulations is the segment of Brisbane from Carseldine to the city (CBD and surrounds). This map contains 1348 directional TMC links. This allows typical peak hour and off peak traffic to be simulated. The use of a full city map would be impractical, and unlikely to provide significantly more information.
The setup of traffic flow the map is shown in Fig. 1, with the break up of flows between quadrants being: 2 -> 8 : 20%; 2 -> 9 : 20%; 3 -> 8 : 10%; 1 -> 5 : 10%; 1 -> 7 : 10%; 7 -> 2 : 10%; 4 -> 6 : 10%; 9 -> 1 : 10%. This simulates a

morning (peak) traffic run, with most traffic heading into or through the CBD, with some heading in the opposite direction.

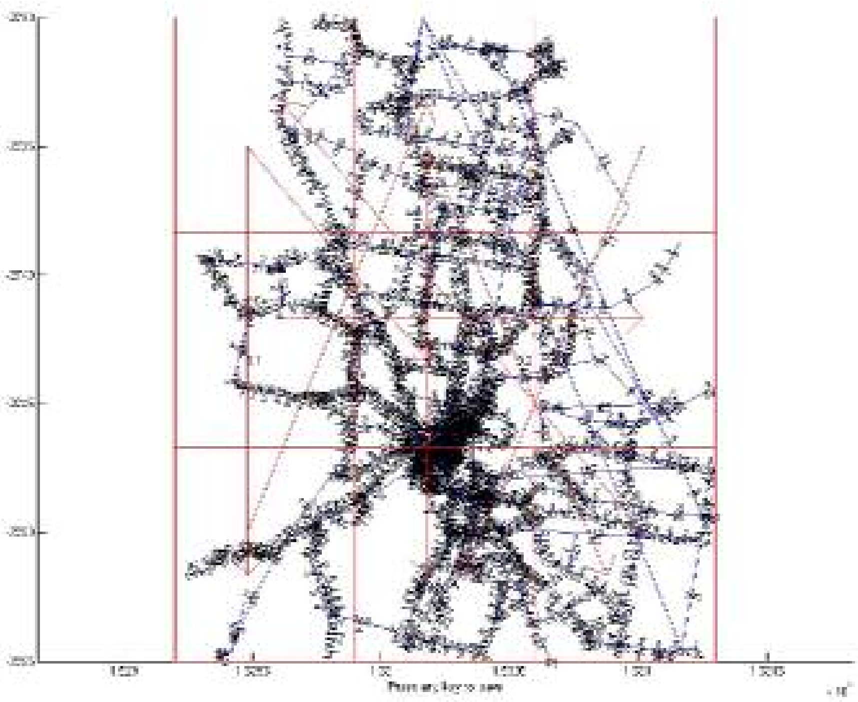

Figure 1: Traffic Flow

Simulations are run for 90 (simulated) minutes, again, to simulate a morning (peak) traffic run, with traffic increasing constantly from the start of the simulation to the end. There is little variation in vehicle counts, or traffic growth, between simulation runs.
A graph of vehicle counts vs. time for a typical simulation is shown in Fig. 2.

The aim of simulations is to determine the relative performance of probe vehicles relative to, and in addition to, induction loops in accurately measuring traffic conditions. Accuracy is measured by comparing the reported speeds against the actual average speeds at each simulation time step; if the speed difference ratio is less than this threshold, then the link's speed is considered to have been accurately reported. The accuracy of probe/loop/TMC is then calculated as the percentage of accurately reported links in the map. An accuracy threshold of 20% has been used for all simulations. Furthermore, when calculating the mean accuracy the first 10 minutes of simulation are removed from the calculation, as time is needed from simulation start for vehicles to traverse links and loops to transmit, prior to traffic information being available. A probe vehicle transmission threshold of 20% is used, whereby the probe doesn't transmit traffic information back to base if the speed difference ratio (reported speed / actual speed) is under this threshold. This parameter is not varied in these simulations, as cost of transmissions is not the issue addressed in this paper.

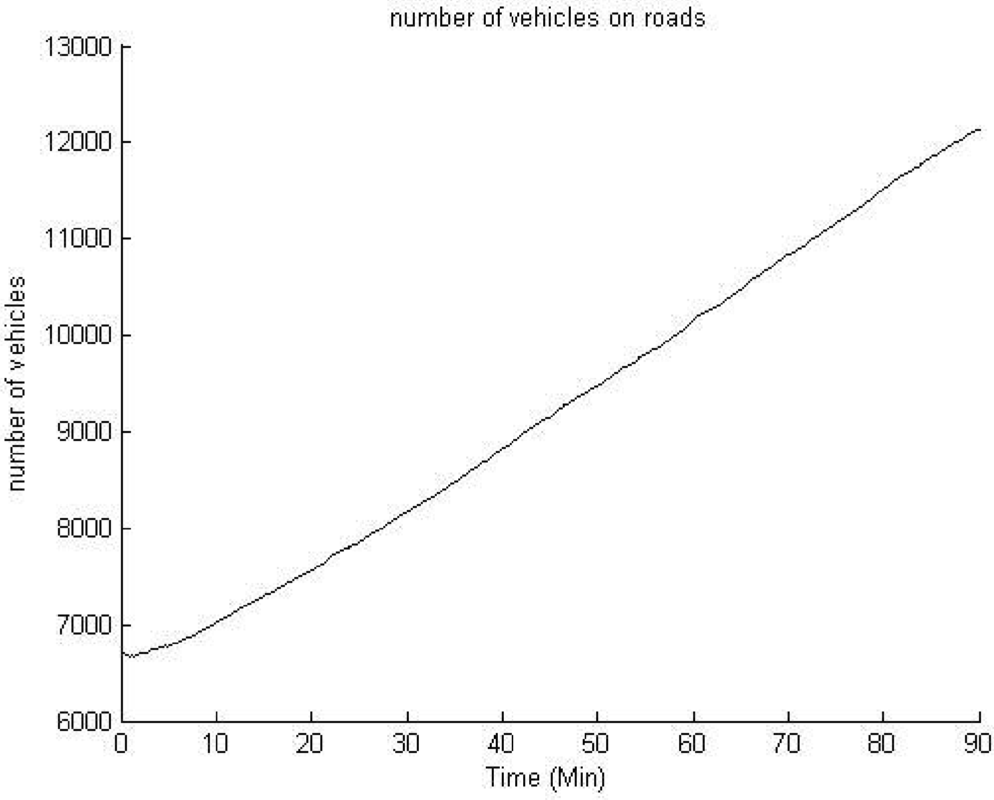

Figure 2: Typical Vehicle Counts

The default parameters, varied in some runs, are:

- The number of malfunctioning induction loops is set at 5%; a value considered as typical of a real life scenario.
- An induction loop update frequency of 10 minutes - induction loops update and transmit the average vehicle speed across the link once every 10 minutes; again, a typical real world value.

Testing Sensitivity of Parameters

Prior to evaluating the number of probe vehicles required to achieve specific accuracy levels of traffic reporting, simulations were done to determine the affect of induction loop fail rates and induction loop update frequencies on the reported accuracies.

Firstly we compared the results using default parameters (the base case) to the results achieved with a lower induction loop fail rate. Five runs were done, with the following results:

	5% Faulty (default)	1% Faulty
Accuracy (Run 1)	14.5	15.5
Accuracy (Run 2)	14.2	15.3
Accuracy (Run 3)	14.2	15.0
Accuracy (Run 4)	14.6	15.2
Accuracy (Run 5)	14.1	14.7
Accuracy (Mean)	14.32	15.14

Table 1: Accuracy for 1% and 5% Induction Loop Fail Rates

A graph of close to mean simulation runs for the two settings is shown in Fig. 3.

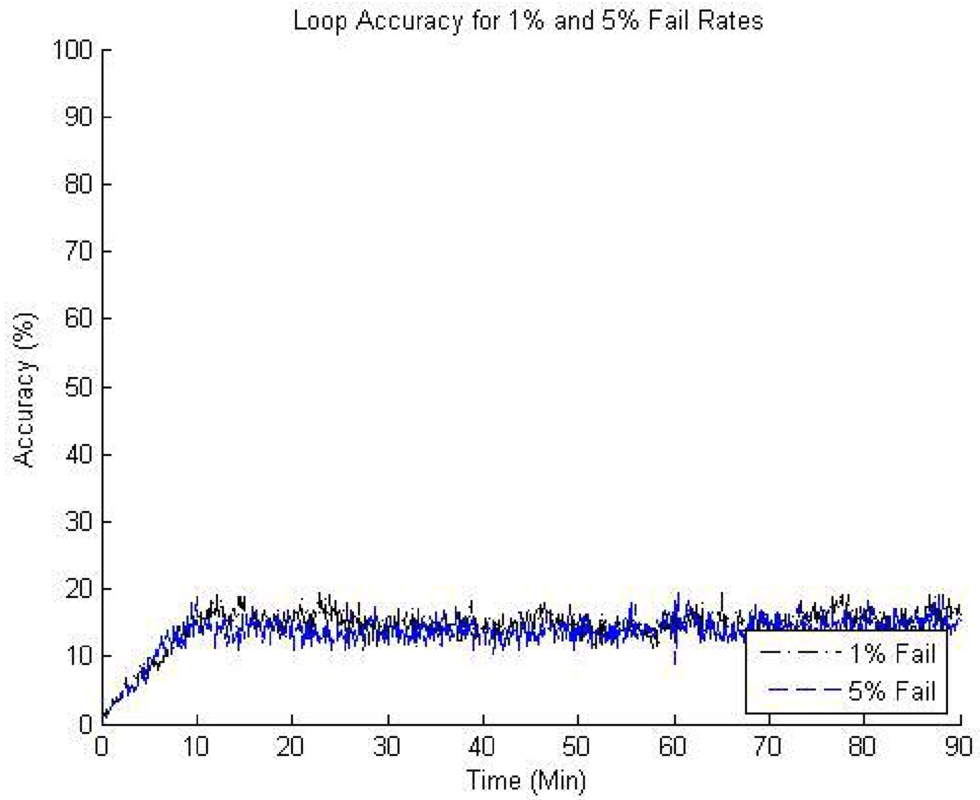

Figure 3: Loop Accuracy for 1% and 5% Fail Rates

These results show that dropping fail rate from 5% to 1% has little discernable effect on simulations with only an average of 0.82% increase in loop accuracy (from 14.3% to 15.1%). Furthermore, this only slightly exceeds the variation found within a set of runs (0.5% for the 5% loop fail rate runs, and 0.8% for the 1% runs). These results justify leaving the percentage of failed induction loops at 5% for the rest of the simulation runs.

Next we compared the affect of more, and less frequent induction loop updates on accuracy, against the results obtained using the default parameters. In this case 3 runs for each induction loop update frequency were done - with frequencies of 5 minutes, 10 minutes (the default) and 15 minutes.

	15 min	10 min (default)	5 min
Accuracy (Run 1)	14.4	14.5	15.6
Accuracy (Run 2)	13.5	14.2	16.4
Accuracy (Run 3)	14.0	14.6	16.0
Accuracy (Mean)	14.0	14.4	16.0

Table 2: Loop Accuracy for 5, 10 and 15 min Loop Update Frequencies

A graph of close to mean simulation runs for the three settings is shown in Fig. 4.

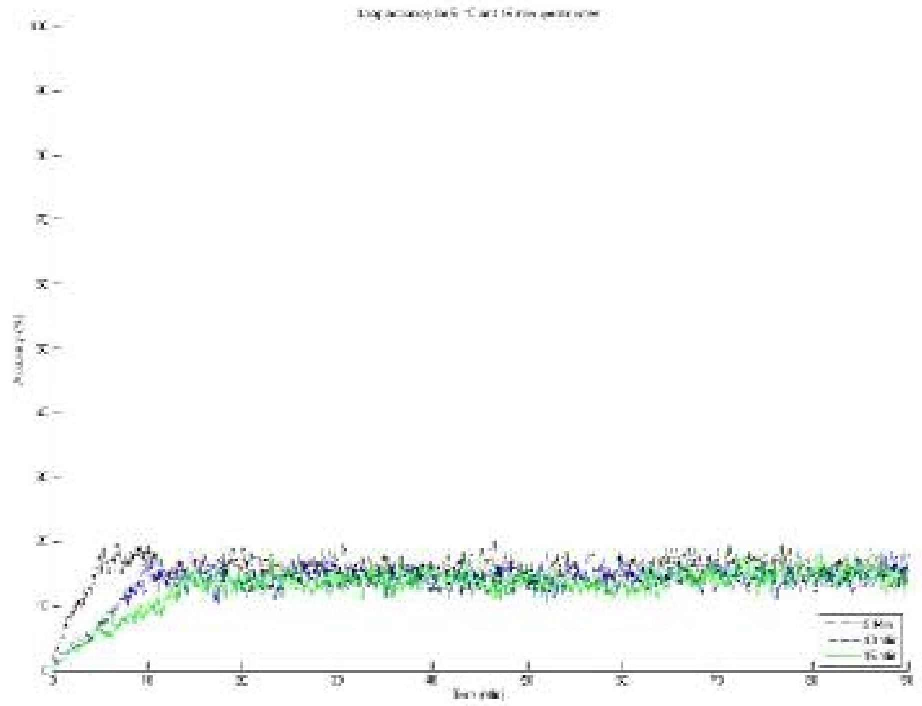

Figure 4: Mean Loop Accuracy for 5, 10 and 15 min Update Frequencies

These show that increasing the loop updates from the default of 10 minutes to every 5 minutes has on average a 1.6% increase in loop accuracy, while decreasing the loop updates has on average a 0.4% loss in accuracy. Given the relatively small differences involved, and the fact that 10 minute loop update frequencies are common, we have used this rate for the remainder of simulation runs.

Determining Optimal Numbers of Traffic Probes

To determine the optimal number of probe vehicles required to meet quality of service requirements, simulations were run with varying probabilities of any given vehicle being a traffic probe, referred to here as the equipped vehicle rate, or *erate* for short. Simulations were run for equipped vehicle rates from 0.1% to 10% (erates beyond 10% were deemed unlikely in the foreseeable future), with initial runs also including erates of 0.25%, 0.5%, 0.75%,1.0%, and 2.5%. Additional runs were then done at the border line between 0.5% and 0.75% where probe vehicle reporting accuracy exceeds that of induction loops. For these, erates of 0.6%, 0.65%, and 0.7% were used. Three sets of simulation runs were done for each value of erate.

For all simulations, the number of vehicles on the road starts out around 6700 (or around 5 vehicles per TMC link) and increases to around 12,200 (around 9 vehicles per TMC link) with an average of around 9210 vehicles (approximately 6.8 per link) across the run. There was little variation in these numbers, as can be seen of the graph of a complete set of runs (varying erate from 0.1% to 10%). A plot of the number of vehicles on the road, for the 5 runs is shown in Fig. 5, which shows this consistency clearly.

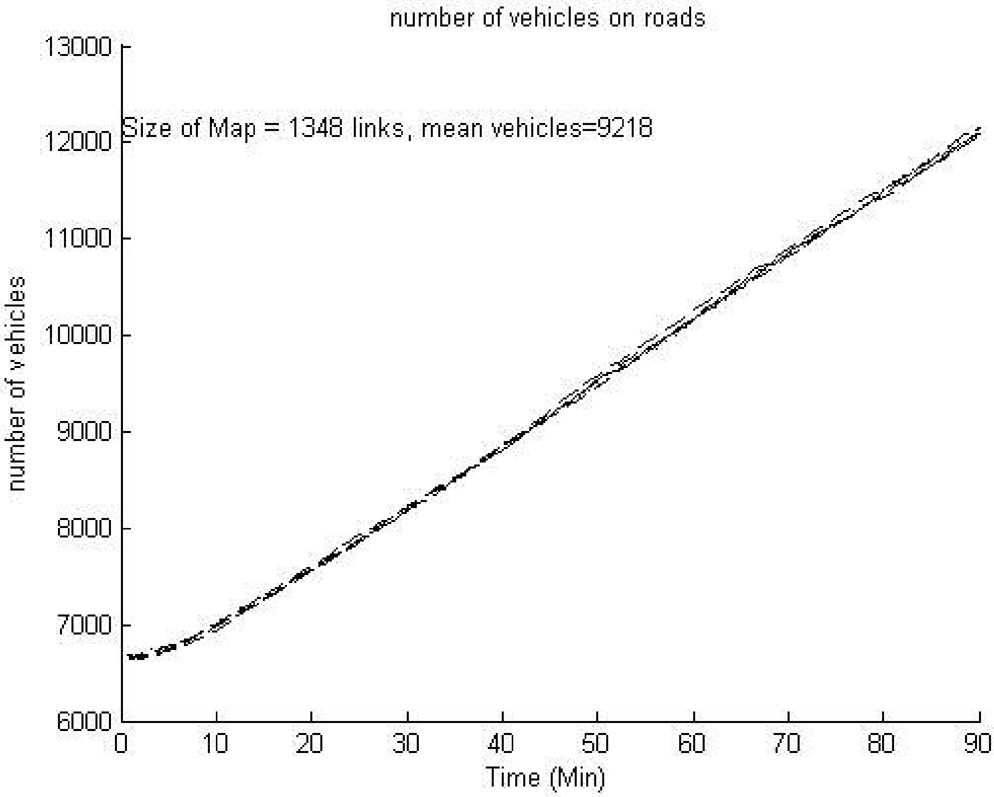

Figure 5: Vehicles on Road for 5 Runs

A plot of the accuracy of reporting for these same 5 runs, with varying equipment rates, is given in Fig. 6 (it is infeasible to include all the runs in a set on a single graph).

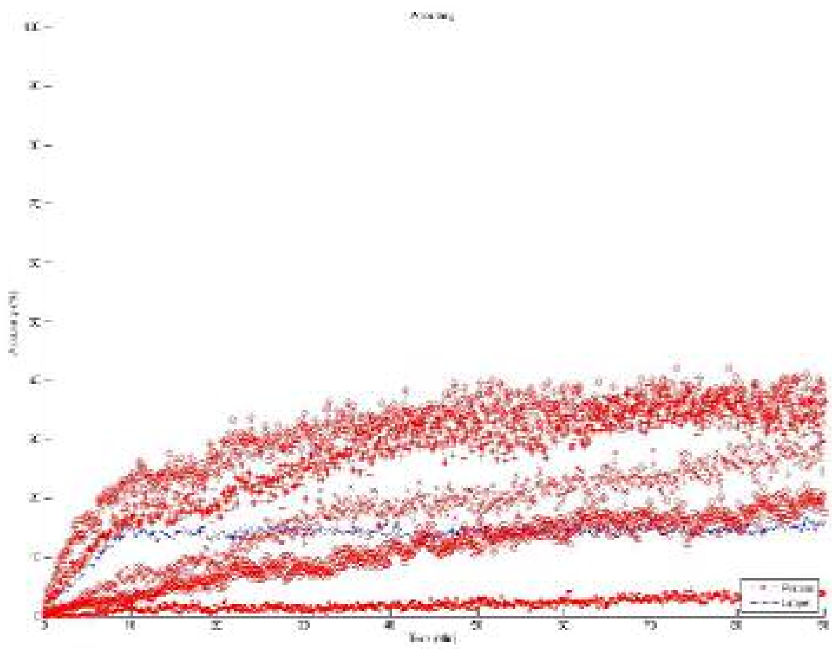

Figure 6: Probe Accuracy varying erate

The accuracy of probe (red) and induction loop (mean of all runs shown in blue) data is shown for erates of 0.1%, 0.5%, 1.0 %, 2.5% and 5%. The accuracy of probes increases as erate is increased, though it is hard to differentiate between the 2.5% and 5% runs (the former are represented with red '+'s). This demonstrates that even with a low erate of 0.5%, probe accuracy is able to exceed induction loop accuracy over time. While, in contrast, induction loops provide a fairly static rate of accuracy during each simulation run.

The mean result (accuracy, probe counts and probes per TMC link) for each erate set of 3 runs is given in table 3, and a graph of the mean accuracy results for probes, loops and TMC is shown in Fig. 7.

erate (%)	Probe Count	Probes Per Link	Probe acc %	Loop acc %	TMC acc %
0.1	9.23	0.0068	2.54	14.3	15.5
0.25	23.0	0.0171	7.12	14.2	16.8
0.5	46.0	0.0341	13.5	14.4	19.9
0.6	55.3	0.0410	14.3	14.2	19.9
0.65	59.8	0.0444	15.0	14.4	20.3
0.7	64.5	0.0478	16.5	14.6	21.1
0.75	68.9	0.0511	17.6	14.7	21.6
1.0	92.1	0.0683	19.4	14.4	22.6
2.5	231.1	0.1714	27.9	14.3	26.7
5.0	459.3	0.3407	32.9	14.5	29.3
10.0	921.7	0.6838	36.4	14.4	32.2
Mean	N/A	N/A	N/A	14.4	N/A

Table 3: Mean Accuracy for Equipment Rates

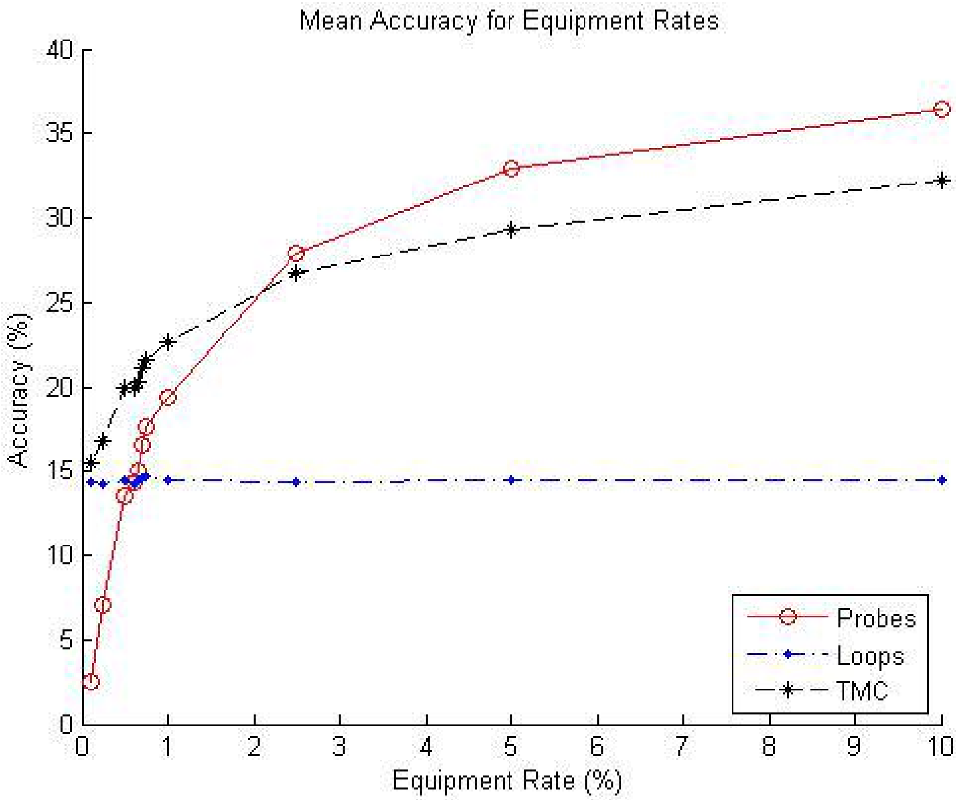

Figure 7: Mean Accuracy for Equipment Rates

These simulations show that traffic reporting accuracy increases rapidly for probes up to around an erate of 2.5% before flattening out, but increasing the erate above 5% has little effect: there appears to be an accuracy ceiling of around 40%.

Discussion

What these results show, is that when compared with the default induction loop parameters, probe vehicles are able to provide more accurate traffic information when they comprise somewhere between of 0.50% and 0.75% of the vehicles on the road. While induction loops typically provide a fairly stable level of traffic information accuracy between 14-15%. Furthermore, probe vehicles are able to provide useful supplementary information even when probe vehicles only comprise a small percentage of the vehicles on the road. For example, probe vehicles provided an increase of 5% traffic accuracy (or 1/3 of the existing accuracy) to the TMC service with an erate of only around 0.5%. Also, with an erate of 1%, the accuracy of the TMC service exceeded the accuracy of both probes and loops, taken in isolation, providing a level of accuracy of around 22-23%. However, beyond this point, while probe accuracy keeps improving, the level of TMC accuracy starts to be less than that of the probes - being dragged down by the loop data (of course this is dependent on the proprietary algorithms used for updating the TMC service, which is beyond the scope of this work as we are not privy to this information).

It should be noted that at an erate of 5%, the probes are able to provide an accurate map of traffic on 1/3rd of the TMC links on the map, at any given time step in the simulation. That is, 1/3rd of transient traffic information across the entire region is accurately reported at any six second simulation time step interval. If accuracy is given a more human timescale, in the scale of minutes rather than seconds, then it is likely that the level of accuracy reported would improve dramatically. However, this would require knowing what degree of latency is acceptable to the TMC service provider. However, a more human-oriented accuracy measure can still be determined if the actual induction loop accuracy is known, by taking the relative performance of probes to induction loops in the simulations.

Lastly, Table 3 shows how erates can be tied to actual probes required on the road. From this table we can see that to obtain an accuracy level of 27.9% (at an erate of 2.5%), 0.1714 probe vehicles per link would be required, which in the case of the Carseldine to CBD map is around 230 vehicles.

Conclusion

From the research carried out through the means of simulation, it is estimated that the optimal number of probe vehicles required for providing a useful supplement to induction loop data lies between 0.5% and 2.5% of vehicles on the road, which equates to between 0.0341 and 0.1714 probe vehicles per TMC link. With less probes than 0.25%, little additional information is provided, while for more probes than 5%, there is only a negligible affect on accuracy for increasingly many probes on the road. These findings are consistent with on-going research work on traffic probe such as (Bhaskar et al, 2008), who found that a probe vehicle sample of 3% has the potential to provide accurate travel time.

Acknowledgements

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