USING ITS DATA FUSION TO ASSESS NETWORK PERFORMANCE AND CORRIDOR INITIATIVES

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ABSTRACT

New Zealand is missing out on benefits from using ITS data fusion to actively monitor and report on transport initiatives. Whether these initiatives be TDM, arterial traffic signal optimisation, or more traditional capacity improvements, using a range of traffic operations information sources can provide an assessment of the ongoing success or otherwise of a strategy. The paper describes the implications for New Zealand from best-practice and in particular reports on using the fusion of readily available ITS data sources including floating car, vehicle tracking and ARTIS to provide performance reporting of direct use to transportation engineers and other professionals.

INTRODUCTION

New Zealand is missing out on benefits from using ITS data fusion to actively monitor and report on transport initiatives. Whether these initiatives be TDM, arterial traffic signal optimisation, or more traditional capacity improvements, fusing data from a range of traffic operations information sources can provide an assessment of the ongoing success or otherwise of a strategy. In recent years, the available technology for implementation has also increased and the paper looks at this and how it can be applied.

This paper describes the implications for New Zealand from best-practice and in particular reports on using the fusion of readily available ITS data sources to provide performance reporting of direct use to transportation engineers and other professionals, particularly relevant to arterial roads. Using ITS data fusion will reduce reliance in New Zealand on micro-simulation modelling and single-source traffic data.

This paper is arranged in the following order:

- ITS technology and data fusion.
- Theory behind analysis of performance reporting.
- Examination of ITS tools for corridor assessment.
- Application of Floating Vehicles and ARTIS.
- Conclusions for future of data fusion in New Zealand context.

ITS TECHNOLOGY AND DATA FUSION

ITS Infrastructure and Data

While ITS technology continues to develop in New Zealand and internationally, when looking at data fusion it is useful to classify the various types of ITS infrastructure currently being used on transport networks into broad categories:

- ✓ Vehicle Counts (including use of pneumatic tubes / induction loops / studs, *etc*.)
- ✓ ATMS systems (point speeds, volumes, classifications)
- ✓ Floating Car / Average Car (including Austroads type methodologies)
- ✓ Vehicle Tracking (ANPR / Bluetooth / MAC / Cellular / Toll Tag, *etc*.)
- ✓ Fleet data (including Public Transport real-time systems)
- ✓ Traffic Signal Information (SCATS, *etc.*)

Data Fusion

Data fusion, is generally defined as the use of techniques that combine data from multiple sources and gather that information in order to achieve inferences, which will be more efficient and potentially more accurate than if they were achieved by means of a single source.

Much work has been done on the theory and application of processing data across large scale systems, typically originating from Defence applications. In the transportation environment, data fusion relates to combining data from different sensor infrastructure, including potentially historic data sets. Dailey *et al.*[1] describe the advantages and key constraints of data fusion in transportation operations. The advantages of multiple-sensor data fusion projects are typically:

- Cost
- Accuracy
- Reliability

A key constraint is the contrast between data fusion with highly accurate single technology systems. From a mathematical perspective, variability in data from inherent inaccuracies from the actual value, get compounded across fusion processes. For data fusion to be desirable, either each data source must be highly accurate, each data source must inform the accuracy of other data, or must provide a 'picture' that no other method can.

This is confirmed by (Sarma & Raju, 1991[2]; Lin et al., 1991[3]). Integrating their statements on the benefits of data fusion with a New Zealand traffic operations focus, data fusion brings:

- Increased confidence: more than one sensor can confirm a change in traffic characteristics, providing data on different aspects of traffic and travel.
- Reduced ambiguity: joint information from multiple sensors reduces the likelihood that an incorrect interpretation will occur (e.g. the cause of reduced travel times)
- Improved detection: integration of multiple measurements (point data may not detect something that vehicle tracking will)
- Increased robustness: one sensor can contribute information where others are unavailable, inoperative, or ineffective (e.g. faulty loops can be compensated for to avoid losing visibility of the network segment)
- Decreased costs: a suite of "average" sensors can achieve the same level of performance as a single, highly-reliable sensor and at a significantly lower cost (e.g. ANPR is highly accurate, but expensive to implement network wide)
- Enhanced spatial and temporal coverage: one sensor can work when or where another sensor cannot (24/7 data may not be reliable without validation from other periodic data)

Building on this last point and to the work of Dailey *et al.*, a key consideration in the benefit of data fusion is around being able to combine 24/7 data sources with periodic data, making use of the strength of each data – an application of this is described in relation to measuring arterial performance using a mixture of 24/7 SCATS data and floating vehicle survey.

This is particularly important in the New Zealand context where for arterial corridor studies in NZ there are insufficient individual sensors for effective evaluation of network performance, and data fusion approaches are required.

THEORY BEHIND ANALYSIS OF PERFORMANCE REPORTING

The ability for performance reporting of the transport network to engage network managers and funding agencies is currently changing due to the increasing information being collected through ITS-type infrastructure. PSMC[a] and Alliance type contracts have required asset performance reporting for some time; operations reporting is now becoming available and internationally, typically the following information is being produced[4]:

- Traffic Volumes (Throughput)
- Travel Times (Efficiency) or Productivity (mix of travel time and throughput)
- Reliability of travel times
- Public Transport information
- Environmental (air quality, run-off, noise)
- Customer Satisfaction

In addition, spatial and temporal characteristics and longer term trends are being introduced (*e.g.* how long do congestion levels last over various parts of the network and how has this

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[a] Performance Specified Maintenance Contract

changed over the last 5 years).

Data Collection and Data Fusion – International Case Studies

The current trend internationally is towards ‘data fusion’ techniques where some combination of floating car surveys, loop detection, automatic number plate recognition, and/or fleet GPS information may be used to monitor congestion. While there are now large ranges of sensors in the roadway, most agencies appear to be retaining floating vehicle surveys as a part of their schemes, particularly in less dense cities or rural areas, as they are the only method to get full coverage of a network with accurate travel times.

The UK Department for Transport currently monitors (as of March 2008) congestion and travel time reliability by using the average vehicle delay, derived from the differences between observed synthesised travel times and a reference travel time that could be theoretically be achieved when traffic is free-flowing, weighted by traffic flows. This was achieved using the Highway Agency Journey Time Database, which derives travel times from an inductive loop system.

While there are technologies such as radar, camera, and studs available which mimic the performance of inductive loops, loops appear to be remaining the dominant data collection method on motorways / freeways. The implementation of induction loops beyond motorways / freeways appears to be mostly limited to traffic signal installations and widely spaced data collection points.

The UK DfT conducted an investigation into travel time variability on the largest 10 urban areas in England. The purpose of the study was to develop a methodology to predict and model travel time variability by determining a relationship between congestion and travel time variability. This would allow for a more robust method for comparing congestion across the network, as well as providing tools to predict changes in congestions as travel demands change over time. The study looked into using data from floating car records, inductive loop systems and number plate recognition systems in use on the road network.

It was concluded that data fused from accurate but limited floating car surveys along with less accurate but larger data sets from fleet data and tracking service providers (such as car security firms) would provide the best set of data for the study as inductive loops or other static means were unable to provide the complete picture of travel time variability.

In another example, Washington State (USA) publishes a quarterly report on the State’s transportation system, which highlights current projects, allocation of funding, and updates progress on management and operations measures. It reports on a comprehensive suite of key performance indicators based by employing a comprehensive system of 5,000 induction loops; spread over 700 miles of highways and operating in real-time. In addition, the state is currently attempting to define congestion occurring as a result of incidents or weather (non-recurrent) as a separate measure to congestion occurring as a result of insufficient capacity.

In terms of the requirements of new performance metrics, a recent Austroads report - “National Performance Indicators for Network Operations 2007”[5] proposes five new NPIs (National Performance Indicators) for use in monitoring and benchmarking congestion between cities. These are as follows:

- Traveller efficiency (travel speed);
- Traveller efficiency (variation from posted speed limits);
- Traveller efficiency (arterial intersection performance);
- Reliability (travel speed), which measures the variability by calculating the coefficient of variation;
- Productivity (speed and flow).

Each of these NPIs may require data from a mix of sources.

Similarly, Washington State publishes a quarterly review of network performance called the "Gray Notebook". Within this document, the State reports on a suite of network performance indicators, of particular interest is the examination of "Lost Throughput Productivity" which is the percentage of a highway's lost throughput due to congestion. This is a typical metric that would be used in a commercial operation, providing better feedback on the impact of operational initiatives, but it requires data from across the network.

Synthesising Travel Times from Point Traffic Speeds

The use of point traffic speeds such as those provided from inductive loops on motorways / grade separated roads to estimate travel times is a good example of where data fusion in sensors provides enhanced performance reporting.

Smith *et al.*[6] report on the significant risks of using point sensors to estimate travel time on congested urban freeways, and recommend that transportation professionals exercise caution when using travel time-based performance measures derived from point sensor data.

The key is that each section of urban corridor will have bottlenecks / characteristics that mean that point speeds need be 'adjusted' using ANPR or other vehicle tracking technologies. Alternatively loops could be installed at close spacings, but this is impractical for the majority of an urban network.

There is a compelling need for data fusion techniques to be used to complement any 24/7 point data available on the network.

Floating Car / Average Car

A current debate is that between the use of fleet data and floating car / average car surveys. Fleet data from GPS logging of positions can provide immediate and widespread information about travel speeds, but does not have the robustness of floating / average car surveys where the driver is instructed on how to drive and does not for example make brief stops or alter route or driving style. A key concern with fleet data is whether the sample is biased towards a particularly commercial driving style or vehicle type.

Where there are limited fleet data runs across a specific network segment, these considerations become important, and where there are many thousands then this becomes less important. The issue is best explained in the statistical statement:

- The effect of larger 'errors'[b] in individual runs are reduced by the number of runs, and for very large samples the mean will approach the actual mean travel time.

For busy parts of the network, such as motorways / freeways, fleet data may be useful in some situations, however ironically this is where the majority of fixed ITS sensors are deployed. For less busy parts of the network, to get accurate performance and trend information then floating / average car surveys will provide the accuracy necessary, albeit for only a sample of the 24/7/365 operation of the network. Two issues are paramount:

- Sufficient sample size
- Fusion with other data for localised performance reporting

It is expected for increasing sample size that there will be increasing level of confidence that the floating car results represent the average travel time.

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[b] 'Error' being the difference between the recorded travel time and actual mean travel time.

ITE provides guidance in "Manual of Transportation Engineering Studies"[7] for the sample-size requirements for floating car surveys. Table 4-1 of that document is reprinted as **Table 1** below and provides the appropriate minimum sample-size requirements for travel-time and delay studies with confidence level of 95%. For before and after studies, the suggested range of permitted error is +/- 1kph to +/- 5kph. The bolded figures reflect that statistically, a relatively small number of runs (between 3 to 4) will provide 95% confidence.

As an example a typical running speed on a congested arterial is around 30 kph, so for the variation in such a route would be expected to be no more than 5 to 10 kph (15% to 30%).

Table 1: Extract from ITE Manual of Transportation Engineering Studies

Average range in running speed (kph)	Minimum number of runs for a permitted error of:				
	2 kph	3.5 kph	5 kph	6.5 kph	8 kph
5 kph	4	**3**	2	2	2
10 kph	8	**4**	3	3	2
15 kph	14	7	5	3	3
20 kph	21	9	6	5	4
25 kph	28	13	8	6	5
30 kph	38	16	10	7	6

This table reflects that where there are stable (reliable) travel times that the sample is far smaller than when there are high levels of unreliability in travel times.

Figure 1 below represents an analysis that was undertaken using synthetic travel times from ITS data on a congested motorway system. Even with very high levels of variability caused by the synthesis process, a sample of around 5 days a month produced a close estimate of the mean for the month in all but a few situations.

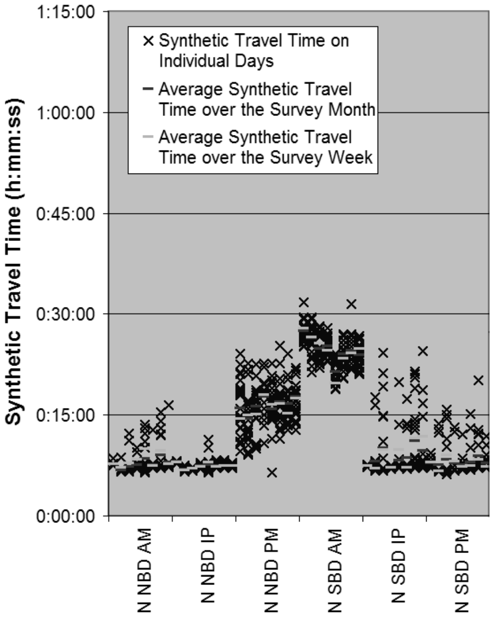

Figure 1 – Average of 5 day sampling compared to average monthly travel times

EXAMINATION OF ITS TOOLS FOR CORRIDOR ASSESSMENT

Corridor performance assessment tools on the motorway system in New Zealand are being progressively developed and implemented.

With the limited ITS sensor deployment on local arterials and roads, floating car surveys remain the dominant method of monitoring travel time trends, with potential supplementation with GPS fleet data and potentially fixed and low-cost vehicle tracking technologies.

When an arterial corridor or localised bottleneck study is carried out, there is both limited ITS information to inform the study or to measure the benefits. Micro-simulation modelling is often used by collecting a sample of data from traffic counts and queue / travel time surveys amongst other data, and initiatives tested in the model against the base case. More recently, SCATSIM technology has been introduced into the modelling process to better reflect the operation of coordinated / adaptive traffic signal operation.

With traffic operations data changing constantly, modelling is an expensive and inefficient means to test on an ongoing basis changes in operations of an arterial corridor. Floating car surveys conducted periodically will only provide longer term trends.

Using the concept of data fusion described in this paper, the key should be to have 24/7/365 data that can be fused with accurate periodic data.

APPLICATION OF ITS FUSION: FLOATING VEHICLES AND ARTIS

Advanced Real-Time Traffic Information System (ARTIS)

The dominant ITS sensors on arterial roads are traffic signal inductive loops, and previously this SCATS data has been underutilised in corridor performance measurement.

ARTIS is an add-on software tool used for monitoring the performance of arterial road networks in real time using data collected from the SCATS traffic control system. It uses actual and dynamic traffic data available from SCATS and through mathematical analysis, provides traffic system performance such as congestion, travel times, unit delay, level of service, a mobility index and spare capacity.

It is useful because it can generate charts and reports summarising traffic conditions which assist in locating congestion areas and in developing solutions. It has the facility to replay the historical data at faster speed than real time (up to 1 second per 15 min. real-time).

Traffic route performance outputs also include (a) daily contour plots of congestion along the route and (b) 24-hour level of service of the approaches for all links along the traffic route. This would enable traffic operators to identify recurrent congestion as well non-recurrent traffic congestion. A simplified version of the overall architecture of ARTIS is presented in **Figure 2** overleaf.

Travel Time Estimation

There are several models that have been proposed for estimating travel times from surveillance data. One of these methods estimates the average speed from the detector volume and occupancy data ignoring the delay at the intersection (Skabardonis 2004)[8]. Due to the issues arising from SCATS loop information in congested conditions, the methodology used by ARTIS to estimate travel time also includes the component of intersection delay that alters with the degree of congestion[9] (DC).

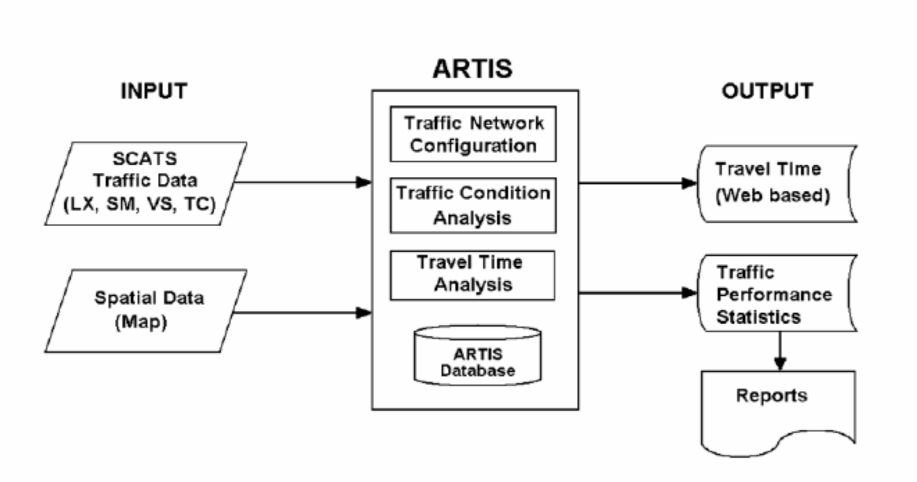

Figure 2 – Simplified View of ARTIS SYSTEM Architecture

Traffic routes consist of a number of links between two consecutive detector loops. Travel time along link (i) is estimated as the sum of the cruising time and stopping or delay time (time waiting for green between signals).

Link travel time = Cruise time + Stopping/Delay time

= $x_i/v_i + s_{i+1}$

Where

x_i is the distance of link i

v_i is the average traffic speed, estimated from SCATS data at signal i

s_{i+1} stop time at the downstream signal (i+1)

Skabardonis (2004) proposed the use of a model based on kinetic wave theory to calculate delay at the traffic signal. In this paper, an empirical method was used to estimate delay, as delay is considered to be a function of signal cycle, phase splits, red time and congestion.

Traffic surveys were carried out to establish this relationship with ARTIS's DC approach. **Figure 3** describes the relationship found between the DC and delay.

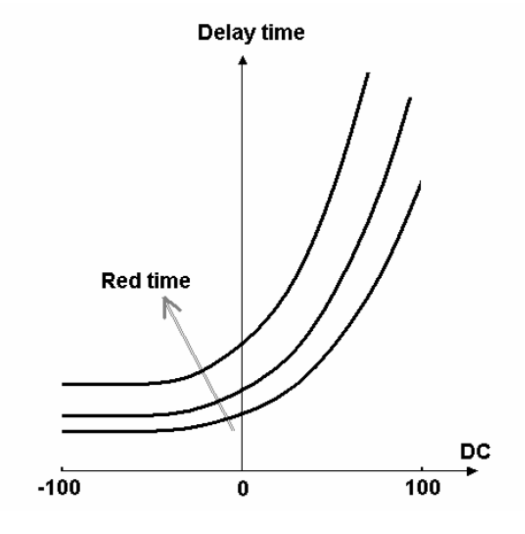

Figure 3 – traffic delay time at SCATS controlled signals

Cruising time is simply the time it takes to propagate across the link *i.e.* from one detector site to the next. Cruising time is calculated from estimated traffic speed crossing the detector loop.

Traffic speed is a function of DC, traffic volume, speed at saturated flow (V_{sat}), and intersection geometrical data i.e. lane geometry and distance to downstream signal. Traffic speed at saturated flow (V_{sat}) can be derived from SCATS data. Knowing the speed on the link and the distance between known points, the cruising time can be calculated. **Figure 4** depicts ARTIS methodology for estimation of link travel times.

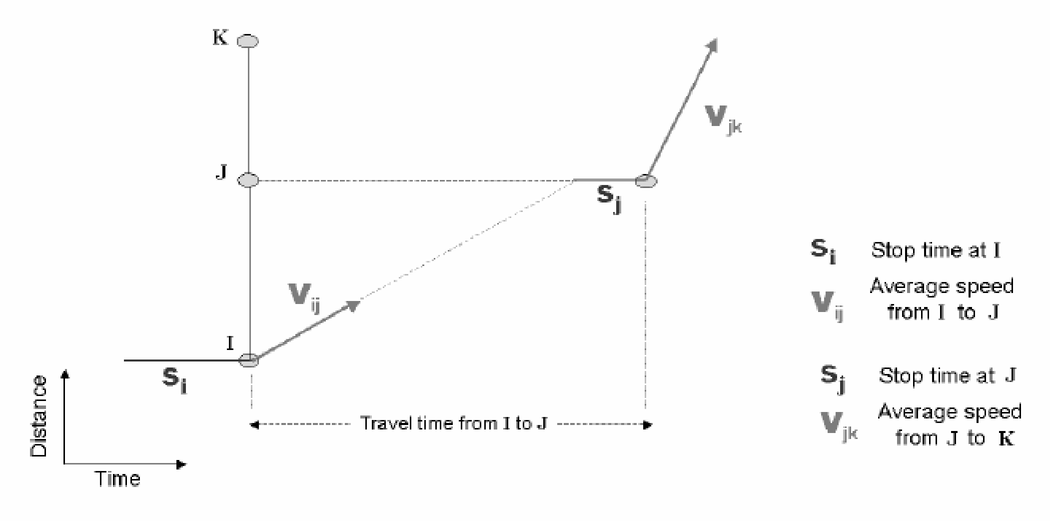

Figure 4 – Estimation of travel times between 2 consecutive SCATS signals

The journey time along the route is then calculated by summing estimates of individual link travel times.

$$\text{Journey time} = \sum(x_i / v_i + s_{i+1})$$

To estimate journey time along arterial route requires the addition of travel times between consecutive SCATS signals. As SCATS data is available at the end of each signal cycle and the intersections along the route are expected to operate at different cycle lengths, all parameters are derived statistically using data collected from the previous 15 minutes.

Validation of the ARTIS system

In March 2005, VicRoads used ARTIS to estimate travel times on two arterial roads under SCATS control in Melbourne. One was the Princess Highway between Windsor and Dandenong; and the other was Springvale Road between Cheltenham Road and Mitcham Road. Both routes were three to four lane highways.

The Princes Hwy route, a 30km section of the road between South Melbourne and Dandenong, had 46 signals of which only 32 signals had data available for analysis. The Springvale Road was 22 km long. Only 17 signals out of a total of 41 intersections had SCATS data available for analysis.

The study involved off-line analysis of real-time data to determine traffic conditions (congestion and travel time). Estimated travel times were then compared with those obtained from floating vehicle surveys on 16 March 2005, a typical weekday. Similarly, travel times for Springvale Road (north-and southbound) were collected of 17 March 2005. In addition to the above, travel times along a shorter section of the Princes Hwy (12.8 km) were measured using the automatic number plate recognition (ANPR) technique.

All travel times for the two routes as well as for the individual links were included in the comparison of estimated times against the measured values as shown in **Figure 8.** It can be seen that there is a good match between the two sets of data.

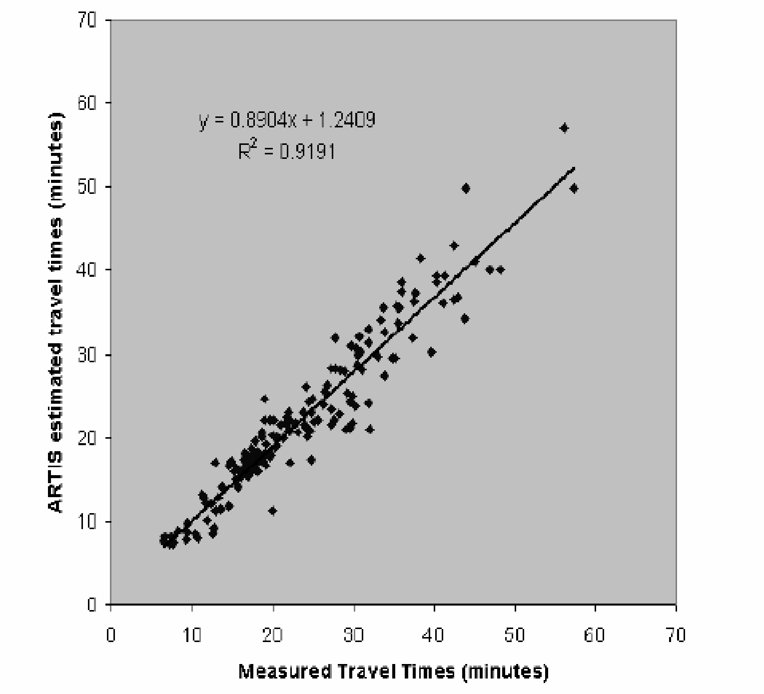

Figure 8 – Comparison of ARTIS and measured travel times

Case Study of using ARTIS – New Zealand

ARTIS has been used with the Auckland SCATS system to test the monitoring of particular arterial and motorway segments; **Figures 9 and 10** below show some of the output from the real-time analysis.

Figure 9 – ARTIS Congestion Plot

Figure 10 – ARTIS Travel Speed Plot

Through ARTIS it is possible to use the following process to monitor performance of arterial corridors, making use of data fusion with floating vehicle / vehicle tracking surveys. ARTIS will also provide pedestrian delay information and the data can be integrated with data from Public Transport real-time information to provide multi-modal performance reporting.

In **Figure 11** below, an indicative process is outlined for using ARTIS as part of corridor performance measurement.

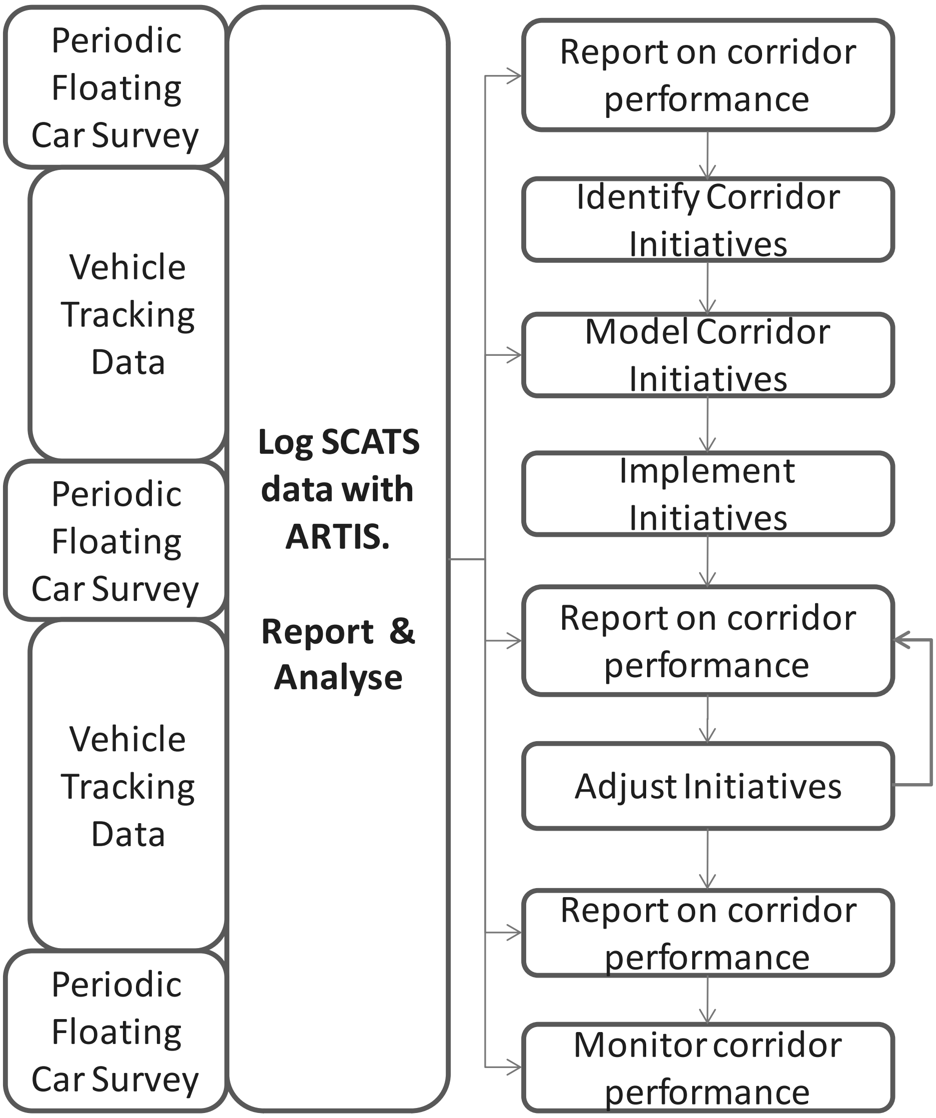

Figure 11 – Proposed Process for Corridor Performance Improvement / Measurement

The fusion ARTIS provides with other vehicle tracking data will mean that the current methods that currently rely on micro-simulation or other modelling to test corridor improvement initiatives will become more effective as the operational benefits from initiatives can be measured / benchmarked / trended on an ongoing basis without the need to re-open up models, or constantly collect floating vehicle data.

The presentation that accompanies this paper at the November 2008 IPENZ Transportation Group conference will include a demonstration of how the tool was used to examine the performance of an arterial before and after optimisation activities. An Appendix to this paper will be made available to attendees with the details of the case study.

CONCLUSIONS

With the continuing development of ITS implementation in New Zealand, there is a need to look to the concept of data fusion, particularly in the areas of the road network that are not well covered by fixed ITS sensors.

Floating vehicles surveys will remain valuable and part of best-practice into the future, increasingly being complemented by fleet GPS, and other vehicle tracking technologies.

ITS data fusion provides the ability to make use of 24/7 data sources, combined with vehicle tracking / floating vehicle surveys to provide a comprehensive picture of traffic operations contributing to performance measurement and monitoring.

Emerging performance management concepts will require the data on the operation of arterial roads where there is currently little reporting. Considering the use of ITS data fusion on arterials and other local roads, the ARTIS software add-on that works with SCATS will allow further benefits to be released from the SCATS sensor infrastructure and provide a framework for reporting on arterial performance.

For signal optimisation initiatives on arterials, ARTIS can supplement the current approach to the point where optimisation initiatives will become less reliant on modelling, and provide the ability to monitor and adjust optimisation and report on real-time or longer term performance trends.

As the updated New Zealand Transport Strategy brings the framework of monitoring and reporting network performance to the forefront, ITS data fusion is a key concept that must be embraced by New Zealand's transportation professionals.

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