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**Detailed Speed and Travel Time Surveys  
using Low Cost GPS Equipment**

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# Detailed Speed and Travel Time Surveys Using Low-Cost GPS Equipment

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## Abstract

*The requirement for detailed and accurate travel time, vehicle speed and delay data is growing rapidly as analysis techniques and requirements change. Traditional methods of survey are time consuming, labour intensive and inflexible due to their tight constraints. The use of GPS equipment for automated data collection has reduced the cost of travel time surveys significantly and increased the volume of data able to be collected. While the data obtained from readily available Global Positioning System (GPS) log files appear to be precise and lends themselves to further computer analysis, in many cases they are too inaccurate to yield valid results.*

*This paper presents methods of using low cost, handheld GPS units to obtain accurate near-instantaneous speed data at short intervals. This data allows valid calculations of speed, delay, and acceleration without the need for costly instrumentation and constant recalibration. The accuracy of the data is also independent of the skill and experience of the survey personnel.*

*The availability of robust acceleration data allows more meaningful evaluation of congestion levels, fuel use, noise production and pollutant emissions than has previously been possible.*

## Introduction

There are a large number of situations where vehicle speed and travel time information is either essential or extremely useful. Typical uses of such information include:

- Traffic model calibration
- Traffic signal optimisation
- Congestion Monitoring
- Capacity evaluations
- Advisory speeds
- Geometry evaluations
- Acceleration lanes / Passing lanes

Travel time surveys are carried out as a matter of course when looking to calibrate traffic models. The requirement to do so is increasing, as is the requirement for greater precision in the collection of travel time data. This is happening as calibration and validation requirements are formalised and more sophisticated and sensitive travel time calculations are attempted in models.

Most travel time study techniques involve using probe vehicles. The only real difference between the individual methods are in the recording, processing and presentation of data. The traditional method uses manual recording of times, and is useful only for collection of travel times over relatively long journeys.

We have recently seen a number of applications using Global Positioning System (GPS) logs to provide information on travel times. While such applications are useful for travel time surveys, they have severe limitations, especially when attempting to use them to derive detailed information.

These limitations can be simply overcome by exploiting the full range of data available from even the simplest and most inexpensive GPS units. This paper describes a methodology which does this and which has been in use by the author since 1999. The techniques described have been used by the author in a number of studies in Waimakariri District, Hurunui District, Whangarei District, Selwyn District, Christchurch City, and Ashburton District.

## **Manual Recording**

Traditional methods of travel time observation and recording have relied on the recording of times passing pre-determined points along the survey route. In general, the surveys have been relatively cumbersome and inconclusive. In order to gain useful and consistent information, the surveys have been necessarily tightly constrained. There are a number of issues in this approach.

- Low repeatability in terms of defining points where recordings are made.
- Relative imprecision precludes detailed evaluation.
- High manpower requirements.
- Requirement for rigid specification means that changing conditions are not well managed. Any unusual conditions or incidents which may occur during the course of the survey often require rejection of that entire run. In many cases it is the “unusual” conditions, and their effect on the transport network, which are of most interest to the analyst.
- Potential for errors in the recording and data input processes. The use of electronic recording has lessened this problem, but does nothing to reduce the other problems inherent in this method.

## **Instrumented Vehicles**

The use of instrumented vehicles has had limited use in NZ, mainly because of the requirement for costly installation and calibration of equipment. Nowadays, distance measuring instruments can be used to automatically record distance, time and speed. However, these units have several disadvantages, including a need for frequent calibrations and verification of factors which have nothing to do with the units themselves (e.g. tyre pressure) and difficulty in using the resulting data in a Geographic Information System (GIS) environment. (Quiroga and Bullock, 1998).

## **Use of GPS Logs**

Recent work has used GPS receivers to collect the data for travel time surveys. Most of the work has involved the use of GPS receivers to provide data on vehicle positions and time. The data collected have then been processed to yield travel time and mean journey speeds. (Kane (2004), Laird (2004), Smith (2003))

The use of GPS receivers to collect position data for later analysis results in surveys which are cheaper than using traditional methods, but only in the data collection phase. If detailed information is sought, there is considerable effort and expense involved in the processing of the

log files, and in the partial compensation for the shortcomings of the data collection. Such shortcomings include:

- Inaccuracy. Although the simplest of handheld receivers report positions to a resolution of approximately 2 metres, most modern low-cost GPS receivers have a stated accuracy to within 15 metres when used in a single-reading mode i.e. each positional point uses a single set of satellite data. This implies a precision in instantaneous speeds calculated from this data of +/-54km/hr if a 2 second sampling interval is used. In reality, accuracy is generally better than this, and has been assessed for speed calculations as +/-14km/hr (Smith,2003).
- Complexity. The inaccuracies outlined above mean that for any real useful purpose, complex rules must be imposed when analysing the data in order to try to reflect the physical situation. An example of such rules is contained in Smith(2003):

*If the speed in the current interval is zero, and the speed in the next interval is less than 14kph, or the speed in this interval is less than 14kph, and the speed in the next interval is zero, then the bus was deemed to have stopped.*

Furthermore, the evaluation must use calculated acceleration values in the analysis of delays. The data are simply not up to the task of providing sensible acceleration values and in fact are incapable of reliably distinguishing between hard acceleration and heavy braking.

## **GPS Receivers and Data**

Modern hand-held GPS receivers are capable of receiving signals from a large number of satellites simultaneously (typically 12 for low-cost receivers), and at short intervals, typically 1 or 2 seconds. Stated accuracy for commercially available receivers is +/-15 metres without differential correction. Survey grade receivers sample at a much higher rate, often 20Hz, and derive their greater accuracy by averaging a large number of positional readings. State of the art equipment can now yield sub-centimetre accuracy if left in a single position for long enough. This advantage is largely negated by using the units in a moving vehicle, and thus survey grade receivers have little advantage over hand-held units for collecting data in moving vehicles.

Modern GPS equipment also has the ability to save a log of the position and time readings, which is available for later download and processing. These logs are, however, of limited use as they still have the inherent failings of the earlier work, and are arguably less accurate than manual methods in certain applications.

GPS receivers also process, and often display, velocity data. These data are inherently more accurate than that obtained by post-processing of position data, because they do not contain the accuracy degradations of the latter. Velocity is obtained by calculating the Doppler-Shift in the satellite signal carrier waves (which are detected separately from the data stream), and accuracy of the magnitude component is stated to be of the order of 0.1kt, or 0.19km/hr. In fact, the work of Clark (1998) suggests that the system error in speed is rarely more than 0.1km/hr. Nothing in the work we have done leads us to dispute this claim. (In fact, we have no simple way of measuring to this accuracy using other methods, and can only therefore verify the mathematics). This compares very favourably to the +/-14km/hr possible for frequent sampling when using default GPS log files. (Smith, 2003).

Zito et al (1995), studied the usage of GPS for Intelligent Vehicle Highway Systems. Among their observations and conclusions drawn from the experimental programme were:

- GPS can provide useful real-time data on vehicle position and speed, provided that account is taken of the quality of signals received in judging the usefulness of the observed data.
- GPS direct speed measurement should always be used in preference to speeds calculated on the basis of vehicle positions over time.
- GPS, when integrated with GIS, is a valuable tool for travel time studies.

## **Direct GPS Speed Survey**

The method described in this paper collects speed information directly from the GPS receiver. The survey simply consists of driving a vehicle containing a GPS receiver which is connected to an external logging device. There is no requirement for pre-determined routes, detailed surveys or measurements of route characteristics, outside of the immediate investigation. A rich set of data already exists, particularly in urban areas, and can simply be accessed for any evaluations required.

## **Data Recording**

Recording is carried out by direct interrogation of the GPS unit. Logs are recorded on either a laptop computer, or by a dedicated datalogger. Either method is suitable, and each has particular advantages and disadvantages. The particular advantages of using a dedicated datalogger include:

- Inexpensive. Currently priced from around \$400.00
- Small and light – can be used by cyclists or pedestrians
- Long battery life
- High capacity – up to 4 weeks continuous recording at 1 second intervals.

Disadvantages of using a datalogger, rather than a notebook computer include:

- Data must be downloaded at regular intervals to allow processing.
- Quality of data cannot be assessed before processing on a separate computer.
- It is usual to record only a subset of the full data available from the GPS receiver.
- A smaller range of GPS receivers is available.

## **Data Processing**

Surveys carried out using GPS equipment produce a large amount of data, particularly if the sampling period is short. A typical survey, recording at 2 second intervals, will produce about 1Mb of data per recording hour.

Specialised software has been developed to extract the relevant data from the GPS output. As part of this process, the important step of rejecting data which have been recorded, but is unreliable due to satellite signal problems, is carried out. Any required post-processing is also

performed. Typical examples of this are calculations of distance run, acceleration rates and intersection delays.

## **Presentation**

The data are further enhanced by the use of GIS software. This allows subsets of the data to be identified and separately analysed.

A particular strength of the method described is the ability to use GIS data which are held by most Road Controlling Authorities. Direct use of other spatial data such as construction drawings from CAD systems, aerial photographs, street maps, cadastral data etc. means that we can tap into a rich set of existing data in order to present and interpret the speed data.

## **Advantages**

Equipment costs are very low. It is possible to construct a self-contained recording system for as little as \$600 on today's prices.

Set-up cost for individual surveys is zero. There are minimal training requirements for operators, consisting of turning on and off machines.

The particular method described is much more accurate than other methods in use, particularly for derived values such as distance run, acceleration etc. This makes the data useful for a much wider range of uses than has previously been possible. This enhanced accuracy does not require any higher level of resource than any of the less accurate methods.

The quality of the recorded data is independent of the characteristics of the survey vehicle, and is not affected by the level of skill and experience of the survey personnel.

The utility of the recorded data is not degraded by the logging capabilities of the GPS receivers.

If the data are to be used in model calibration and validation, there is total independence from any current or future proposed modelling system. This means that the data collected can be analysed in a way which suits the particular modelling methods chosen. It is very rare that a methodology for modelling is finalised before the base year for model calibration is well past. The extreme sensitivity of modern models means that the requirement for relevant base data, which can be analysed in ways not envisaged when it was collected, is high.

An incredibly rich data set is obtained, which is independent from decisions on the end-use of the data. This means that the data can be "sliced-and-diced" in any way desired at any time after collection, without compromising the original data.

## **Disadvantages**

There are no major disadvantages in using the techniques described, but there are a number of factors which must be considered. These include:

- Reliance on electrical equipment. All of the components of the survey equipment require some sort of continuous power supply. This is not a significant problem as long as ample preparation is carried out.

- Loss of signal can, and does happen, albeit rarely. The richness of the data set collected means that information is still very useful for that portion that is collected reliably.
- Degradation of accuracy can occur due to less than optimal satellite configuration, urban canyons, tree cover etc. In reality, this has proved to be less of a problem than originally envisaged. Embedded in the GPS data collected is an indicator of the reliability of the GPS signals, allowing potentially degraded data to be rejected before it dilutes the survey results. This is an important attribute of the GPS data, as outlined in Zito et al (1995)

## **Limitations**

There are some limitations with the method, principally concerned with the availability of reliable signals from a sufficient number of satellites. Signal loss will occur in:

- Buildings. At present the signal is not available inside buildings. This problem is also a major hurdle with fleet tracking systems, as the GPS signal is not received in parking buildings, warehouses, many loading docks etc.
- Urban Canyons. High buildings close to the street can present problems with multi-path signals. Essentially this occurs when the satellite signal bounces off walls etc, thus creating a longer path to the GPS receiver. As we are dealing with multiple satellites, generally the circle of confusion grows larger and thus accuracy degrades. This effect is compounded by the smaller arc of sky being “visible” to the GPS receiver, and therefore the likelihood that fewer satellites are providing a usable signal.
- Bridges and Tunnels. Overbridges can sometimes present a problem when we pass below them, by blocking the satellite signals. Usually, however, the GPS receiver only momentarily loses signal, if at all. The advantage of utilising the entire GPS dataset is that the data which are unreliable are identified and can be rejected. Tunnels present a greater problem. The GPS data collection must be supplemented by other means if the characteristics inside the tunnel are important to us.

## **Survey Example**

The following section of the paper describes an example of a speed and travel time survey carried out using the techniques described above. In this example, Christchurch City Council (CCC) wished to collect data on the speeds and travel times for cars travelling along selected bus routes in the city. Bus travel times were separately collected, and were not part of this survey. Figure 1 illustrates the routes surveyed. On each route, 10 runs were made with a probe vehicle in each direction in both the morning and evening peak periods. Surveying 10 routes meant a total of 400 survey runs were driven.

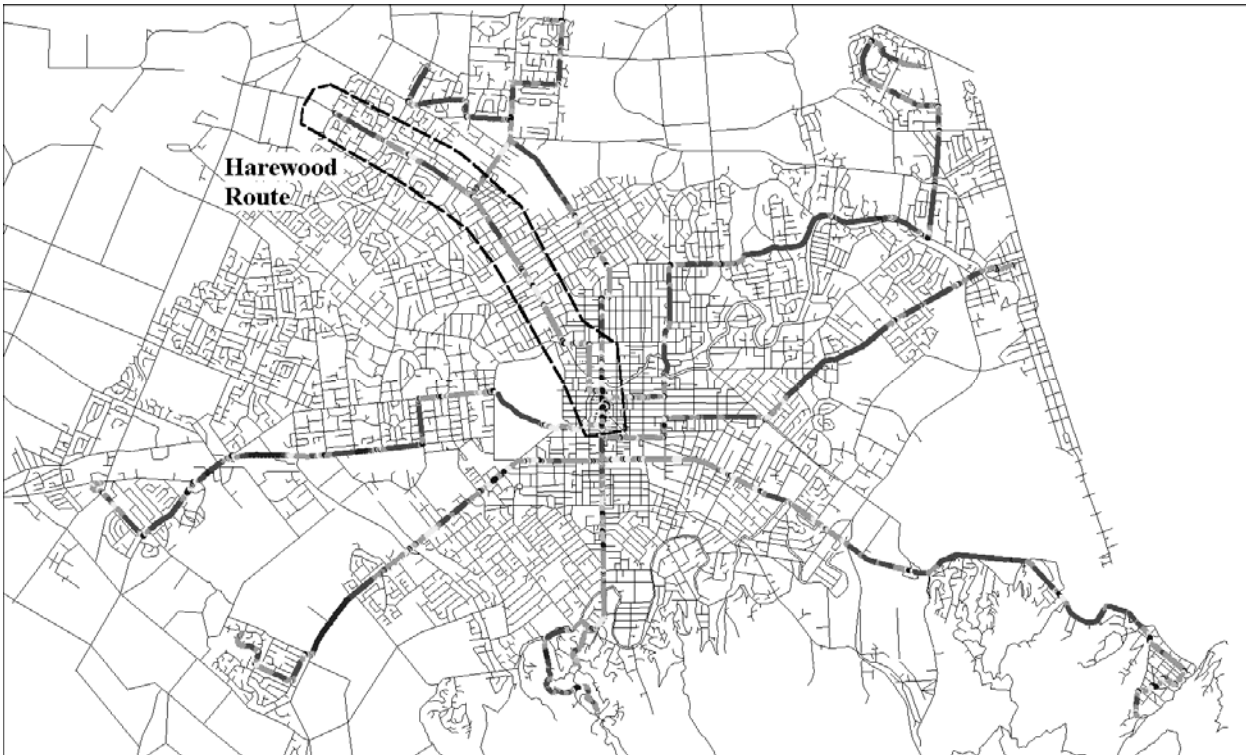


Figure 1 - Christchurch Bus Routes in GPS Speed Survey

The data presented in the remainder of the figures are for the Harewood route and concern travel into the Christchurch CBD in the morning peak period. Figure 2 outlines the variations in speed along the route for a single survey run. The different shades of grey on the plotted points indicate speeds in bands of generally 10km/hr. This figure is produced by a direct overlay of the GPS output data over a GIS street centreline file supplied by CCC. No spatial transformation of either set of data is required, in spite of the fact that the GPS data are in terms of latitude and longitude, and the CCC data are expressed as northings and eastings on the NZ National Grid.

The separate inset in the map shows the roads around the traffic signals at point B (Papanui) to a larger scale. In this, it is possible to see the individual recorded GPS points. Each of these points has its full set of GPS data linked to it, so it is possible, using the GIS software, to interrogate any single point or set of points. We see in the inset how the probe vehicle stopped in a queue of traffic upstream of the intersection and then accelerated away from the intersection, albeit rather slowly.

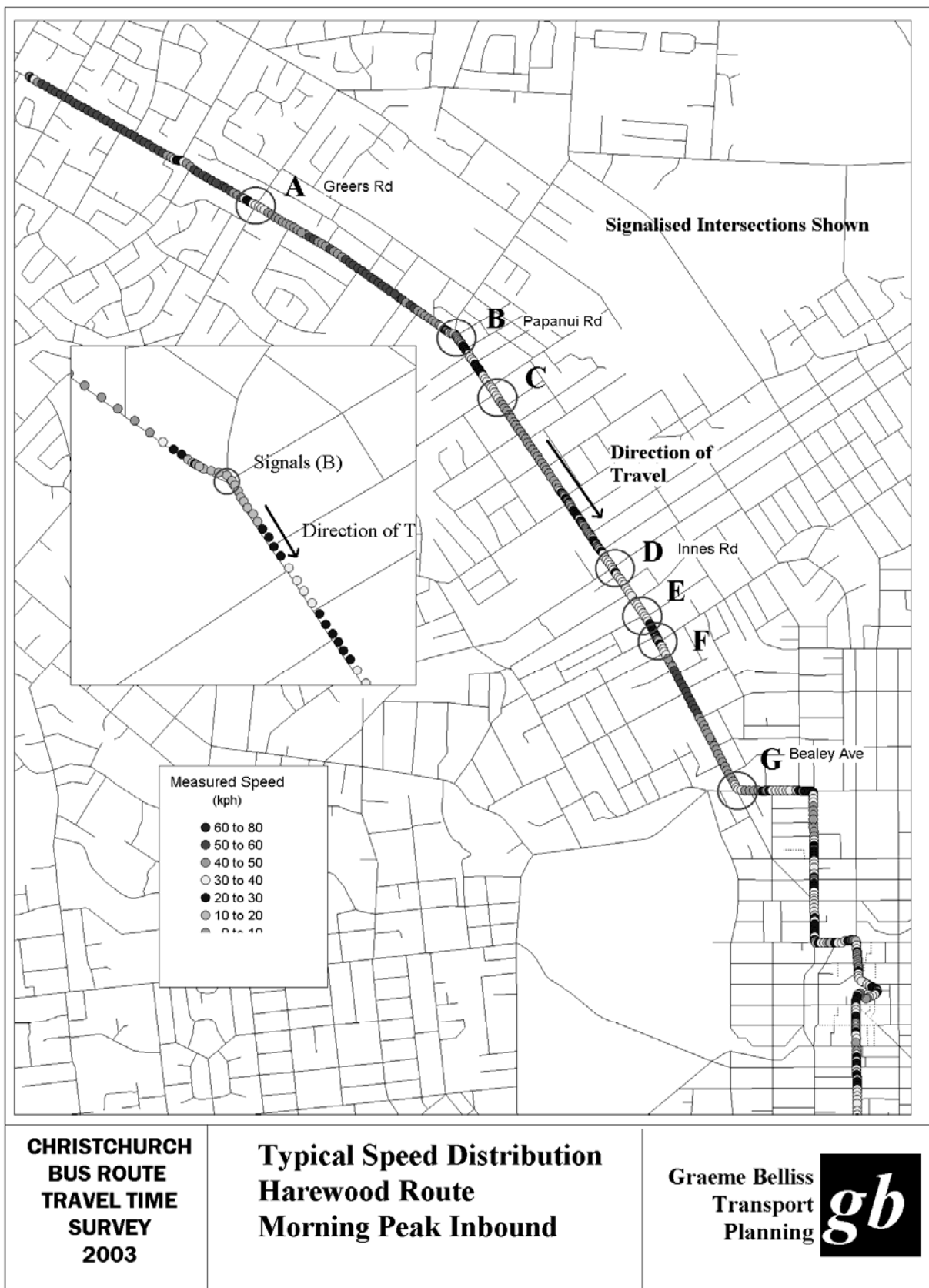


Figure 2 – Example of GIS Presentation of GPS Survey Data

## Speed Profiles

A useful presentation of the survey data is a plot of elapsed time vs travelled distance. Such a plot is contained in Figure 3. This immediately lets us see a number of attributes of travel on the survey route. Firstly we can gain an instant appreciation of the variability in travel times along the route, at the same time being able to see which sections of the route are contributing to the variations in travel time.

Secondly, we see from the plot where vehicles stop, i.e. where the plotted lines are vertical. The stop-start nature of the traffic flow is evident in some sections of the route. Also indicated in Figure 3 is the timetabled bus travel time along the same route, based on the bus service timing points for the route. We can see from this that the car travel times along this route are approximately 60% to 70% of the bus travel time, assuming the bus runs to schedule.

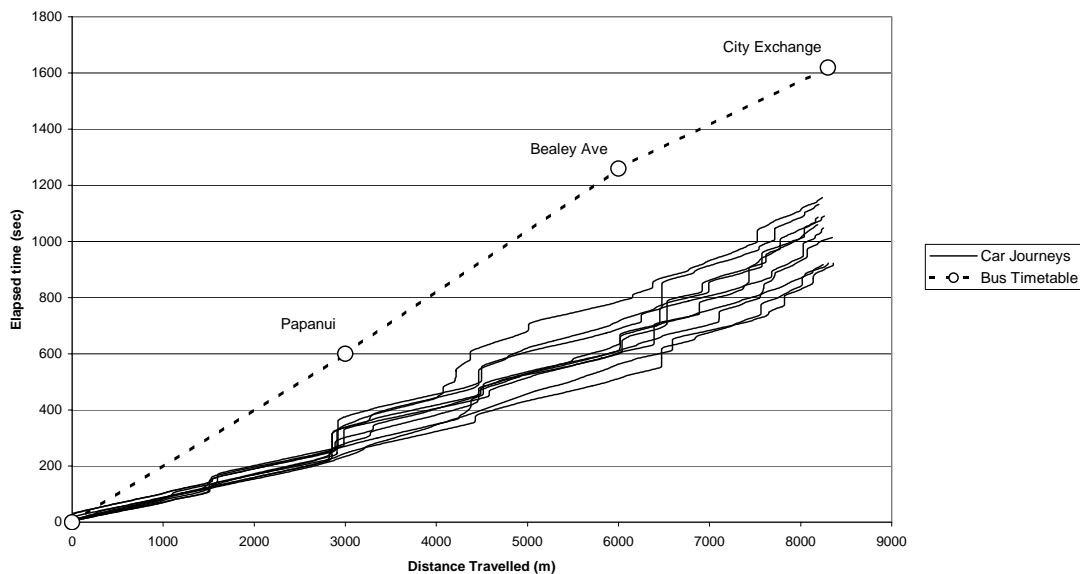


Figure 3 – Time-Distance Plot for All Runs on Single Route

An alternative way of presenting the same set of data is to plot a profile of travel speed along the route. This plot, for the same data presented in Figure 3, is shown below in Figure 4. Once again, this plot shows quite clearly the sections of the route which experience wide variations in travel speed. This variation is not only between subsequent runs in the survey, but within individual survey runs where the speed is increasing and decreasing rapidly over short sections of road. This is particularly evident immediately upstream of Innes Rd and in the entire section of the route downstream of Bealey Ave.

Figure 5 contains the measured speeds plotted against the elapsed time for a single survey of the route. It can clearly be seen when the speed has reduced to zero, and for how long the probe vehicle has been stopped at intersections. Of particular interest is the section between Papanui Rd and Innes Rd, where the vehicle comes to a standstill a number of times within the queue forming at the Innes Rd signals.

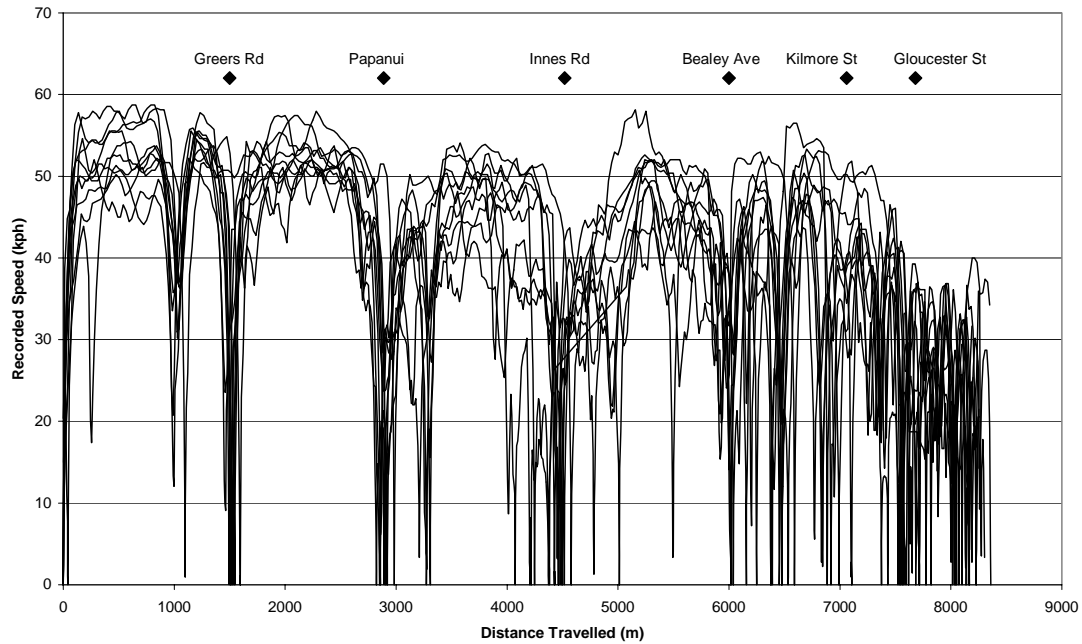


Figure 4 – Speed-Distance Profiles for All Runs on Single Route

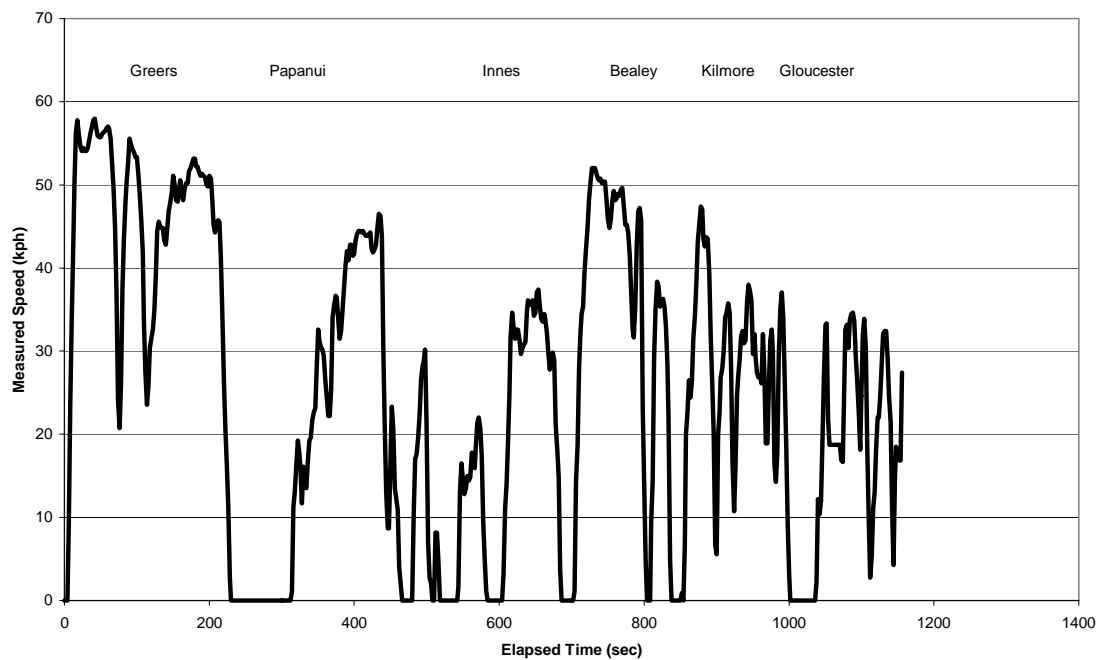


Figure 5 – Speed-Time Profile for Single Survey Run

### **Acceleration and Acceleration Noise**

It is feasible, using the methods described in this paper, to collect data which will enable acceleration values to be calculated with some accuracy. For an update interval of 1 second, mean acceleration values can be confidently calculated to within  $0.1\text{m/s}^2$ , making the process useful for a myriad of uses.

The use of short-term acceleration values is the only valid way to predict traffic noise, fuel use, or pollutant emissions. Difficulties in reliably measuring acceleration characteristics, and

referencing these spatially, has been a major barrier to more effective prediction of the adverse effects of congestion. As we have seen earlier in this paper, the use of positional GPS logs cannot provide reliable data in this area. The method described in this paper, however, can provide reliable acceleration data and allows much more credible modelling and prediction of fuel use, emissions and traffic noise than those currently in use in New Zealand.

A useful measure of the variability of traffic speeds and the “lumpiness” of flow is acceleration noise. Acceleration noise can be seen as a direct measurement of the level of congestion. Of course it is not the only measurement, with levels of delay, stopped time, average speed etc all having their place. All of these measures may be derived from the data collected in surveys described in this paper.

Acceleration Noise is a measure of smoothness of flow, and is the standard deviation of the acceleration distribution. In the past this has been difficult to measure as it requires measurement of short-term accelerations, which has required complex instrumentation within a vehicle. Such instrumentation is costly, requires constant recalibration, and is influenced by such things as tyre pressure, road surface variations, suspension response etc.

Much work has been carried out to relate acceleration noise to measures of the **effects** of congestion such as fuel use and pollutant emissions.

Figure 6 below contains a plot of acceleration vs time for a single survey run on the Harewood route. The data are that presented in Figures 2 and 5 above. From this plot it is evident that the acceleration and deceleration pattern is quite different for different sections of the route. These differences are clearly indicated in the values of acceleration noise, printed across the top of the graph for the various route sections. These values range from  $0.32\text{m/s}^2$ , in the section between Greers Rd and Papanui Rd, to  $0.85\text{m/s}^2$  between Bealey Ave and Kilmore St. The inconsistency in speed and stop-start nature of the traffic flow in these areas can be clearly seen in all of the figures.

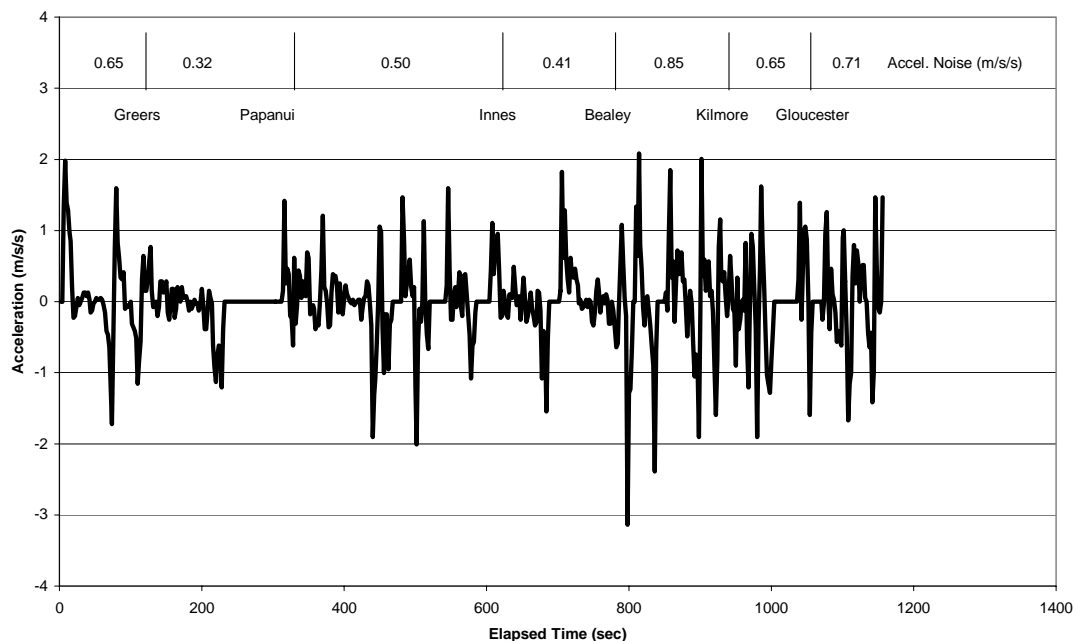


Figure 6 – Acceleration Rates and Acceleration Noise Calculated from GPS Speed Data

## Conclusions

The use of GPS receivers for travel time and speed surveys allows more accurate and reliable data to be collected at a lower cost than other methods currently in use. The combination of GPS derived data and GIS software for analysis, visualisation and presentation makes it possible to gain information which was previously unobtainable.

The use of GPS data for speed surveys requires that the speed data available through the GPS receiver are directly recorded, rather than calculated by using position data. The latter method is simply too inaccurate to use for anything other than deriving travel times and hence mean speeds over relatively long journeys.

The accuracy of GPS speed data makes it viable and economic to calculate acceleration characteristics of traffic streams. This allows a much more rigorous treatment of such issues as noise production, pollutant emissions, fuel use etc., and makes it possible to properly monitor congestion and to predict the effects of such congestion with some confidence.

The data derived from GPS survey methods are not constrained by the use to which they will be put in the short term. This is evident in the example presented in this paper, where data collected to determine overall travel time differences between buses and cars on the same routes, can later be used to examine the speed characteristics at individual traffic signals in some detail. This is a specific use which was not envisaged at the time of undertaking the survey, but the data are capable of such use, or indeed any other use, at any time.

There are limitations in the techniques where the GPS signals are affected by buildings, vegetation, tunnels etc, and critical data in such areas must be verified or collected by other means. This is, however, a predictable situation which can be planned for.

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