IPENZ Technical Conference 2003

JOURNEY TIME ANALYSIS FROM GPS BASED TRACKING SYSTEMS

Author:

MG Smith BE(Civil), CEng, MICE, MIPENZ

Director of:

GABITES PORTER

JOURNEY TIME ANALYSIS FROM GPS BASED TRACKING SYSTEMS

MG Smith BE(Civil), CEng, MICE, MIPENZ

Abstract

The time that vehicles take to travel along a road is an important component of transport modelling. Matching modelled and measured journey times provides one of the validation checks that a network is behaving correctly. At a more detailed level, journey times can provide checks on the delays at intersections.

Traditionally, travel times have been derived from moving car surveys, with an observer noting times at various points along a predefined journey, as well as estimating delays at the approaches to intersections.

The advent of Global Positioning Systems(GPS) and their more accurate location has provided an alternative methodology by which to measure journey times. Coupled with Geographic Information System (GIS) based network models, a GPS reader in a car replacing the observer provides a powerful tool for accurate, easy and cost effective data collection.

Bus travel times are equally important. Most planning software suites use the speeds and delays from a loaded private vehicle network to estimate bus travel times, with allowance for the additional time taken to pick up and set down passengers, a factor generally in the order of 25-30% of the car travel times. Again, the traditional methodology involves manual survey by observers riding the buses, noting times along the route and timing points to calculate the time taken to pick up and set down passengers.

Real time tracking of buses using on-board GPS systems is becoming more common in urban areas as bus operators, and planners place importance on the need for passengers to be given constantly up-dated information on the position of buses in the network, and the time that they will need to wait for the next bus. Systems such as those in San Francisco, and Portland are recent, but well developed examples.

Two recent New Zealand surveys have used GPS technology to collect journey time data. A relatively simple exercise to determine car travel times has been carried out in Hawke's Bay as part of the Hawke's Bay Regional Traffic Study.

In Christchurch, the buses have recently been equipped with GPS devices, and on all routes are sampled twice a minute to about 10 metres accuracy. The position of the bus stops is also known. From this data, the time spent moving, time stopped at intersections, and the deceleration time spent at the bus stop, and acceleration time back into the traffic stream can be separately identified.

The paper describes briefly the data collection techniques in the two surveys, the way in which the surveys have been analysed, and the ongoing utility of, in particular, the Real Time Tracking data.

1. Introduction

Transportation modelling relies on an accurate representation of the network, particularly in terms of travel times and intersection delays. When modelling public transport, although the network times and delays are known from the vehicle assignment, allowance has to be made for the time taken to pick up and set down passengers. In addition, the deceleration and acceleration times, and the time taken to re-enter the traffic stream if the roads are congested have to be included.

Generally, in the past, this data has been collected manually. Road travel times (journey times) are collected using the moving car technique, with travel time and intersection delays recorded separately by an observer sitting in the vehicle.

Public transport (bus) times are generally recorded by observers riding the buses.

Both methods are expensive and time consuming, and the quality of the data is often suspect as the number of observations necessary for statistical significance are not often taken.

This paper is essentially in two parts. The first part looks at data collected to help with the verification of the transport model being built for the Hawke's Bay Traffic Study. It was a relatively simple journey time survey using a GPS device to record positions every three seconds along a number of predetermined journeys. This then provided the measured values against which modelled link speeds and intersection delays could be compared.

The second part looks at the data that is routinely collected as part of the Christchurch Bus Real Time Tracking System. It was originally accessed to establish the relationship that exists between car and bus travel times for use in the multi modal model built for Wollongong in New South Wales. However, during that analysis, the value of the system as a rich source of data for a wide range of transport planning uses became apparent, and some of these uses are explored toward the end of the paper.

2. The Hawke's Bay Travel Time Survey

2.1 Introduction

One of the primary uses of a transportation model is to compare the network operation between one transport scenario and another. The travel time through the network and the corresponding vehicle operating costs forms the integral part of any economic assessment for benefit/cost analysis.

Accordingly, a model must realistically estimate travel times on the road network, and part of the validation process is to check that the modelled journey times over a series of routes matches that observed, taking into account both travel speed and delays at intersections. The resulting average speed over the journey is then compared to the modelled speed for the same journey.

2.2 The Hawke's Bay Transportation Model

The Hawke's Bay has had a transport model since the 1970's, originally developed by Roading Division of the then Ministry of Works. It has been updated at almost every census since then, and has incorporated the latest technology available at each update. The current study (the Hawke's Bay Regional Traffic Study) has brought the base model up to the 2001 census, and has revalidated against traffic counts, heavy vehicle movements, and journey time data.

2.3 Travel Time Surveys

As part of the data collection phase of the study extensive floating car travel time surveys were undertaken to establish vehicle speeds and delays on the road network. Journey times were required over five routes in each direction for each of the three time periods, giving a total of thirty[1] journeys for which mean times were to be measured. Depending on the variability of the network speeds, there were potentially hundreds of individual runs required. The decision was therefore taken to use a Global Positioning System (GPS) recorder in the moving car, meaning that the only labour charge was that of the driver.

The GPS recorded a position at precisely every 3 seconds and to an estimated accuracy of ± 10m. Analysis software was written to establish time (and therefore speeds) spent while the vehicle was moving, and the amount of time delayed at intersections, including deceleration and acceleration times. The quality of the data proved to be excellent, and considerably better than manual recording by an observer.

Initially, the GPS data was used to establish intersections by matching these against the network. (It should be appreciated that the Hawke's Bay model is GIS based, and the location of every intersection, and the curved roads between intersections has co-ordinates attached.) Automatic position location did not work because the 10m accuracy was not precise enough – particularly as the network has, for example, free left turns where the nodes are closer than 10m.

Accordingly, the routes were specified using the journey time editor in Tracks (the software platform used for this study), and the GPS data matched to the journey. There was a secondary benefit in this, as the routes in that format were needed for the model validation checks in any event.

In order to determine the minimum number of runs per route needed to obtain results in a targeted 95% confidence interval, two routes were analysed for changes in confidence interval after each survey run. It was shown that the confidence interval changed minimally between runs four and five and five runs were accordingly done on each of the thirty journeys, giving 150 runs in total.

The transport models are average weekday models, therefore the travel time surveys were undertaken on a Wednesday or Thursday.

[1] Thirty journeys comes from 5 routes x 2 directions x 3 time periods.

2.4 Analysis

The routes chosen for the analysis are shown on Figure 1.

The comparison of modelled against measured travel times are shown on Figure 2. This shows the 95% confidence interval for each of the 30 surveyed journeys, and the position of the modelled journey time as a mark within the range. It is beyond the scope of this paper to investigate the validation, but it can be seen that in all cases the modelled values fell within the interval, or were only marginally outside it. Results for the Evening Peak as an example are in Table 1 below.

TABLE 1

EVENING PEAK TRAVEL TIME VALIDATION

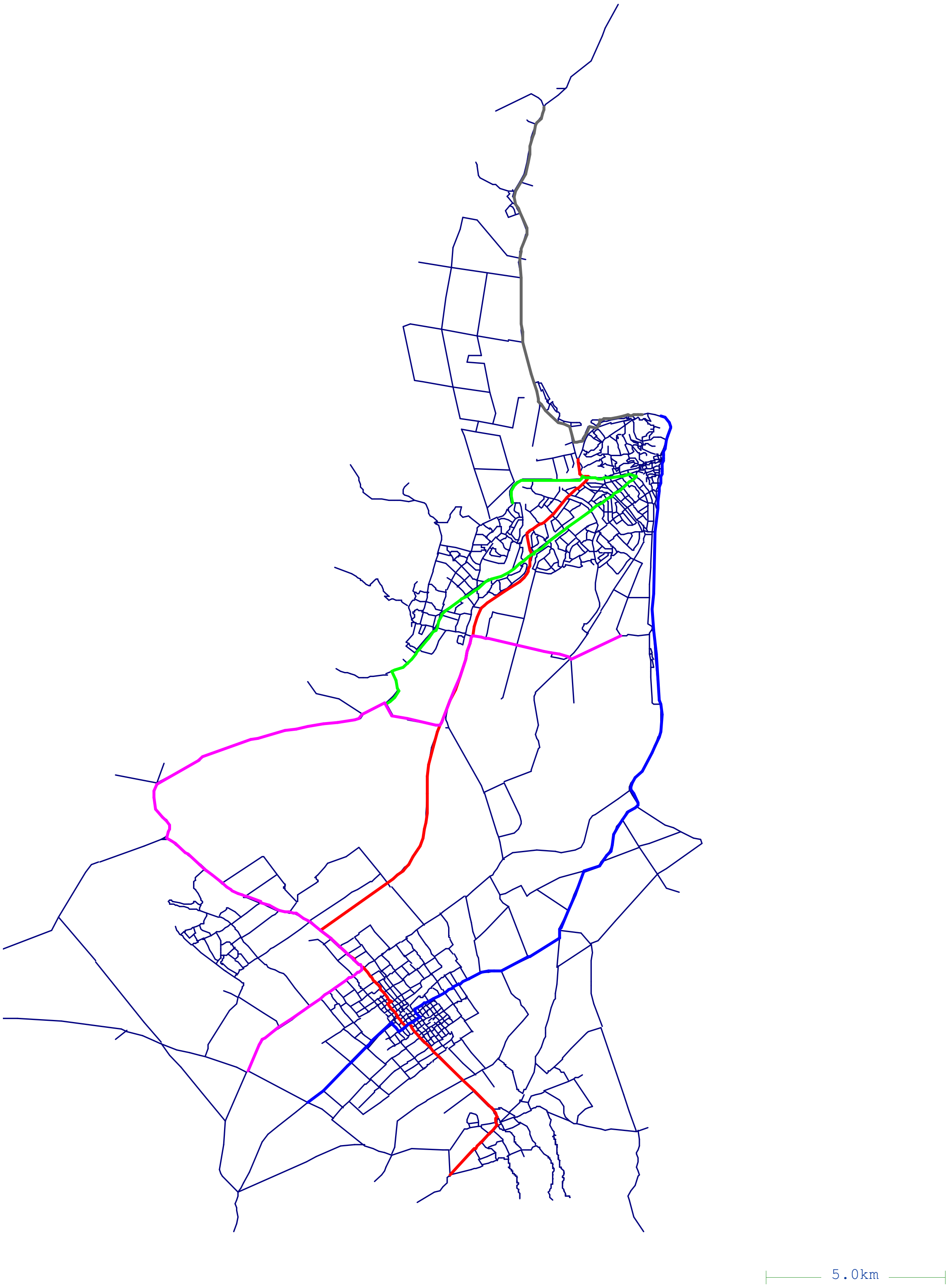
PM Peak	***Distance (km)***	***Mean (sec)***	***Min (sec)***	***Max (sec)***	***Model (sec)***
Route No 1A SH2/SH5 Intersection to the Port	13.82	820	798	842	*817*
Route No 1B Port to SH2/SH5 Intersection	13.41	843	778	908	*826*
Route No.2A Hyderabad Road to Havelock North	26.10	1980	1929	2031	*1914*
Route No.2B Havelock North to Hyderabad Road	27.15	1948	1837	2060	*2006*
Route No.3A The Port to Longlands	26.05	1621	1592	1651	*1659*
Route No.3B Longlands to The Port	26.24	1637	1590	1685	*1664*
Route No.4A Waiohiki Golf Course to Tamatea via City	13.69	1226	1165	1288	*1172*
Route No.4B Tamatea to Waiohiki Golf Course via City	13.42	1199	1188	1210	*1188*
Route No.5A Awatoto to Longlands	23.25	1306	1258	1353	*1290*
Route No.5B Longlands to Awatoto	22.89	1278	1211	1345	*1248*

Some interesting statistics from the exercise are:

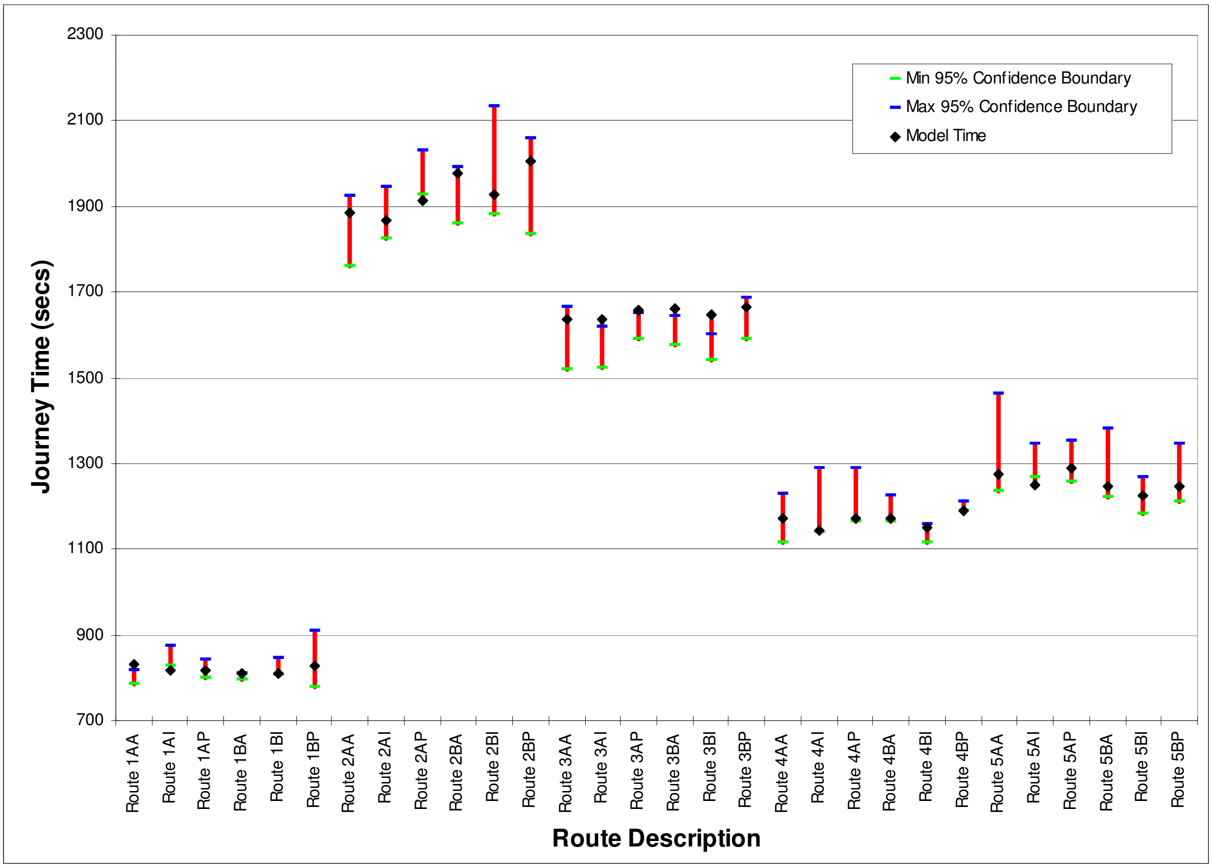
Total journey distance over all routes	206.0 km
Total distance travelled	6,180 km
Survey cost (data collection)	$2,500
Cost per journey ($2,500/30)	$83.30

2.5 Conclusion

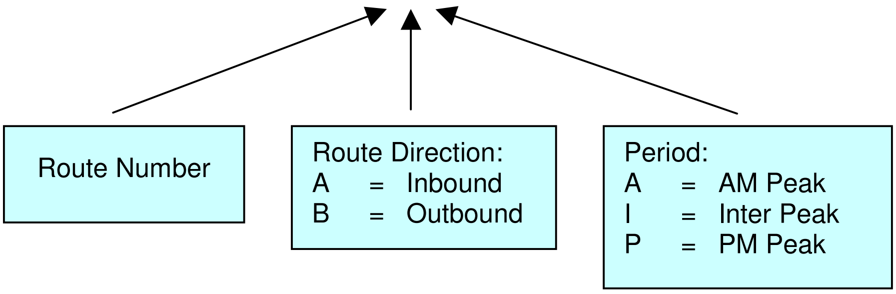
The methodology is an accurate, cost effective means of using GPS technology to record travel times and intersection delays.



IPENZ 2003	**Routes used for Journey Time Surveys**	Figure 1
Gabites Porter (NZ) Ltd		



Key : Route 1AA



IPENZ 2003	**ROUTE JOURNEY TIME CONFIDENCE INTERVAL PLOT**	Figure 2
Gabites Porter (NZ) Ltd		

3. The Christchurch Bus Real Time Tracking System

3.1 Introduction

Public transport in Christchurch is a bus system, currently run by two main operators using about 200 buses. The Canterbury Regional Council is responsible for planning, monitoring, and administering the system, which carries some 13 million passengers a year or about 40,000 passengers per day. There has been a conscious policy over the past few years of improving the rolling stock, and passenger information that has resulted in an 80% increase in passenger numbers since 1992, with a 10% increase in the year to June 2001, and a further 23% to June 2002.

3.2 The System

Part of the reason for the patronage increase has been the implementation of a real time tracking system which uses GPS and radio technology to track buses moving across the city network and calculates en route transit and arrival times. The first route to be commissioned was the airport to city service, and it experienced a 12% increase in patronage since the implementation of information displays in the airport terminal and en route.

The system works by sending the position of each bus by radio to a central computer, which analyses the data for operational, passenger information, and regulatory purposes. Some statistics are given in Table 2.

TABLE 2

THE CHRISTCHURCH REAL TIME PASSENGER INFORMATION SYSTEM

Conditions	*Numbers*
Buses tracked	215
Frequency of signal	Every 30 seconds
Hours of operation	14 hours per day, 7 days a week
Number of transactions per year	92 million

This number of transactions and the capacity of the radio system have dictated the frequency of signal polling, but it is adequate for the purpose for which it has been designed. Initially, the airport route (the first to be commissioned) was polled at 40 times per minute (once every 1.5 seconds), and originally this was to be the data that was to be used in the analysis. However, for system capacity reasons, the polling has been reset to 30 seconds on that route, and the historic data was only stored at 30 second intervals. Accordingly, mass data at high sampling rates is not currently available.

The data is stored on disc, and includes the following fields.

Date
Time (hh:mm:ss) with seconds to 3 decimal places
Company name
Bus number
Latitude
Longitude

The latitude and longitude were converted into X and Y co-ordinates to match the Geographic Information System (GIS) used by both the Canterbury Regional Council and the Christchurch City Council. It is also the system that the Christchurch Transportation Study (CTS) model is based on.

The readings from the GPS can provide erroneous data, in that the signals will often bounce off buildings and give false readings. About 99% of all readings fall within ± 20m of the GIS centreline and any data point that fell outside that was excluded from the analysis. No other checks were undertaken, or indeed were necessary, except that lay-over times at the termini were identified and excluded. Figure 3 shows a plot of the raw total data for one week in November 2002. There are aver a million points, and the main routes show up as solid lines. However, there are a number of spurious readings as can be seen on a journey to the east of Rangiora, and into the sea off Belfast. The data for the airport route only is shown on Figure 4 after outliers had been excluded – that is any point beyond 20m from the centreline.

The data needs a little explanation. The denser lines show the routes that have high frequencies, or where buses travel slowly while a dotted line may be only one bus, perhaps on a trip to join a route. On Figure 4, the bus journey from the depot to the Square can be seen on the right hand edge of the picture, as can a single journey over part of Fendalton Road, presumably when the bus was not in service.

3.3 Bus Stop Locations

Christchurch City Council keep a database of bus stops, and part of the data includes X and Y co-ordinates of the location of each stop. This data was used to determine when a bus was stopped at a bus stop, as opposed to an intersection. A sample picture of the Christchurch Bus Stops is shown on Figure 5.

3.4 The Transportation Model

The Christchurch transport model has its origins in the late 1960's, and has been in constant use since then. It has been kept current, and has been re-validated each time the 5 yearly census data became available. The model was converted to Tracks[2] in the early 1980's and, when the Councils formed their GIS systems, the road centrelines from the GIS were used to replace the custom digitised network used in the original model. Accordingly, there is complete consistency of mapping between the model, the bus stop locations, and the GPS data.

Data that can be extracted from the model include:

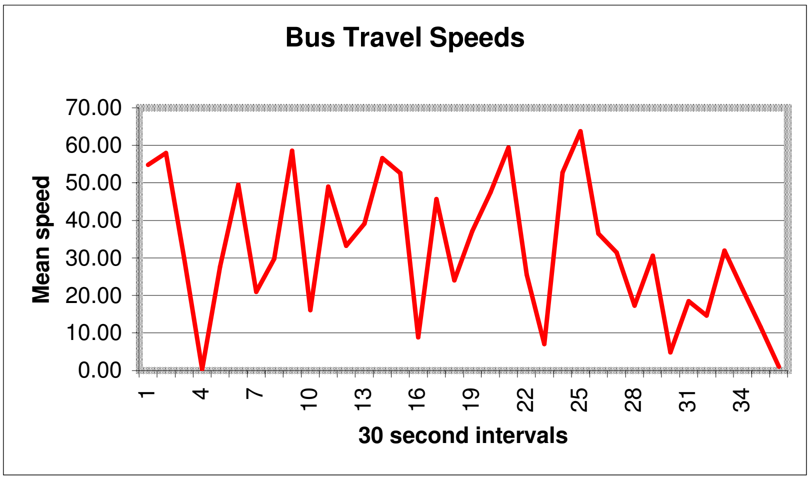
The location of each intersection
Traffic flow on each link, and turning movement
Link speed
Delay on each turning movement
Link Type

[2] *'Tracks – A landuse and transportation planning system.'* Transportation and Traffic Systems Ltd 2003 www.gabites.co.nz

3.5 Analysis

As noted earlier, the data was expected to be in intervals of 1.5 seconds. At 50 km/hr, a bus would travel 20m and at 5 km/hr – as it slows to a stop, or an intersection – it will travel 2m in the interval. Determining whether and where a bus had stopped would have been relatively straightforward at that dense sampling rate. Sampling at 30 second intervals means that the bus could move over 400m at 50 km/hr or 40m at 5km/hr in the interval. Accordingly some assumptions needed to be made.

Inspection of the data showed that the bus speeds followed a cyclic pattern, as shown in the diagram below. This sample data covers a period of about 20 minutes.



The first assumption is that the low point that occurs between each of the highs represents a period when the bus has been delayed. In the example shown, the first trough has a 30 second (or greater) period of stopped time, but other stops are less than 30 seconds, or are delays where the bus may not have stopped, but has slowed.

The second assumption is that the troughs represent the point where the bus was closest to the event causing the delay.

The third assumption was that if the trough was within 60m of a bus stop the delay was caused by the stop, otherwise it was caused by an intersection or congestion. Where a stop was within 60m of an intersection, the closest one was chosen.

Finally, the undelayed time was assumed to be based on the average speed of two adjacent peaks.

The results for the Airport service (11.2 km from Airport to the Square) are shown in Table 3 below.

TABLE 3 BUS TRAVEL TIMES				
	Travel Time Seconds	***Travel distance (m)***	***Time at bus stops (sec)***	***Congestion delay (sec)***
Am Peak	44,599	314,633	9,433	5,127
Inter Peak	164,204	1,080,462	42,349	25,493
Evening peak	46,358	306,871	8,529	5,394
Night time	18,037	147,878	2,797	1,385
All Day	273,197	1,849,843	63,108	37,400

A further assumption is that when the time at bus stops is removed, the bus will travel at the same speed as the rest of the traffic stream. The assumption is valid for single lane roads, but will understate vehicle speeds on two lane roads, and overstate them where there is a dedicated bus lane. Christchurch has few dedicated bus lanes.

The figures derived from the data are shown in Table 4 below.

TABLE 4 BUS AND CAR TRAVEL SPEEDS (KMS PER HOUR)					
	Bus Average Speed	***Vehicle Speed from GPS (excluding stops)***	***Modelled Vehicle Speed***	***Undelayed Speed***	***Stopping Factor***
Am Peak	25.4	32.2	31.2	37.7	1.27
Inter Peak	23.7	31.9	30.8	40.4	1.35
Evening peak	23.8	29.2	32.1	34.1	1.23
Night time	29.5	34.9	34.7	38.4	1.18
All Day	24.4	31.7	33.4	38.6	1.30

The first use of the data is the check that the model is matching the vehicle speeds from the GPS data once pick-up times are excluded. A journey time calculation following the same route as the bus was taken from the loaded network produced by the model. As can be seen from the table the match is extremely good, with only the evening peak about 10% higher than the GPS.

The second direct use of the data is to find the factor that needs to be applied to the assigned network times for use in the public transport assignment. This is shown as the stopping factor in Table 4.

4. Closer Sampling

4.1 Introduction

The 30-second interval is too long for accurate estimation, and also makes it impossible to separate intersection delays from link delays (although that may not be possible in any event) Accordingly, a separate exercise was set up to try and determine the optimum sampling rate.

In January 2003, the polling rate was set to two seconds for one bus at intervals during the day on the Papanui to Cashmere route. This is one of the oldest routes in the city dating back to the tramway system in the 19th century, and is still one of the best-patronised services in the City. A week's worth of data was collected from the 15th to the 22nd January.

The object of the exercise was to analyse the data to check the sampling rate at which accuracy was lost when results were compared against those obtained from 2 second sampling. A comparison was also made against the model, but this needs to be treated with some caution, as mid January is the period when a number of people are on holiday, as are schools, and traffic volumes and travel times are generally lower.

The polling rate was set to 2 seconds on one bus at a time, and this small interval data was interspersed among the normal GPS data at 30 seconds or more, over the whole of the city.

4.2 Analysis

The buses using the Papanui – Cashmere route were cut out from the main dataset to provide a manageable file. The full data for the week was 63 megabytes, while the subset was a little over 4.5 megabytes, containing more than 43,000 observations.

The data as expected was 'dirty'. Although it was set at 2 seconds, generally the interval varied between 0 and 3 seconds. Occasionally intervals of 18 to 20 seconds were recorded – generally as an isolated interval. The interval may well have been more constant than the data suggested, but it was supplied as integer seconds. This was accepted for the purposes of this research, but operational analyses should store the data to at least seconds to one decimal place. Using integer times, speeds can have an error of around 14kph. However, having said that, the GPS accuracy is supposed to be $\pm$ 10m, although the data showed it was significantly better than that.

Often, there was a time interval recorded, but no distance, while there were distances showing for the intervals on either side. While this could indicate that the vehicle had stopped, it is unlikely that it would rapidly decelerate, stop for 2 seconds and then rapidly accelerate – even if the bus had the capability of physically achieving it. In these instances, the interval was assumed to be travel at the average speed of the interval on either side, and a distance calculated accordingly.

The journeys were defined as beginning or ending at a terminus and/or where the poling at 2-second intervals began or ended. Initially, all intervals greater than 3 seconds were excluded, but this fragmented the journeys. Over 700 individual segments were created, significantly underestimating delays.

Accordingly, any interval of 20 seconds or less was accepted as valid for this exercise, reducing the number of segments to 135. The terminus to terminus distance is 15.2 km, and the average segment distance is 3.3 km.

The rules for accepting that the bus had stopped were as follows.

> *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 14 kph, and the speed in the next interval is zero, then the bus was deemed to have stopped.*

If the stopped position was within 20 metres of a bus stop, then it was assumed to have stopped to set down or pick up passengers.

These are more precise definitions than used for the 30 second analysis described earlier where minima were sought – i.e. the bus actually had to stop for at least two intervals. It also means that the congestion delay calculated from the 30-second analysis is different – here it includes only the delay at intersections. However the delay was calculated in the same way being the difference in time taken to travel from the beginning of deceleration to the end of acceleration compared with the time taken travelling at the average speed at the two points.

The results of the 2-second analysis are shown in Tables 5 and 6 below.

TABLE 5
BUS TRAVEL TIMES – 2 SECOND INTERVALS

	Travel Seconds	*Travel Distance (m)*	*Time at bus stops (sec)*	*Time at Intersections (sec)*
Am Peak	20,024	113,639	4,212	1,902
Inter Peak	49,438	259,603	9,484	7,943
Evening peak	13,811	77,265	2,413	2,034
Total	83,273	450,507	16,109	11,880

TABLE 6
BUS AND CAR TRAVEL SPEEDS (KMS PER HOUR)

	Bus Average Speed	*Vehicle Speed from GPS*	*Modelled Vehicle Speed*	*Undelayed Speed*	*Stopping Factor*
Am Peak	20.43	25.87	32.2	29.41	1.27
Inter Peak	18.90	23.39	31.9	29.20	1.24
Evening peak	20.14	24.40	31.2	29.70	1.21
All Day	19.48	24.15		29.34	1.24

A number of observations can be made from this analysis. Firstly, the morning peak and evening peak stopping factors (that is the ratio of total time to time net of passenger pick up and set down) are almost the same for the morning and evening peak for the 30 second and 2 second analyses. The inter peak is rather less in the 2-second analysis. This is likely to be a function of the time of year, and the lower number of passengers using buses inter peak in mid January when schools are closed.

Secondly the bus speed on the Papanui route is significantly slower at about 20kph than the Airport route. This may be explained by the differing volumes of traffic, and the fact that the Airport route has considerable distances of dual carriageway.

The modelled speeds on the airport route agree quite well, but the model is too fast in Papanui, even though it was originally calibrated against moving car travel time observations. It implies that this needs a review next time the model is updated.

Finally, and almost counter intuitively, there is little difference in average speeds between the three daytime periods, but again this may be a function of January traffic.

4.3 Coarser Interval Analysis

Sampling at 2-second intervals is at the limit of the radio's ability to transmit data from the bus to the control room. Accordingly, the intervals were successively amalgamated into nominal 4-second, 6-second, and 8-second bands. The total times, distances and speeds were almost the same, with minor differences as segment lengths changed. However, delay estimates did begin to vary as shown in Table 7 below.

TABLE 7

A COMPARISON OF INTERVAL SIZE

Interval	*Delays At bus stops*	*Delays at Intersections*	*Stopping Factor*
2-Second	16,109	11,880	1.24
4-Second	15,495	11,589	1.23
6-second	14,958	11,821	1.24
8-second	15,976	13,037	1.24

The rules to determine whether a bus had stopped had to be relaxed for the 6 and 8 second analyses as the interval amalgamation lost a significant number of the stopped intervals. Also, the minimum speeds to determine a stop had to be varied in order to get a comparable numbers. Although there is not much in it, the conclusion is that a 5-second interval with times to one decimal place would appear likely to provide the best and most reliable data.

5. Conclusions From The Real Time System Analysis

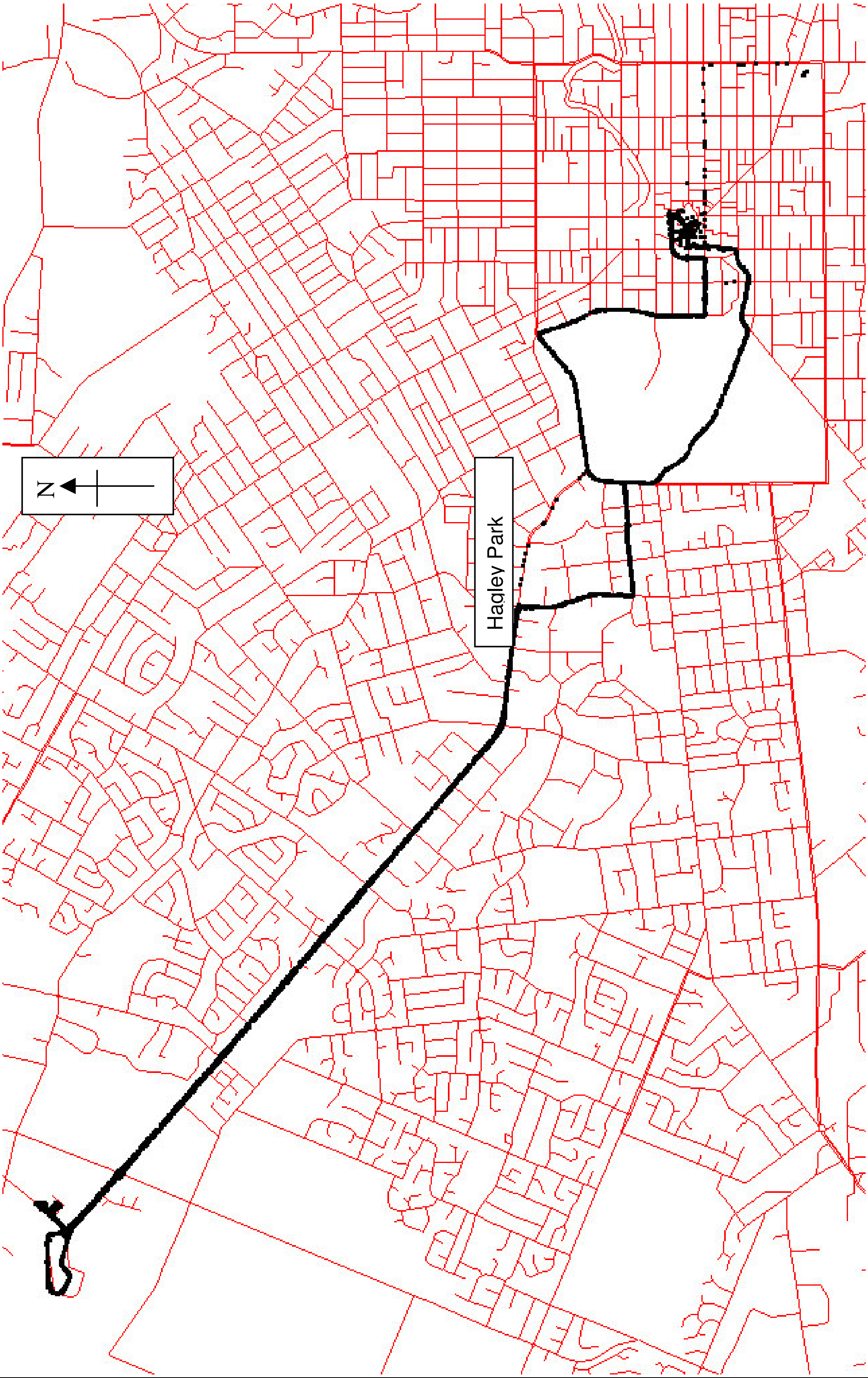
The GPS Real Time Tracking system being used in Christchurch provides a rich source of data that is hitherto unavailable, but is extremely valuable for use in calibrating and validating transport models.

Even from a small sample analysis in Christchurch, it has been shown that the model could do with some revision, but this data could be made available for every major corridor in Christchurch. A small extension of the analysis could identify where bus priority lanes would be most useful, and provide an estimate of the benefits of introduction. The system also lends itself to frequent, and long term monitoring of the major routes in the city.

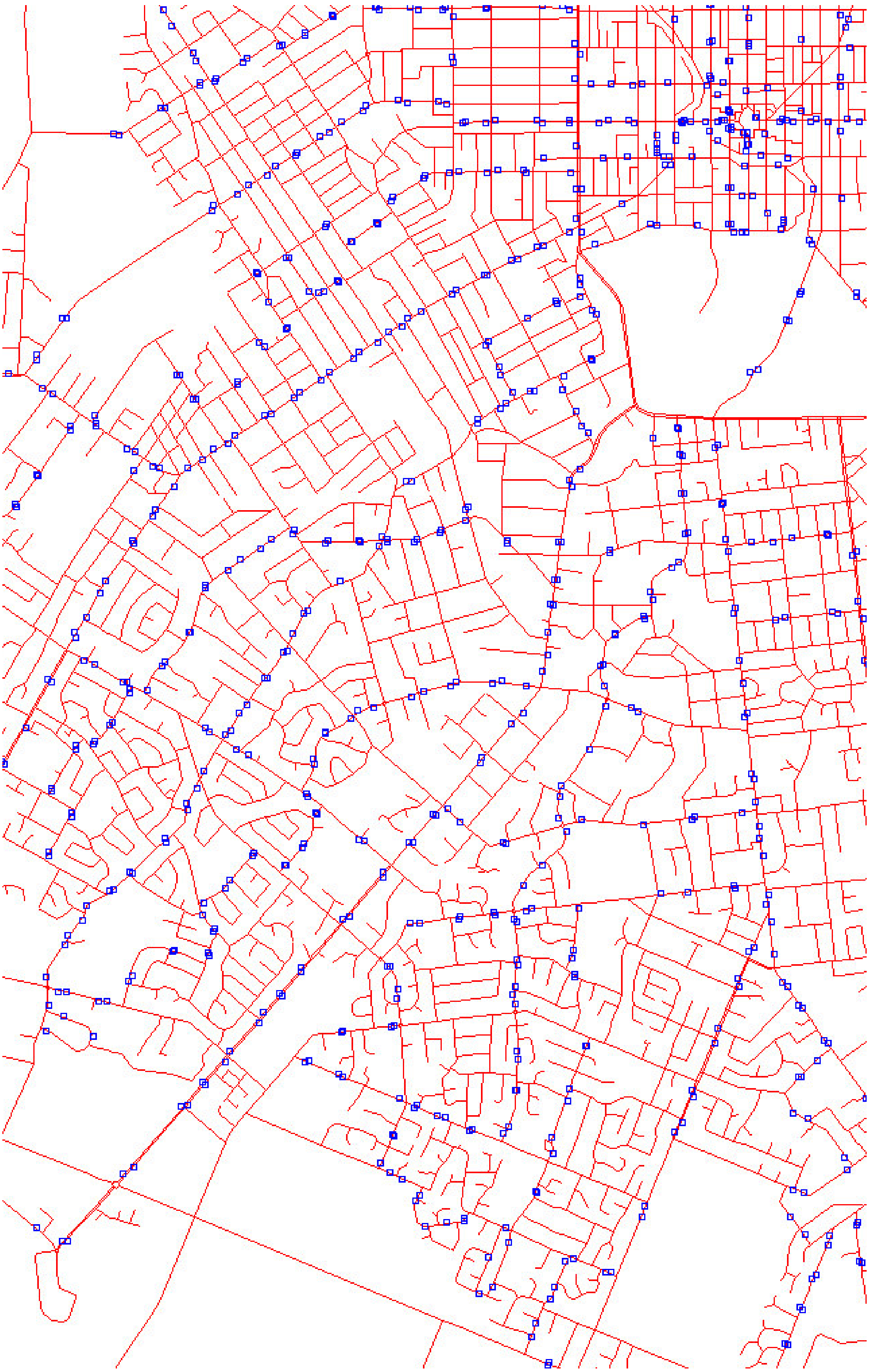
GPS data, now that accuracies are improving, is a cheap, and highly useful source of data for transport planning purposes.

In terms of Public Transport modelling, it has confirmed the stopping factors that have been used in New Zealand models, but has provided a distinction between the three periods.

This analysis has only just scratched the surface of the uses to which the data can be put, particularly when intersection co-ordinates are extracted from the model, and intersection delays identified for each intersection.



IPENZ 2003	**Airport Route GPS Readings**	Figure 4
Gabites Porter (NZ) Ltd		



IPENZ 2003	**Christchurch Bus Stops in the North West**	Figure 5
Gabites Porter (NZ) Ltd		