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GPS Measurement of Travel Times, Driving Cycles, and Congestion

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ABSTRACT: In the past few years, various types of GPS devices have been developed for use in connection with travel surveys of various types. This paper describes an application in Sydney, Australia, in which GPS devices were used to collect data on automobile trips within the urban area, with the goal of developing information about travel times, driving cycles, and the incidence and severity of congestion. The paper describes steps taken in designing the sample in both cases, and presents the results of the data collection, together with estimates of the sampling errors on segment, link, and corridor travel times. It is concluded that GPS technology represents an accurate and inexpensive method for collecting travel time and speed information, even if samples are relatively small.

KEY WORDS: GPS, travel time, driving cycle, congestion, sample design, GIS.

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1. Introduction

In the past few years, various types of GPS devices have been developed for use in connection with travel surveys of various types. In particular, there has been a substantial interest in using GPS in conjunction with household travel surveys and traffic studies. Since the mid 1990s, a number of fully fledged GPS based household surveys have been undertaken, mainly in the US (Wolf *et al.* 1999, California Department of Transportation 2002). Travel time research with GPS, on the other hand, has not progressed much beyond proof-of-concept stages. This paper describes an application in Sydney, Australia, in which GPS devices were used to collect data on automobile trips within the urban area, with the goal of developing information about travel times, driving cycles, and the incidence and severity of congestion.

The first issue in applying GPS to the measurement of travel times along specific corridors is to develop a process for sampling segments of streets and then to determine how to combine the segment data to provide data on corridor levels of service, as well as updating link travel times. The paper describes the procedure used to develop the samples for a study in which measurements were made to update the travel times on major arterial routes through a region within Sydney, for the purposes of developing plans for alternative congestion relief. Details are provided on how the data were collected, managed and processed.

The paper describes the results of the data collection, estimates the sampling errors on segment, link, and corridor travel times, and compares the results with posted speed limits and more traditional speed data. In addition, the paper shows how the data can also be used to identify the extent and severity of congestion along these corridors, and how the data can also be used to determine more information about the driving cycles for vehicles driven along these routes. It is shown that the GPS provides an accurate and inexpensive method to determine speeds, acceleration, deceleration, and the incidence of congestion. The samples, which are not large, are shown to provide accurate data for different time periods of the day, and for each link along the arterial route.

2. Approaches to Measuring Travel Time

Irrespective of what methodology may be used, the central aim of any traffic survey is to assess road performance. Commonly used performance indicators include level of service (LOS), v/c ratio, delay/congestion, and travel time and speed. It has been argued that LOS indicators tend to be complicated, require expensive site specific input data, and are often considered by many transport planners to be unsatisfactory measures of performance. Travel time measures on the other hand, are accurate, flexible and can be easily understood by professional transport planners as well as the wider community (Quiroga 1997).

The floating car technique, also known as the test vehicle technique or moving observer technique, is the most common method used to measure travel times. This involves a ‘probe vehicle’ driving in the general flow of traffic to collect information on travel times, average speeds, and time spent in queues. Data may be collected on specific links or segments of a road, or entire routes. This method is widely acknowledged to be an accurate, practical, and low cost method for gathering traffic related data, even though there is some potential for the measurement instrument to interfere with the medium being observed (Marca *et al*. 2001).

The floating vehicle technique most often involves occupants in the probe vehicle recording times either with a stopwatch and clipboard, or distance measuring instrument, at designated checkpoints. Information may also be collected on average speeds, the number of cars on the road and the length of queues at intersections. The National Roads and Motorists Association (NRMA) adopted this technique in a recent travel time survey of the M2 motorway in Sydney's northwest (NRMA 2000). Despite its widespread use, this approach has a number of fundamental problems. Manual collection of travel time data is labour intensive, often inaccurate, and may even pose safety risks to drivers if they are required to interact with timing devices and other instruments while operating a vehicle.

Automatic vehicle location (AVL) technology such as passive GPS on the other hand, is capable of collecting extremely precise data on geographic position, time of day, speed and direction of travel, and operates independently of the vehicle driver. Using passive GPS, travel time information can be recorded on pre-defined time intervals of a second or more, stored on a portable memory device, and then retrieved and analysed later on a standard GIS package.

While interest in using this technology in travel time research has grown considerably in recent years (Quiroga and Bullock 1998, Taylor *et al*. 2000, Marca *et al*. 2001), there are some hurdles that need to be overcome before the benefits of GPS can be realised. One of the biggest challenges in working with GPS is how to manage, manipulate, and analyse the extremely large quantities of data that devices capture. Although raw GPS track points can be viewed on most standard GIS packages, on-screen visual analysis is extremely time consuming for even small amounts of data. These difficulties were recognised by Quiroga, among others. In 1997, Quiroga developed a set of procedures for conducting travel time studies using GIS – GPS technology, and a methodology to automate data collection and processing. The benefit of this was that it provided a cost effective means of collecting large, statistically significant samples, with relatively little effort. The following sections describe an application of this approach to a region within Sydney, Australia.

3. The Study

In late 2002, The Institute of Transport Studies (ITS) undertook a survey of travel times and speeds on arterial roads on the Warringah Peninsula, in northern Sydney (hereafter referred to as Warringah). ITS was commissioned by the Australian Federal Government to undertake the survey in response to on-going traffic problems and congestion in the area. Information collected in the survey was used in ITS's Transport and Environment Strategy Impact Simulator (TRESIS) model, to evaluate the impact of various strategies aimed at addressing traffic congestion and increasing travel demand in the area. In geographical terms, the Warringah Peninsula is unique from other parts of Sydney because it is relatively isolated from the network. There are really only three main access points from this region to the greater city area – the Spit Bridge in the south-east corner of the region, The Pacific Hwy and Mona Vale Road on the western side, and Warringah and Melwood Roads in the south-west. These points are shown in Figure 1.1. Continuing high density based population growth in the area in recent years has lead to increasing complaints about congestion from local councils and residents alike (BTRE, 2002).

It is worth noting that another travel time study was undertaken by ITS in the early part of 2002, but is not be discussed in detail in this paper. This research project was a survey of travel times on the M2 Hills Motorway, a major urban toll road in the north western part of Sydney, and the alternate non-toll surface routes with which it competed. Although the original intent of this survey was evaluate the accuracy of travel time savings forecasted prior to the construction of the motorway, only limited data were collected due to financial and time constraints. In spite of this, the exercise served as a useful pilot project for the development of a practical sampling methodology, and a GPS data processing algorithm, which were subsequently used for the much larger Warringah study.

4. Sample Design

The first issue in applying GPS to the measurement of travel times along specific corridors is to develop a process for sampling segments of streets and then to determine how to combine the segment data to provide data on corridor levels of service, as well as updating link travel times. This section outlines the process used to develop the samples of the Warringah survey. A description is provided on how the routes were selected and how the sample frames were established. The pilot testing process is described along with how the final samples were drawn. The technique used to design the sample for the Warringah study was very similar to the process used in the earlier M2 pilot project.

4.1 Selecting the routes

Three sources of information were used in order to identify the routes utilized by northern beaches residents to access the greater Sydney area: road capacity data stored in the TRESIS network, average annual daily traffic (AADT) volumes at points on the northern beaches road network (RTA 1998), and the knowledge of northern beaches residents, local government and commuters. Following broad examination of AADT data, it was decided to focus on segments with average daily volumes upwards of 20,000 vehicles. These data, along with local knowledge, suggested that the data collection task should concentrate on six main routes used by northern beaches residents to access other parts of Sydney. These routes are shown in Figure 1.1. Although travel times across the harbour bridge and into the city were used in the transport models for the project, the starting point for north-bound trips in the survey was North Sydney, and so data were not collected for the main approach to the CBD. Driving into and out of the city on the Freeway would have added significant time to the project. Data for these routes were derived from pooled data collected through numerous other GPS research projects conducted by the Institute.

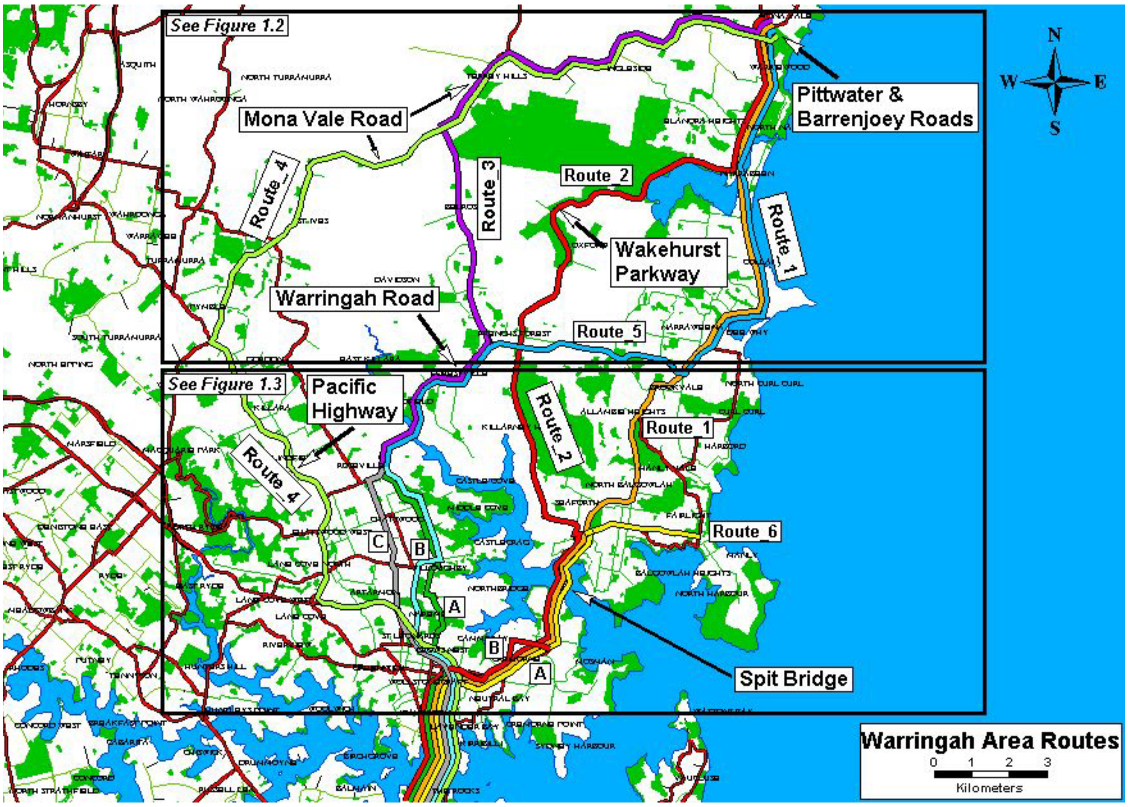

Figure 1.1 Six Key Routes with Sub-Routes Examined in Original Study

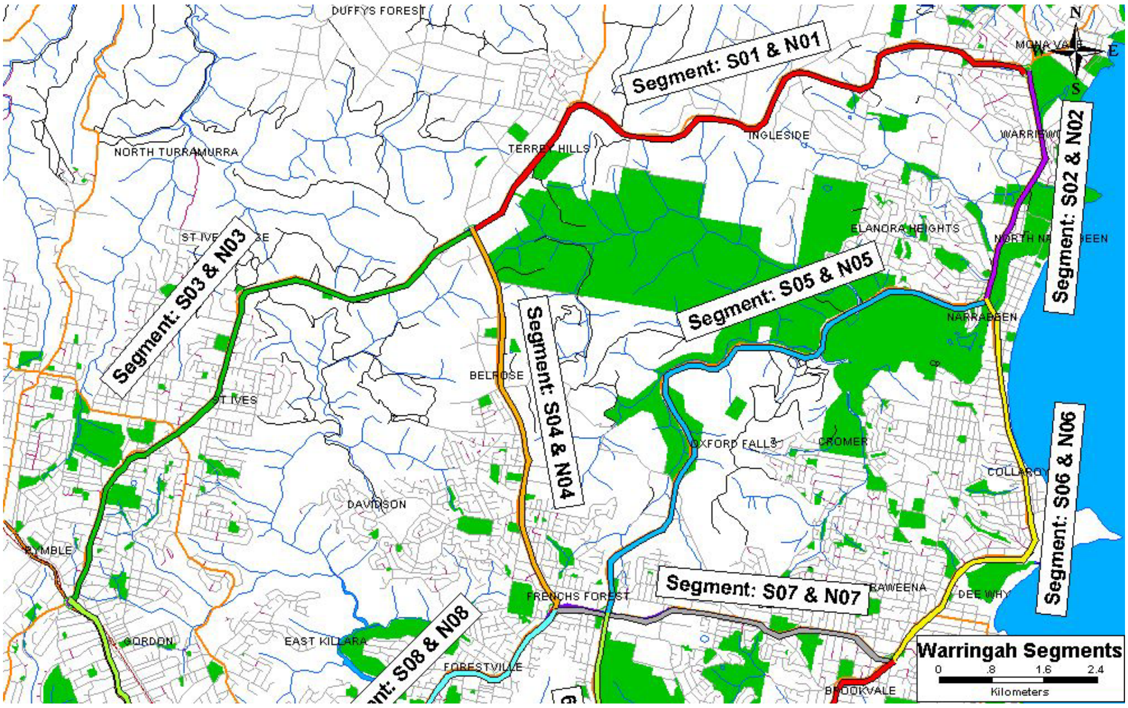

Figure 1.2 Segments in the Northern Section of the Warringah Peninsula

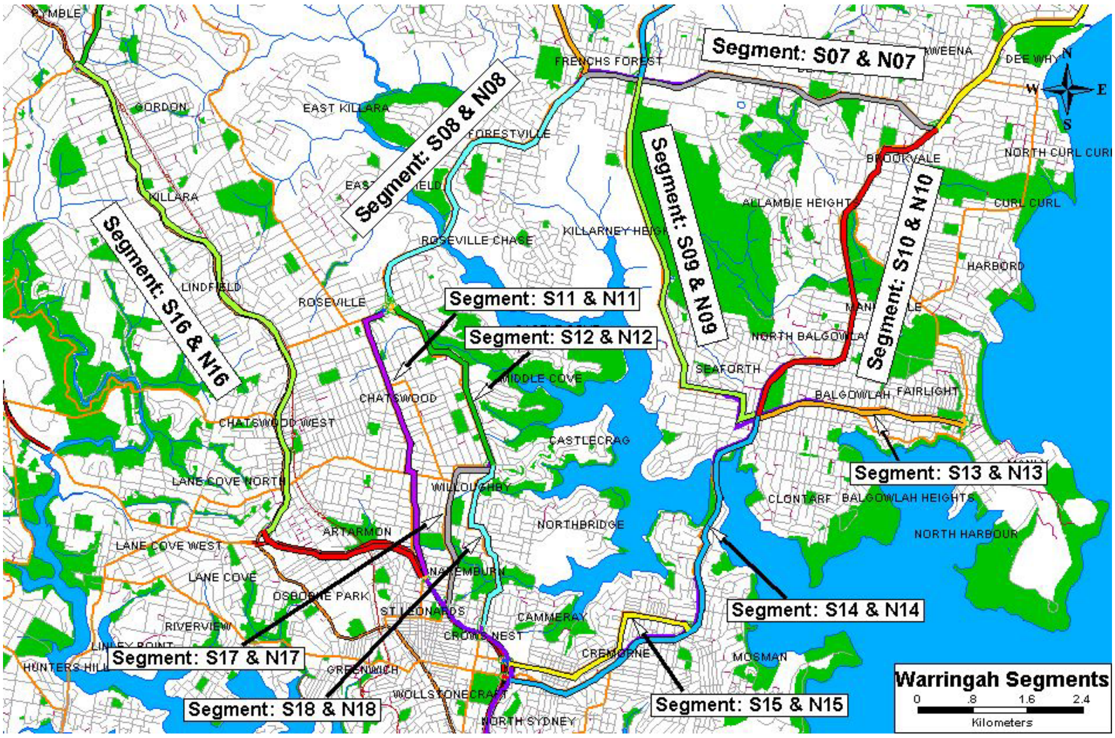

Figure 1.3 Segments in the Southern Section of the Warringah Peninsula

4.2 Establishing the sample frames

New South Wales Roads and Traffic Authority (RTA) Hourly traffic counts passing through Spit Road at Spit Bridge; and, Warringah Road, west of Melwood Ave, in Forestville provided the basis for grouping day-and-time-intervals into strata. Shown as 'Spit Bridge' and 'Warringah Rd' in Figure 1.3, these two points were used because they are common to five of the six routes. Similar levels of traffic volumes were observed at the two locations during weekdays and these were found to be consistent with other major intersections in the study area. Four periods of differing traffic volumes were observed: peak, shoulder peak, medium and low. This was considered a sufficient level of detail for the TRESIS model.

As shown in Table 1.1, peak periods were defined as those with volumes above 3,000 vehicles per hour. The shoulder peak was defined as those with volumes greater than 2,000 but less than 3,000 vehicles per hour. The shoulder peak periods occurred one hour preceding, and two hours following, the morning southbound peak, and two hours preceding and an hour following the afternoon northbound peak. Periods of medium volume were those with traffic volumes between 1,500 and 2,000. Because the main purpose of the study was to model strategies to alleviate congestion and other traffic problems, collection of data during low volume periods was not considered important, and so not explicitly considered in the sample design. For the weekend period, medium and high volumes were apparent throughout the day from 09:00 to 19:00. Although volumes exceed 2,000 for certain times during the day, all of these periods were classified into a single stratum for practicality.

Table 1.1 Traffic Volume Categories Based on Traffic Count Data at Spit Bridge/Warringah Road Access Points

Stratum	Mean Range (no. of vehicles)	Categories Beginning
Inbound peak	> 3000	Mon-Fri 07:00 - 08:55
Inbound peak shoulder	2000 – 3000	Mon-Fri 6:15 - 6:55, 9:00 - 10:55
Inbound medium volume	1500 – 2000	Mon-Fri 11:00 - 18:55, Sat-Sun 9:00 - 19:00
Outbound peak	> 3000	Mon-Fri 15:30 - 18:35
Outbound peak shoulder	2000 – 3000	Mon-Fri 13:40 - 15:25, 18:40 - 19:35
Outbound medium volume	1500 – 2000	Mon-Fri 07:40 - 13:35, Sat-Sun 8:55 - 18:55

4.3 Pilot testing

A pilot test was conducted around mid August, 2002. The pilot tests served several objectives, including:

- To familiarise researchers with the routes;
- To ascertain travelling times on the routes during different times of the day, in order to obtain a rough guideline of variance in journey times and average travel times. These values were then used to assist in the calculation of sample sizes;
- To test for the presence of any urban canyon effects.

Due to the scale of the project, pilot runs were not collected for all segments and strata. When data were not available, estimates were made of variance based on the observed variances on other segments in the network. Sampling errors were calculated upon the completion of the survey to ensure that the original sample design was appropriate.

4.4 Drawing the sample

Because many sections of road were common to two or more of the routes, a segment based sampling approach was considered to be more appropriate than drawing times for entire routes. Start times were drawn independently and separately for each segment for inbound and outbound directions, respectively. Within each stratum, units were drawn using simple random sampling without replacement. A total of 20 units were successively drawn for each stratum, but only the first *n* values were included in the final sample. While all sample sizes were calculated at a confidence level of 95%, the actual level of accuracy varied between 1.5 minutes (for segments under 20 minutes) and three minutes (for segments over 20 minutes). For analysis purposes, the minimum sample size within each stratum was set to five.

Because strata times were based on volumes observed at two points in the network, adjustments needed to be made to the sample frames for segments north and south of these areas; the traffic conditions experienced on Segment 14 at 07:15, for instance, would obviously be very different to those on Segment 2 at the same time of day. Hence, time strata were adjusted in accordance with average travel times observed in the pilot study. If the average travel time on the segment before or after the point of observation was 10 minutes, the sampling frame for this segment/time of day would be shifted forwards or backwards by 10 minutes (e.g., peak hour would start, and finish 10 minutes earlier than the peak time on the segment after it). While it may have been better to devise time strata based on traffic volumes observed on each segment, this would have complicated the sample design, and would have created a number of difficulties in administering and managing the survey.

The segment samples were drawn independently of scheduling issues. However, after drawing the samples, matches were made between segments, to enable the required data to be collected in the minimum amount of time. Through knowledge of segment times gained in the pilot study, segments were matched, e.g., the start time of 10:00 for Segment 2, southbound trip could be matched with a 10:25 start time for a southbound run on Segment 6. While this matching would induce a level of inter-dependence or correlation between what should ideally be independently timed segments chosen randomly within the segmented periods, it permitted additional sample runs to be undertaken. This may have increased the width of the confidence interval used, to a small but unknown degree. On balance, this seemed a reasonable outcome within the time constraints of the study.

Due to the size of the sample frame, it was not possible to start each run at the exact time drawn from the sample. As previously outlined, segments were joined together into driving schedules when start times fell within 15 to 30 minutes of the expected finishing time on a corresponding link. Although this could be considered a source of bias, it was unlikely to be significant given that the variations were, in a way, random in themselves, because they are contingent on scheduling a large number of segments in many different time periods. Overall, the actual start times matched the sampled times quite closely, and observations were evenly spread within most strata.

5. Data Collection

5.1 Data collection instruments

The GPS device used for data collection in both projects was a GeoLogger® passive GPS, provided by GeoStats of Atlanta, GA. The Geologger is fitted with a Garmin GPS receiver which has an accuracy rating of ±15 metres, although the experience of ITS is that on average it is closer to ±5 metres. The GPS instruments were set to poll every five seconds for the M2 study, and every second for the Warringah study. A higher polling rate was used for the Warringah study to enable limited analysis of performance at intersections.

No problems were experienced with signal accuracy, because little or no driving was done in areas where there were extensive tree canopies or high buildings (urban canyons). The Geologgers were equipped with four megabyte storage units, capable of storing approximately 720,000 data points. Time of day, travel time and average speed data from the GPS track points was extracted using a specially designed procedure in the TransCAD GIS program, outlined in the following section. Differential correction and/or linear referencing were not considered to be necessary for the project.

5.2 Collecting and managing the data

Two dedicated University owned vehicles operated by ITS staff were used for the majority of the data collection. All drivers were instructed to drive with the flow of traffic. This meant that if other vehicles on the road were driving close to, or on the speed limit, then so too would the driver of the data collection vehicle. The driver was instructed to adhere to the posted speed limit, even if the general flow of traffic exceeded it.

Supplementary data were also collected from two members of staff that regularly drove in the Warringah area. Vehicles belonging to these staff members were equipped with Geologgers and they were instructed to continue driving to and from work as per usual. The advantage of this was that it provided additional data for no cost and at no inconvenience to the drivers involved. This is certainly one of the principle advantages of using passive GPS for traffic studies. Because vehicle occupants are not required to interact with any equipment or devices while operating the vehicle, data could even be collected using regular commuters. If a longer time frame was available for the project, it may have been feasible to use a sample of residents living at various points in the region. Given that traffic congestion is a well publicised problem in the area, residents probably would have been quite willing to volunteer to participate in the study.

Data collection began in late August 2002, and was undertaken in three main periods, ending in late September. It was originally anticipated that most of the runs could be completed during a 7-14 day period, however this proved to be difficult for a number of reasons. In particular, scheduling of vehicles proved to be very time consuming. Because the sampling frame required five or more runs on 108 segments (i.e., 18 segments in two directions for three separate time periods), the scheduling task involved piecing together 552 random start times into workable driving programs. It was not possible to develop a way to automate this process in the available time period, so this task was performed manually during the data collection period. To a large extent, this was an unexpected problem and has not been addressed in GPS-travel time literature. This aspect of data collection would need to be examined in more detail before similar studies are undertaken in the future.

Unfortunately, one day’s worth of data was lost during the data collection period because a Geologger was configured incorrectly, but beyond this, no major problems were encountered. Data were collected between 06:30 and 20:00 on weekdays and between 09:00 and 19:00 on weekends. Including time spent driving to and from the study area, a total of 10951 km were driven over 265 hours.

5.3 Extracting and processing the data

GPS data were initially analysed on a segment by segment basis. Segment based reporting of travel times and average speeds provided meaningful output on the performance on the six major routes, and allowed areas of congestion to be isolated. To extract the data, a series of ‘buffers’ were created around links and nodes at the endpoints of segments. An example of this is shown in Figure 1.4. Buffers were created in a 50m radius around each intersection Each time a vehicle drove the length of a segment (i.e., two intersections/buffers), the program would create a record in a database containing the direction of travel, the ID and local time for records in the first and second buffers, the date of the trip, as well as the travel time and average speed. The start GPS record for a segment was defined as the first GPS record appearing in the area of the first intersection, while the end GPS record for a segment was defined as the last GPS record appearing in the area of the second intersection. This approach was taken to ensure the procedure would account for traffic conditions at intersections. Table 1.2 shows an example of the output data stored in the database.

Table 1.2 Example of Data Collected for Segment 1, Northbound

CAR ID	DRIVER ID	TRIP NUM	LOC DATE	WEEKDAY	S_TIME	S_ID	E_TIME	E_ID	TRA_T	AVG_S	DIST
Car1	GP	25	260802	Monday	150927	780	152046	1370	11.32	57.3	10.82
Car1	GP	16	20902	Monday	155127	1642	160237	2271	11.16	58.2	10.82
Car1	GP	17	20902	Monday	171155	1974	172356	2638	12.01	54.3	10.87
Car1	GP	17	20902	Monday	174226	3474	175337	4022	11.19	58.8	10.97
Car1	GP	17	20902	Monday	181927	5348	182930	5920	10.05	64.7	10.84
Car1	GP	9	30902	Tuesday	142959	1874	144018	2467	10.32	63.0	10.84
Car1	GP	9	30902	Tuesday	152140	4417	153140	4993	10.00	65.3	10.88

Without this specialised software, data analysis would have been extremely difficult, if not impossible. Considering the complexity of the sampling scheme and large number of observations collected, it would have taken hundreds of hours to provide any detailed information about travel times through manual inspection of the GPS track points.

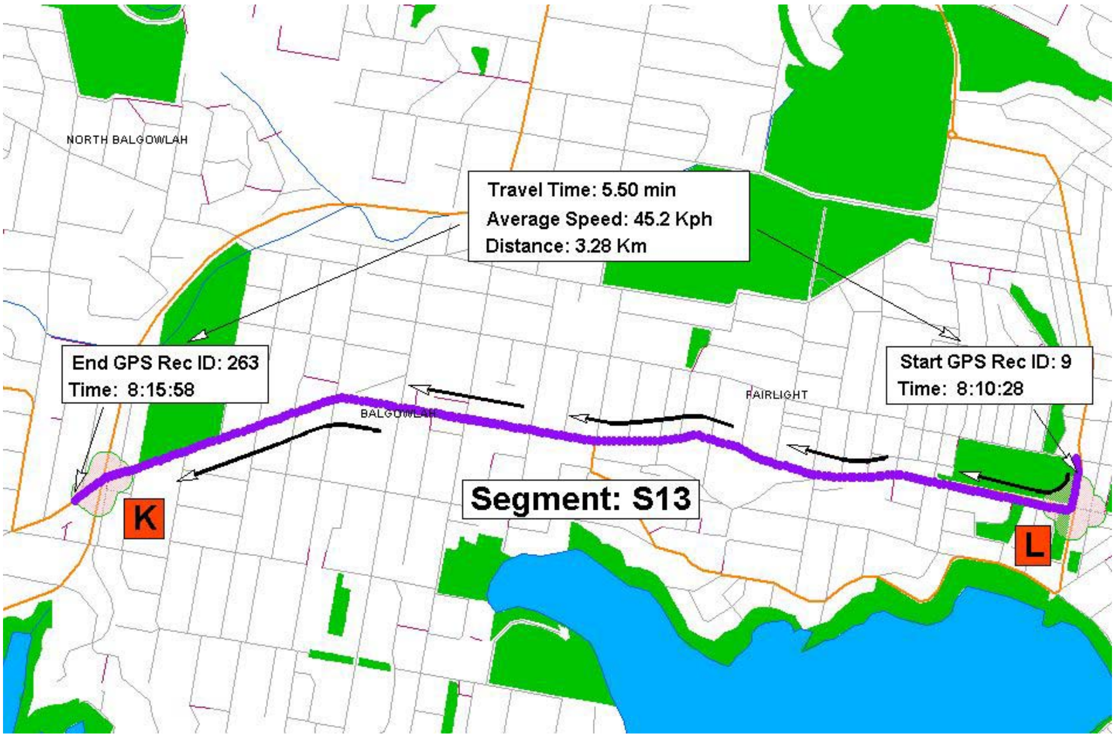

Figure 1.4 Matching track points with street segments

A total of 541 of the required 552 required observations were collected, which represented a shortfall of just two percent. Generally speaking, it was very easy to satisfy medium volume observations because this time frame was much larger than the peak and peak shoulder periods. In part, scheduling issues discussed earlier were responsible for the data collection taking longer than envisaged. Including runs made during the low volume period, which were not explicitly included in the sample design, a total of 1098 observations were collected for the 18 segments. Eleven runs were found to have problems. Two of these observations were the result of drivers taking circuitous routes (which the program did not detect), and the remaining nine contained inaccuracies due to canyoning, and were subsequently edited prior to analysis. This left a total of 1096 observations.

6. Results

6.1 Segment travel times

It is beyond the scope of this paper to present findings for all the segments considered in the study, and so results are presented only for two of the six routes. These are shown in Figure 1.1 as Route 1(a) and Route 5(b), and are described in Table 1.3. These were chosen because they represent the two main routes residents in the Warringah area use to access most other parts of the city. For simplicity, these Routes 1(a) and 5(b) will hereafter be referred to as Routes A and B respectively. Travel times and speeds observed on other routes are reported elsewhere in more detail (ITS 2002).

Table 1.3 Description of routes to examined in paper

Route on Map	Segments	Description of Route
1(a)	2, 6, 10, 14	*Military Road (23.72 km)*: Pittwater Road proceeding south through Brookvale, Condamine Street, Burnt Bridge Creek Deviation, Manly Road, Spit Road, Military Road, Warringah Freeway at Neutral Bay, Harbour Bridge.
5(b)	2, 6, 7, 8, 12, 18	*Warringah Rd (27.81 km)*: Pittwater Road, Warringah Road, Roseville Bridge, Eastern Valley Way, Edinburgh Road, Alpha Road, Flat Rock Drive, Brook Street, Warringah Freeway at Crows Nest

Tables 1.4 and 1.5 show observed travel times and average speeds for the segments of Routes A and B. Because Segments 2 and 6 are common to both of the routes, they have been excluded from Table 1.5 and Figure 1.6 to avoid repetition. Average travel times are also displayed in Figures 1.5 and 1.6. Calculated and achieved samples are shown for each segment and stratum in the tables. Mean travel times and speeds are displayed along with posted speed limits. Confidence intervals for travel times were calculated at the 95% level after determining the sampling errors for each segment.

For almost all segments on both routes, the actual number of observations equalled, or exceeded the calculated sample sizes. The mean travel times and speeds observed for each segment give a good indication of traffic conditions across different times of the day. For Route A inbound, for example, we can see that peaking patterns are more pronounced on Segments 10 and 14 than they are on Segments 2 and 6. As Table 1.4 shows, travel times on Segment 14 during the peak period were noticeably higher than other times during the day. Peak times were 36% higher than peak shoulder times, and 46% higher than low volume times.

On the other hand, such differences are not apparent for Segments 2 and 6. On Segment 2 for example, there is generally very little difference between the mean travel times observed across various times of the day. For this segment, the slowest travel times were actually recorded during the medium volume period (5.12 minutes), and not the peak period, as expected. While this occurrence is not immediately explainable, it may suggest some problems with the definition used for medium volume time of day strata, or the presence of local traffic that many have been unaccounted for during the planning phase. Irrespective of this, however, the data suggest an absence of any substantive peak hour congestion on the northern parts of the network.

Differences in average speeds and posted speed limits give a relatively imprecise, but nevertheless very useful guide to the LOS of the road. Strictly speaking, LOS calculations require information on lane widths, lateral obstructions, traffic composition and road grades. Such data, however, are costly and difficult to obtain, particularly for a study area as large as the Warringah area. Differences between posted speeds and observed speeds provide a good indication of whether or not a road is operating at its maximum capacity. On any given two lane road with a posted speed limit of 60 km/h for example, an average speed below 50 km/h is probably indicative of LOS D or lower. Thus, the average of 21.20 km/h on Segment 14 is indicative of serious levels of congestion, and probably a very low LOS (level E or F). Even during the low volume period, average speeds on this segment were well below 40 km/h. This finding certainly highlights the traffic problems associated with this section of road, and confirmed its status as a key constraint on traffic flows between the CBD and the greater Northern Beaches area. For other segments, such congestion is less apparent. Considering Segment 2 again, it can be seen that even during the morning peak, average speeds were generally well above 50 km/h. Average speeds were also relatively high on Segment 6 during the same period.

Table 1.4 and Figure 1.5 also highlight a number of important differences between the am and pm peak periods. Overall, peaking patterns are less pronounced during the evening period. On Segment 14, travel times during the evening peak are only seven percent higher than the medium volume period. With the exception of the low volume period, all average travel times on outbound trips were lower than corresponding inbound times. On Segment 14 for example, outbound peak travel times were 40% lower than inbound times. In addition to this, average speeds are also higher for outbound trips compared to inbound trips. Overall, outbound travel times were actually highest during the peak shoulder and not the peak period. Clearly, this shows the tendency for peak flows to be more dispersed, and bottlenecks less apparent, during the evening. This is not surprising, given that the northern beaches area is relatively isolated from the rest of the Sydney network. As such, northerly flows of traffic are not subjected to bottlenecks caused by vehicles originating from other parts of the network (e.g., where Segment 15 joins the Warringah Freeway before the Sydney Harbour Bridge).

Table 1.4 GPS Output for Route A Segment

		Segment	Sample n	Actual n	Mean travel time (min)	Std. Dev. Of travel time (min)	95% CI (min)	Mean Speed (km/h)	Posted Speed Limit (km/h)
Inbound	**Peak**	**2**	5	5	4.09	0.81	0.68	57.66	60 – 70
		6	5	5	9.47	0.83	0.70	44.48	60
		10	5	5	13.75	3.94	**3.31**	28.34	70 – 80
		14	12	10	20.65	4.44	**2.26**	21.20	60
	Peak Shoulder	**2**	5	6	3.91	0.43	0.36	59.60	60 – 70
		6	5	5	9.98	1.26	1.07	42.66	60
		10	5	6	10.21	1.04	0.88	35.77	70 – 80
		14	5	6	13.63	4.35	**3.67**	32.17	60
	Medium Volume	**2**	5	15	5.12	1.13	0.97	46.81	60 – 70
		6	5	10	10.58	1.15	0.99	39.96	60
		10	5	14	9.59	1.57	1.35	38.32	70 – 80
		14	5	18	13.3	2.36	**2.02**	31.64	60
	Low Volume	**2**	-	4	4.39	0.50	-	53.28	60 – 70
		6	-	3	8.21	0.64	-	51.23	60
		10	-	5	8.10	1.71	-	46.46	70 – 80
		14	-	6	11.08	1.24	-	37.47	60
Outbound	**Peak**	**2**	5	5	5.07	1.19	1.02	47.24	60 – 70
		6	5	6	10.24	0.47	0.40	41.00	60
		10	6	9	11.09	2.1	**1.56**	34.30	70 – 80
		14	9	14	12.29	2.22	1.35	34.31	60
	Peak Shoulder	**2**	5	7	5.46	0.48	0.40	42.63	60 – 70
		6	5	6	11.13	1.34	1.13	38.28	60
		10	5	3	12.64	3.43	**2.95**	30.83	70 – 80
		14	5	6	11.62	1.76	1.49	36.30	60
	Medium Volume	**2**	5	12	5.25	1.28	1.10	46.43	60 – 70
		6	5	12	10	0.9	0.77	42.13	60
		10	5	14	10.96	1.36	1.16	33.97	70 – 80
		14	5	11	11.44	1.92	**1.65**	36.80	60
	Low Volume	**2**	-	11	4.93	0.49	-	47.59	60 – 70
		6	-	11	8.57	1.57	-	49.40	60
		10	-	9	7.94	7.52	-	48.37	70 – 80
		14	-	8	9.36	1.88	-	45.66	60

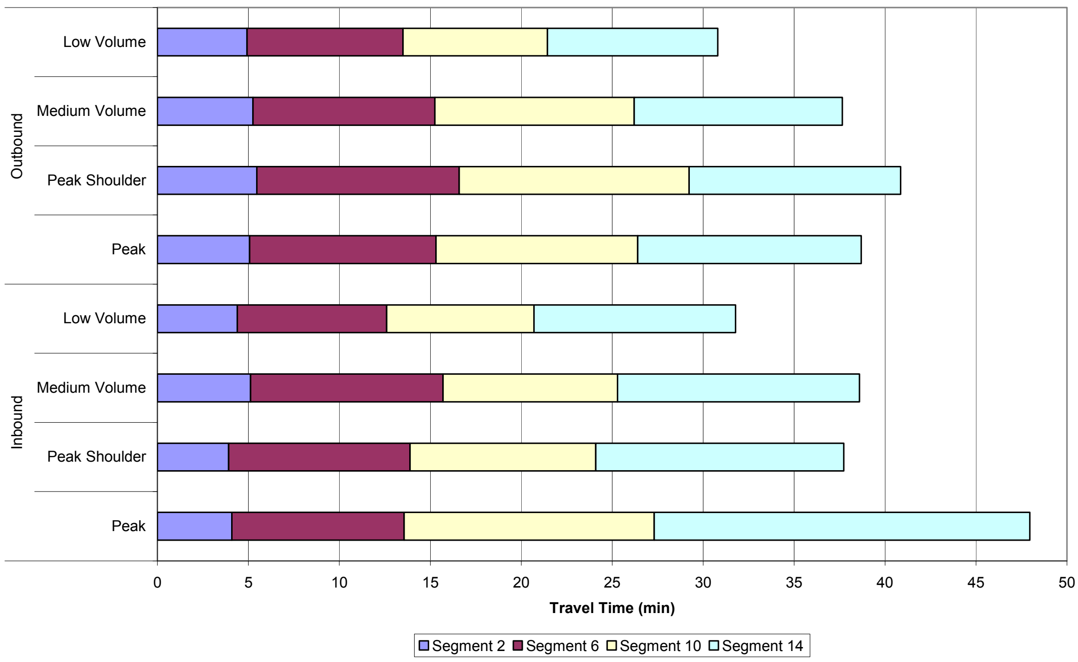

Figure 1.5 Travel Times for Route A Segments

Similar trends are evident in Table 1.5 and Figure 1.6, that show GPS output data collected for the additional segments comprising Route B. Peaking patterns are most noticeable for inbound travel times of all segments, and to a lesser extent, outbound times, for Segments 7 and 8. During the am peak, for example, travel times on Segment 7 were more than 25% higher than medium volume times, while the corresponding difference on Segment 8 was 35%. Similar to Segments 10 and 14 on Route A, am peak average speeds on Segments 7 and 8, are well below the posted speed limits. In the case of Segment 7, average speeds were 27.43 km/h, which was less than half the limit of 60 - 70 km/h. Peak hour travel times and average speeds deteriorated on Segments 12 and 18 during the peak period, but were generally quite stable across most other times of day. As was the case with Route A, travel times during the evening peak and peak shoulder periods are lower than most inbound peak times on the same segments.

The 95% confidence intervals shown in Table 1.4 and Table 1.5 can be used to determine the adequacy of the final data sample. In the original sample size calculations, confidence limits of 1.5 minutes were assumed for segments/strata with average travel times of less than 20 minutes, and three minutes for those with averages greater than 20 minutes. For Routes A and B, confidence limits of 1.5 were assumed for all segments and times of day expect Segment 10 inbound during the peak period (three minutes). Confidence intervals are not shown for low volume periods, because these were not explicitly considered in the sample design. Figures shown in bold in Tables 1.4 and 1.5 show the estimated confidence limits that exceeded those assumed in the sample design.

Examining Route A firstly, it can be seen that confidence intervals calculated from the sampling errors exceeded original confidence limits for Segment 10 inbound peak, and outbound peak and peak shoulder periods. This was also the case for Segment 14, inbound for all time periods, and outbound for medium volume periods. In other words, travel times on these segments/strata varied to a greater extent than was assumed in the planning phase. The majority of these discrepancies, however, are quite small and can probably be considered acceptable. The sample size calculations for the Segment 14 peak group for instance, were based on mean travel time of 19 minutes, and so a confidence interval of plus or minus three minutes would have been more appropriate for this segment anyway. If a higher level of accuracy was required, it would probably be desirable to collect more observations on Segment 14 inbound and Segment 10 outbound during the peak shoulder periods. Considering Route B, the number of observations could be considered sufficient for all segments/strata with the only exception being Segment 7 outbound during the during the peak period.

Overall, the final confidence intervals are low enough to suggest that the sample was more than adequate for the purpose for which it was intended. Excluding the Segment 10 inbound peak for which an interval of plus or minus three minutes was assumed, the average confidence interval based on sampling errors on the two routes was plus or minus 1.17 minutes, well below the assumed level of 1.5 minutes. The complete sample was also very accurate - for all segments examined in the study, travel times could be considered accurate at the 95% level to an average of plus or minus 1.27 minutes.

Table 1.5 GPS output for Route B Segments, Inbound and Outbound

		Segment	Sample n	Actual n	Mean travel time (min)	Std. Dev. Of travel time (min)	95% CI (min)	Mean Speed (km/h)	Posted Speed Limit (km/h)
Inbound	**Peak**	**7**	5	4	12.36	1.36	1.15	27.43	60 – 70
		8	5	5	8.38	1.81	**1.52**	39.24	70 – 80
		12	5	5	6.99	1.96	**1.65**	29.92	60
		18	5	5	5.77	1.41	1.18	33.74	60
	Peak Shoulder	**7**	5	7	8.94	2.32	**1.95**	38.86	60 – 70
		8	5	23	5.31	0.48	0.36	59.44	70 – 80
		12	5	26	4.19	0.51	0.38	45.57	60
		18	5	7	4.78	0.35	0.29	38.96	60
	Medium Volume	**7**	5	12	8.94	1.87	**1.61**	40.42	60 – 70
		8	5	18	6.19	2.15	**1.84**	53.81	70 – 80
		12	5	19	4.67	0.69	0.59	41.23	60
		18	5	15	5.1	0.66	0.57	36.59	60
	Low Volume	**7**	-	1	8.06	-	-	40.60	60 – 70
		8	-	6	5.17	0.72	-	61.77	70 – 80
		12	-	1	2.99	-	-	62.80	60
		18	-	2	4.35	1.56	-	44.95	60
Outbound	**Peak**	**7**	5	5	9.6	1.32	1.13	35.76	60 – 70
		8	5	26	6.45	0.73	0.55	49.54	70 – 80
		12	5	23	5.44	1.3	1.00	36.33	60
		18	5	22	5.58	1.26	0.98	34.78	60
	Peak Shoulder	**7**	5	3	7.35	2.87	**2.47**	46.33	60 – 70
		8	5	7	6.23	0.76	0.64	51.50	70 – 80
		12	5	6	4.31	1.25	1.06	45.37	60
		18	5	6	5.13	1.04	0.88	37.52	60
	Medium Volume	**7**	5	9	8.31	0.71	0.61	41.20	60 – 70
		8	5	18	6.39	0.85	0.72	50.57	70 – 80
		12	5	19	4.89	1.26	1.07	40.36	60
		18	5	14	5.81	0.92	0.79	32.77	60
	Low Volume	**7**	-	-	-	-	-	-	60 – 70
		8	-	6	5.85	0.87	-	55.12	70 – 80
		12	-	7	3.88	0.58	-	48.91	60
		18	-	6	4.53	0.61	-	41.90	60

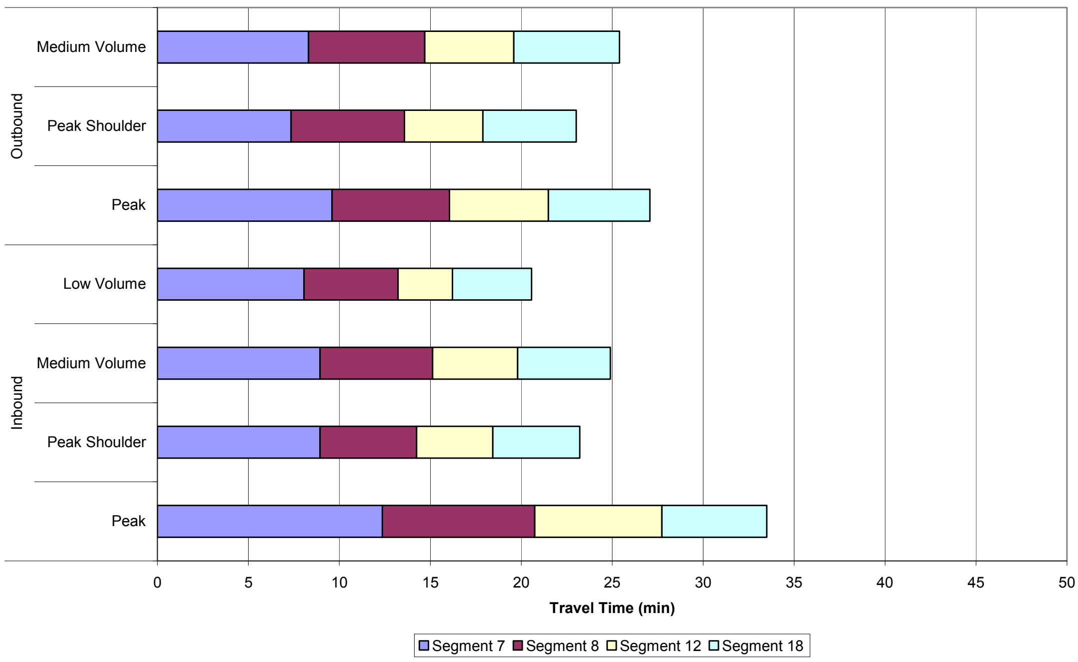

Figure 1.6 Travel Times for Route B Segments

6.2 Route travel times

By combining the means observed for each of the segments, one can estimate overall route travel times (Table 1.6). Similarly, the confidence intervals derived from the sampling errors can be summed to provide an estimate of the accuracy of the combined travel times. No observations were collected for Segment 7 outbound during the low volume period, and so a combined travel time for Route B during this period is not shown in Table 1.6.

Table 1.6 Amalgamated Route Travel Times

Route	Direction	Peak		Peak Shoulder		Medium Volume		Low Volume	
		Agg. Mean	Agg. CI	Agg. Mean	Agg. CI	Agg. Mean	Agg. CI	Agg. Mean	Agg. CI
A	Inbound	47.96	6.95	37.73	5.98	38.59	5.33	31.78	-
	Outbound	38.69	4.33	40.85	5.97	37.65	4.68	30.8	-
B	Inbound	47.06	6.88	37.11	4.41	40.6	6.57	33.17	-
	Outbound	42.38	5.08	39.61	6.58	40.65	5.06	-	-

It is interesting to note that there is very little difference between the inbound travel times for the two routes; the largest discrepancy being only 2.01 minutes during the medium volume period. Neither of the routes appear to offer any distinct time savings, which suggests the main arterials are operating close to their maximum capacity, at least during the am peak. Differences in outbound times were more noticeable between the two routes. Most of these differences are numerically quite small, however, with the possible exception of the peak period. For the outbound peak and medium volume periods, Route A was found to be faster than Route B, while the reverse was true for the peak shoulder period. It is interesting to compare the inbound and outbound travel times within the two routes. A.m. peak travel times were always slower than p.m. peak times, while the reverse was true in the peak shoulder periods. This again confirms the tendency for peak spreading during the evening. There are no substantive differences between travel times for medium periods. The confidence intervals for the combined segment times range from plus or minus 4.33 minutes to plus or minus 6.95 minutes.

7. Conclusion

The main challenge of conducting traffic studies with GPS lies not in the data collection or analysis, but in the vehicle scheduling and processing of data. If a large number of routes or segments need to be examined across two or three periods of the day, sample design may be complicated, and data collection difficult. A large number of randomly drawn segment start times may take some time to arrange into workable driving schedules. In addition, data processing is, for all practical purposes, impossible to do effectively in the absence of specialised GIS-based software applications.

However, the benefits clearly outweigh these difficulties. GPS data are highly accurate, while data collected using a stopwatch and clipboard or DMI technique tend to be inaccurate and are often subjective. In addition to improvements in the data quality, GPS allows more data to be collected at lower costs. GPS has the added bonus of operating independently of the driver of the vehicle, which reduces researcher burden.

Because passive GPS operates independently of the driver, it makes it an attractive survey instrument, particularly in the context of a traffic study, where respondents are required to give little or no information beyond what is collected from the GPS device (unlike, say, a household travel survey). Even basic output on travel times and speeds provide extremely rich data on driving cycles and the incidence and severity of congestion. The confidence intervals estimated from the sampling errors show that samples of only 5 observations can provide data sufficiently accurate for validating traffic models.

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