DEVELOPMENT AND IMPLEMENTATION OF A GPS/INTERNET-BASED DESIGN FOR LONGITUDINAL BEFORE-AND-AFTER TRAVEL BEHAVIOUR STUDIES

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ABSTRACT

This paper details the development and implementation of a technological solution to support a longitudinal (10 week) study of driving behaviour in Sydney, Australia. The aim of the study was to facilitate, predict and detect changes in driving and encourage safer driving practices through kilometre-based charges that varied based on the drivers themselves and how much, when and how they drove (specifically speeding). The study comprised a five-week 'before' period of monitoring to establish how motorists drove normally, followed by a five-week 'after' period of monitoring in which charges were levied and changes assessed. Financial incentives were then paid to motorists for any reductions in charges between the two five-week periods. The data requirements of the study were intense: 10 weeks of detailed driving usage information (Vehicle Kilometres of Travel, times, speeds and speeding, origins/destinations and routes) together with additional information on trip purpose, who was driving and the number of passengers without unduly burdening participants. The solution used Global Positioning System (GPS) technology to derive the driving usage information and provide the basis for an Internet-based survey, in which participants were able to view their trips from the previous day and provide the additional trip information in a straightforward Google-map style interface. An additional feature of the study was the wireless transmission of the GPS data in near real-time for processing enabling the quality of data to be regularly assessed and any problems/issues attended to quickly as well as providing the basis for the update of the Internet survey in a timely manner. The paper details implementation of the approach for the 148 motorists participating in the study and includes an assessment of the quality of data and reaction of participants to providing data for this length of time gathered through exit interviews. The over-riding conclusion drawn is that new technologies are opening up possibilities for conducting (previously impractical) surveys of travel behaviour, with relatively marginal impacts on participant burden.

Keywords: GPS, Prompted-Recall, Longitudinal surveys, Before-and-after surveys

INTRODUCTION

Over the last fifteen years, developments in Global Positioning Systems (GPS) have revolutionised the potential to improve the accuracy and precision of travel data. This has most noticeably been demonstrated through the many validation studies of conventional diary-based household travel surveys done using GPS in the United States (Nustats, 2008) and Australia in particular (Stopher and Greaves, 2009). Building on the use of GPS as a means to improve existing data collection efforts, is a growing recognition of the potential of GPS to open up new possibilities in understanding travel behaviour. First, GPS provides the potential to extend the period of data collection with (arguably) little additional respondent burden. For instance, applications in which a GPS is installed within a vehicle have successfully collected data for several weeks (Nielsen et al. 2004) and in the case of the Atlanta Commute project, multiple years (Elango et al. 2007). Other researchers have demonstrated that well-designed personal GPS systems (which have to be physically carried around and charged) can be used to collect data for around one month (Stopher et al., 2008; Li and Shalaby, 2008). Second, the easy integration with digital-based maps coupled with developments in web-based technology has facilitated the potential to go back to participants to both confirm trip details are correct and prompt them for information not directly discernible from GPS data such as trip purpose, who was driving, number of passengers etc (Auld et al., 2009; Doherty et al. 2006). Third, the capability to provide new data elements (speeds etc) opens up new avenues for investigation in driving behaviour, a topic of increasing interest primarily from a safety perspective (Jun et al. 2006).

Within this context, the current paper details both the development and implementation of a GPS/Internet-based prompted-recall solution to support a longitudinal study of driving behaviour in Sydney, Australia. The aim of the study was to facilitate, predict and detect changes in driving and encourage safer driving practices through kilometre-based charges that varied based on the drivers themselves and how much, when and how they drive (specifically speeding). The data requirements of the study were intense: several weeks of detailed driving usage information (Vehicle Kilometres of Travel, times, speeds and speeding, origins/destinations and routes) together with additional information on trip purpose, who was driving and the number of passengers without unduly burdening participants.

The merits of using GPS technology for this type of application have been witnessed through a number of experiments focused around motorist responses to kilometre-based charges (e.g., Nielsen et al., 2004; Xu et al., 2009). While the primary focus has been congestion-mitigation, there have been a few examples focused on encouraging safer driving. In the Dutch *Beloniter* study, motorists were rewarded for staying within the speed limit and maintaining a safe following distance (Mazureck and van Hatten, 2006). They found that speeding was reduced by around 20 percent based on a reward of 0.04 Euros for every 15 seconds spent not speeding – notably, once the rewards were removed, drivers largely reverted back to their original behaviour. In a similar study, the Swedish Intelligent Economic Speed Adaptation study participants were paid a lump sum bonus, which was reduced by a certain charge for every minute participants drove above the speed limit within the study period (Gunnar et al., 2005).

The system was piloted in June/July of 2009 on 30 motorists for a period of eight weeks, to gauge their acceptance of the technology and use of the prompted-recall over this extended a period of time (Greaves et al. 2010). The results were largely positive with only one motorist dropping out and an estimated 3 percent missing trip rate, which was largely attributed to connection problems between the GPS device and the vehicle cigarette lighter. Following a recap of the major elements of the technological configuration, the focus of this paper is on the main survey, which involved 148 motorists and many more challenges and issues than were involved with the pilot survey.

STUDY OVERVIEW

The study involved four major phases, depicted in Figure 1. Following recruitment, motorists were provided with an in-vehicle GPS device, which recorded their driving for the five week 'before' phase. At the end of the five-week period, half of the sample completed a Stated Choice (SC) experiment designed to hypothetically assess their sensitivities to a kilometre-based charging regime focused around reductions in kilometres, night-time driving and speeding (Fifer et al., 2010). Note, the GPS data was used to provide the context for the reference alternatives in the SC experiment, injecting a greater level of realism into the choice sets. In the 'after' phase, motorists were offered the opportunity to make money by reducing kilometres, night-time driving and speeding, relative to the 'before period' with the charges set to the same rates as those they had seen in the SC experiment. Finally, the other half of the sample completed the SC experiment while the first sample repeated the SC experiment to see if their responses changed after having actually experienced a real kilometre-based charging scheme. This splitting of the sample was designed to test any differences in the order of completion and hence measure the affect of experience. It is crucial to stress that no mention was made at the time of recruitment of the behavioural change experiment and the potential to make money through changes in driving, because of the potential to affect driving in the 'Before' phase. Motorists were simply told they were being invited to participate in a 12 week GPS study of driving in Sydney.

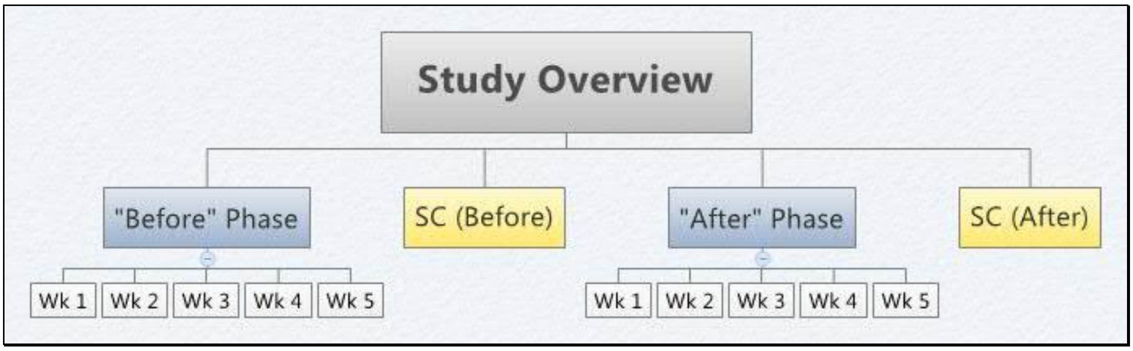

Figure 1: Study Design

The Charging Regime

The charging regime used in both the SC and GPS experiments is shown in Table 1. While full details of how the charging regime was established are provide provided by Greaves and Fifer (2010), a summary of the key issues are provided here. The basic rationale of the scheme was that motorists would be 'rewarded' financially for reducing their kilometres, night-time driving and speeding relative to the before period. The rates were set based on crash-risk and crash-cost information for Sydney as well as pragmatic issues relating to motorist comprehension of the scheme and rates that were substantial enough to warrant some change in behaviour while staying within the project budget.

Table 1 - Per Kilometre Charging System (Adapted from Greaves and Fifer, 2010)

Charging Rates	17-30 Age-Group	31-65 Age-Group
Day - Non Speeding	$0.20	$0.15
Day - Speeding	$0.60	$0.45
Night - Non Speeding	$0.80	$0.60
Night - Speeding	$2.40	$1.20

The rates were combined with the relevant GPS data for each motorist to establish, a 'base incentive', which (in effect) represented the maximum amount they could make in the 'after' phase. Money was deducted from this base incentive according to if/how they drove and motorists were able to see this updated on both a trip-by-trip and daily basis via the project website, detailed later in the paper. The range of 'base incentives' ran from AU$25 to $AU879, with an average of AU$300. For a five-week period, these were deemed significant amounts of money that could potentially be made.

SYSTEM SETUP

The system setup for the study is shown in Figure 2. Following recruitment, participants were provided with a GPS data logger, which transmitted second-by-second information in near real-time to our project partner, Smart Car Technologies (SCT) central server for map-matching (including the tagging of speed limit) and processing into trip records. Processed trip summary files and second-by-second GPS files were then transmitted nightly to the University of Sydney Webserver, where they were downloaded to form the basis for an

Internet-based prompted-recall survey. Participants could then log in to the survey and provide the required trip information, which would be automatically written to the database. Each of the system elements is now described in more detail.

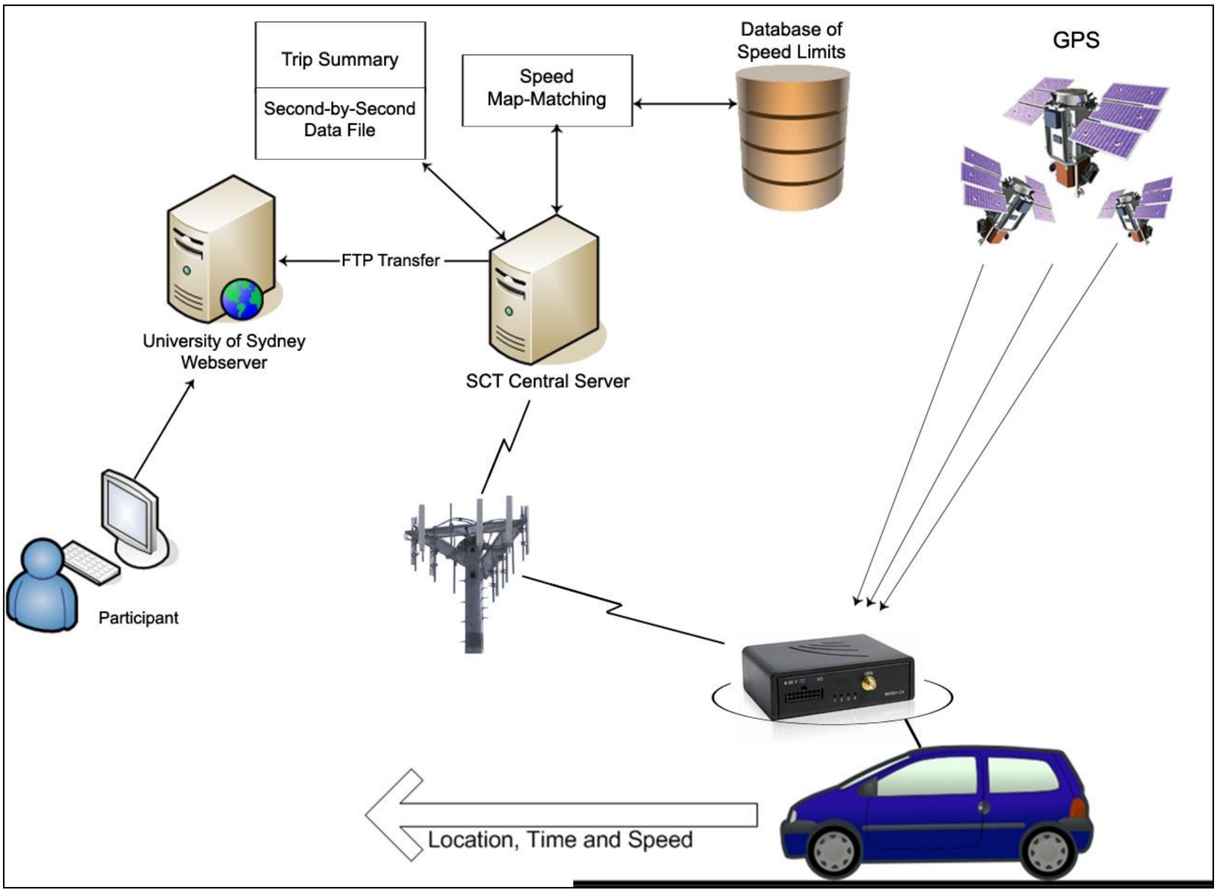

Figure 2 – System Setup

The GPS Device

The device selected was the C4 Mobile Device manufactured by Mobile Devices Ingenierie (Figure 3) because it met the main specifications of the project. First, it required little of participants other than to keep it plugged into the cigarette lighter. Second, it was able to provide the second-by-second GPS data for accurate speed information used in the assessment of speeding. Third, through built-in GPRS functionality it was able to transmit data in near real-time, required both for checking data as it came in and to provide the basis for the daily update of the prompted-recall survey. Finally, it was priced within the resource constraints of the project at around AU$400/device. The device was configured to be powered from the cigarette lighter such that the GPS would 'wake up' when the engine ignition was switched on and 'sleep' when the engine was switched off to enable the automatic detection of trip-ends.

Data Logger In-vehicle charger Antenna

Figure 3 – The C4 Mobile Device

Data Processing

The data processing phase of the project involved the following steps. First, the regular transmission of the data enabled real-time monitoring through Google Earth to ensure the system was always working and to quickly address any general problems that arose. It must be stressed here participant privacy was strictly maintained in that details of participants were only accessible to the University of Sydney research team. Second, the GPS data were map-matched to a GIS-based representation of the Sydney street network, which includes accurate speed limits, collected by SCT. The speed limit database has been developed from the ground up by driving all the streets in Sydney and includes temporal variations in speed limits such as school zones[1]. Third, the map-matched GPS data were then aggregated into trip files, which provided summary information (origin, destination, distance, time, speeding behaviour etc) for each trip undertaken by a participant for a particular day. The summary files were downloaded nightly (automatically through a batch process job) with the second-by-second GPS data to the University of Sydney Webserver. This download procedure included the first phase of a data-checking component via a short report that covered issues relating to:

- *Participants* (number of trips for the previous day, how long since they had logged into the prompted-recall survey, days since last GPS activity),
- *Very short trips* such as moving a car in a drive-way (defined as less than 100 meters), and
- *Potential missing trips* (defined as one trip-end starting more than one kilometre from the previous trip-end).

[1] School zones typically operate from 8:00 a.m. – 9:30 and from 2:00 p.m. – 4 p.m. in Sydney during which time the speed limit is reduced to 40 km/h.

Web-Based Prompted Recall Survey

The specifications for the prompted-recall survey were that it needed to be simple for participants to use, avoid long refresh times and appealing and attractive to keep them motivated for several weeks. Following extensive testing during the Pilot phase of the project, the interface shown in Figure 4 was developed. Key elements of the interface were a familiar tabular format that was quick and intuitive to use, the use of open-source mapping software (Google Maps) that refreshes comparatively quickly on the majority of browser/connection setups, and optional viewing of trips. This last point emerged as important because of the slow refresh speed of Internet Explorer (still the most widely used web browser) even using a high-speed connection combined with the fact that the repetitive nature of most travel implied participants did not need to see a visual depiction for most of the trips to jog their memory on the other trip attributes.

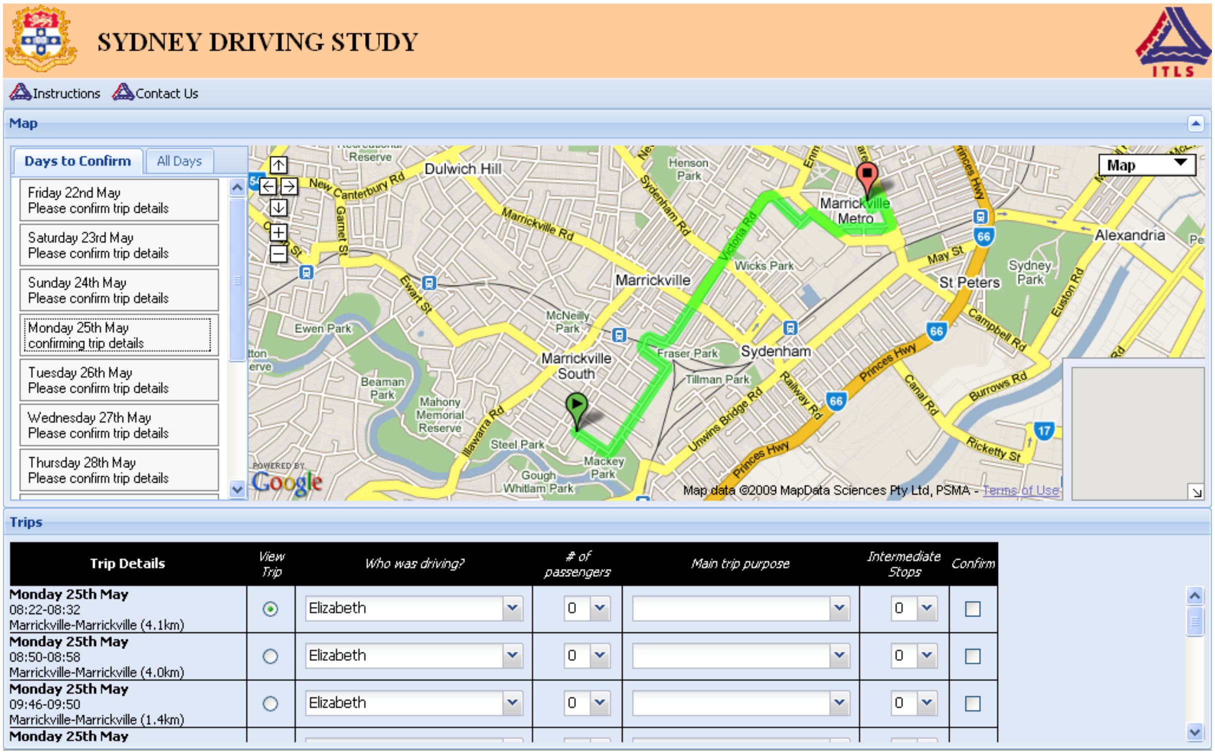

Figure 4 – Prompted-Recall Survey Interface (Before Phase)

To access the interface, participants were sent a URL via the survey management interface (see next Section), which was unique to them (they were advised to Bookmark) and took them straight to their trips without having to remember logins and passwords[2]. Once in the interface, clicking on a day under 'Days to Confirm' brought up the trip list for that day underneath the map. Participants could view the trip to 'prompt' their memory and then fill in some simple information on the trip; namely who was driving, the number of passengers, the main trip purpose and whether any intermediate stops were made (e.g., dropping off children at school on the way to work). At the bottom of the trip list was a dialogue box enabling participants to record any missing trips or other data issues they notice. Once they had

[2] The login key was generated by running a cryptographic hash (MD5) on a random sequence of 32 characters which is then checked to make sure it is unique to that specific participant.

finished the trip is confirmed, meaning that data is written to the database (they could unconfirm and change information) until all days were completed.

Survey Management Interface

The survey was managed through a similar interface to the one shown Figure 4, which was only accessible to survey managers (Figure 5) and enabled them to do the following:

- Check the general status of each participant including last GPS update, time since last login to the website and where the GPS devices were currently located. Participants would be sent a reminder e-mail if there had been no GPS activity for more than 72 hours and/or they had not logged onto the prompted-recall for more than seven days. This would be followed up by a phone call if necessary.
- Check short trips and missing trips flagged as part of the daily report.
- Check missing trips flagged by participants.
- Export the GPS second-by-second data and trip data by date range and/or participants as required into a .csv format for further analysis.
- E-mail participants with the weekly newsmail on the study, reminders and their unique URL (generated through encryption programming) for logging into the prompted-recall survey.
- Generate graphs and reports of travel characteristics to date by participant and as an aggregate across the sample.

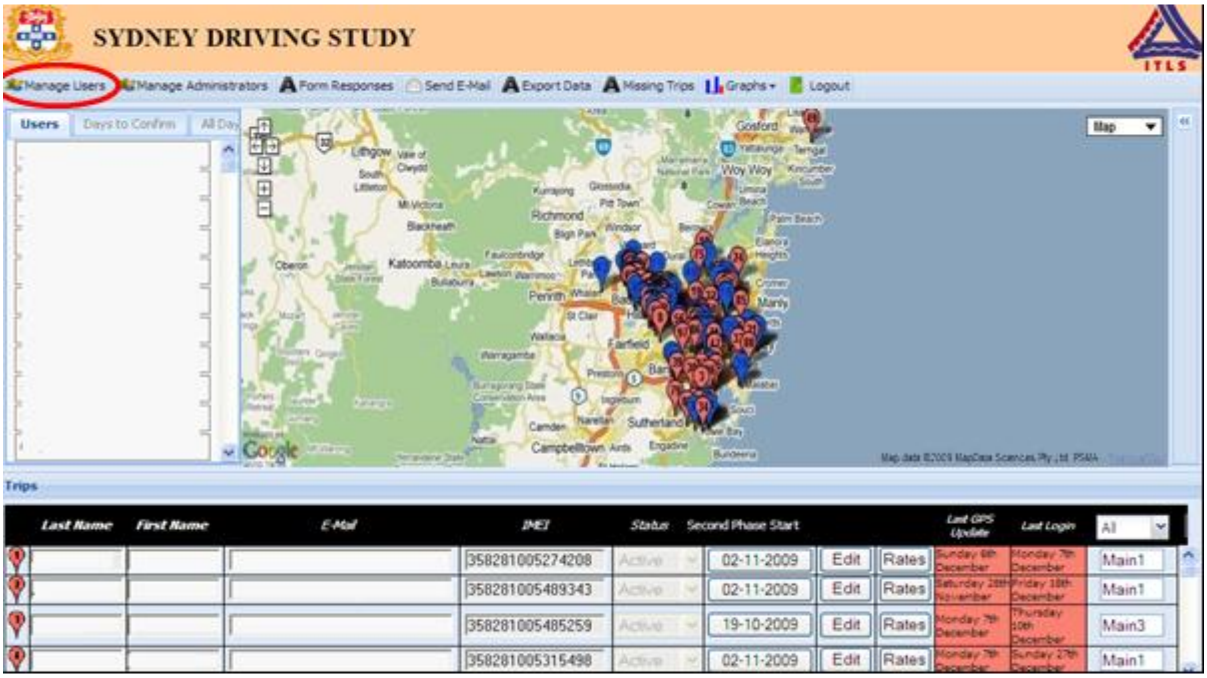

Figure 5 – Survey Management Interface

Driver Feedback

During the 'after' phase, the interface was changed to provide feedback to drivers on the costs of their travel (Figure 6). Each trip now included the percentage of time over the speed limit, whether the trip was made during the day or night and the associated cost of that trip. The graph on the right showed their starting/base incentive and how much they had remaining. As with the 'before' phase, the interface was updated daily.

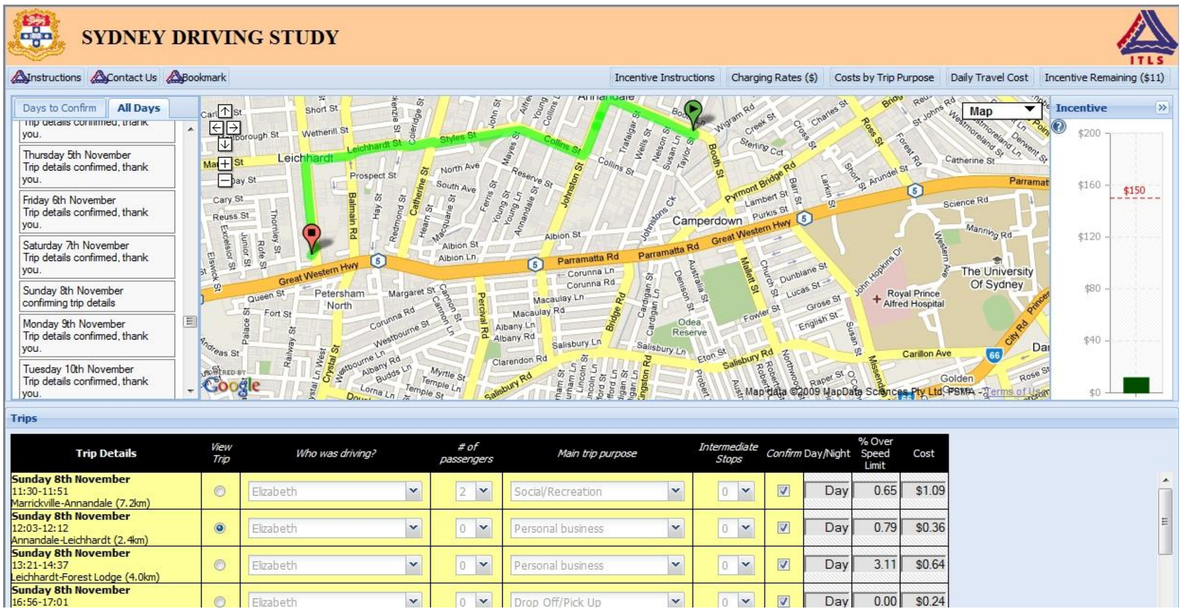

Figure 6 - Prompted-Recall Survey Interface (After Phase)

SURVEY IMPLEMENTATION

Recruitment

Participants were recruited from six suburban hubs and surrounding suburbs (Chatswood, Hurstville, Parramatta, Strathfield, Randwick and Sutherland) in the Sydney metropolitan area. Participants were recruited via an online panel according to strict criteria that reflected the main aims of the study as well as practicalities about using the equipment. In terms of the main aims of the study, only participants with a valid license from one-car households were recruited[3] and they needed to be the primary driver and drive more than two days per week on average. In terms of practicalities, cars needed a working cigarette lighter, which did not stay on when the engine turned off (a problem for a very small proportion of high-end vehicles in Australia) and needed to be parked off-street at night. Unfortunately, this last criterion was imposed following the pilot study in which two devices were lost in the first week because they were in vehicles that were parked on-street that were stolen and later dumped[4].

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[3] The proportions of one-car households in the selected suburbs were Chatswood (48%), Hurstville (46%), Parramatta (50%), Strathfield (35%), Randwick (51%) and Sutherland (52%).
[4] Perhaps ironically, these were the only two devices out of 150 that were lost in the entire study.

All the devices were delivered face to face using a local field force agency at a cost of approximately AU$50 per participant. The use of couriers for device delivery was originally considered but face to face delivery was finally chosen as the preferred method for several reasons. First, the device could be installed by the fieldworker – even though the installation was simple, never-the-less, it was critical to ensure this was done correctly. Second, odometer information (used to cross-check the distance information coming off the GPS device) could be collected and consent forms signed rather than having to wait for people to return this information. Third, because of the way couriers schedule deliveries (they are paid based on attempted deliveries if a signature is required) and specify wide time-windows in Sydney, it proved very difficult to ensure the devices were delivered safely and/or cost-effectively. Finally, and most importantly, the survey required considerable 'buy-in' from participants, which was thought to be more effectively achieved using face-to-face trained interviewers.

The original aim was to recruit 148 motorists (based on the number of available devices) with equal proportions of young (17-30 year-old drivers) and middle-aged (31-65 year-old drivers). Recruitment was initiated by e-mailing panel members with details of the study. The recruitment and final sample composition is shown in Table 2. Interested panel members went through the screening survey to determine eligibility, which resulted in 429 people qualifying for the study. Of this number, 376 people notionally agreed to participate with 148 devices being installed. Unfortunately, recruitment proved much more difficult and slower than anticipated. This was primarily due to scheduling difficulties brought about by the lack of flexibility with delivery times by respondents, a restricted number of field staff available, problems at delivery such as the cigarette lighter turning out not to work, and the demographic quotas imposed. This last point primarily refers to the fact that it proved very difficult to recruit young drivers, particularly males as shown in Table 2. The breakdown by suburb (which did not stipulate the need to be evenly spread) was Parramatta (50), Strathfield (30), Chatswood (17), Sutherland (24), Blacktown (19), and Randwick (8). In total the installation process lasted 6 weeks, instead of the expected 2 week duration. By the end of the fieldwork period some participants had actually been participating in the study for as long as four months.

Table 2 – Sample Recruitment and Breakdown Details

	No. of Participants
Number qualifying	429 (100%)
Numbers notionally agreeing to participate	376 (88%)
Numbers actually recruited and installed	148 (34%)
Demographics (n=148 100%)	
Male 17-30 years of age	16 (11%)
Female 17-30 years of age	25 (17%)
Male 31-65 years of age	52 (35%)
Female 31-65 years of age	55 (37%)
Target Sample	119 (80%)
Control Sample	29 (20%)

Also shown in Table 2 are the 'target' and 'control' samples. The target sample refers to participants who received incentives to change behaviour during the after period, while the control sample did not. Rather, they were included to establish whether there were any external influences that may have impacted changes in driving behaviour.

Participant Issues

During the course of such a complex and long-duration data collection such as this, it was perhaps inevitable that despite the best efforts of the survey team, there would be participants dropping out and/or other reasons affecting data completeness. Overall, 117/148 (79 percent) participants provided usable data for both the before periods with 108/119 (91 percent) of target participants and 9/29 (31 percent) of control participants complying respectively. Table 3 summarises the reasons for this loss of numbers. Focusing on attrition, 12 participants dropped out due to loss of interest/fatigue (all in the control group) while only two target group participants and four control group participants had incomplete prompted-recall data for the comparison time periods. Intuitively, the opportunity to make money kept the target participants interested while unfortunately control participants lost interest and motivation as the study extended well past the original ten weeks. In terms of other issues, despite incorporating screeners about the need for constant power from cigarettes lighters, three participants were still lost from the study due to this problem. Another two participants dropped out due to 'computer issues' meaning they could not visit the website. In addition, one target participant changed their vehicle the day before the after period commenced and failed to put the device in the new vehicle, claiming he was under the impression that this was based on changes in driving in the original vehicle! An additional issue that emerged during the after phase of the study was the taking of extended holidays (greater than one week, involving no driving) by eight target participants. These participants were excluded from the target sample because their data no longer allowed for an accurate comparison to the 'Before' period. However all participants were invited back to participate in a further driving study phase in February 2010.

Table 3 – Participant Issues During the Data Collection

	Target	Control
Original Number	119	29
Dropped Out	0	12
Incomplete Prompted Recall	2	4
Device Problems	0	3
Computer Issues	1	1
Holiday Participants	8	0
Final Usable Sample for Before and After Analysis	**108**	**9**

A final, yet important point to make in the context of participant issues was device retrieval. This proved particularly problematic in this study with 20 percent of participants requiring at least five reminders (e-mail, SMS, personal call) to return the device. The last device was finally retrieved more than three months after the survey ended.

Data Issues

It must be stressed that GPS has been widely demonstrated to be a superior method of recording travel than relying on personal recall (Stopher and Greaves, 2009). However, it is still susceptible to missing data caused by both unintentional and intentional removal/tampering with the device. In this study, other than three devices that malfunctioned, the main reasons for missing data were identified as participants removing the device (presumably for security reasons) and then failing to remember to put it back into the cigarette lighter. To this end, several assessments of data quality, largely focused on missing data were run and are reported here as a precursor of using the data.

No Travel Days

Table 4 summarises information on the total number of days of travel days recorded by the GPS for the before and after periods for the target and control groups. The table also indicates days for which data were not recorded. The main issue from a data quality perspective is to ascertain whether these days were genuine no travel days or whether they were days when the participant had travelled but data had not been recorded. To try to derive this breakdown, the survey interface included a tab in which participants could indicate missing trip problems. This proved much more effective at helping to identify missing trips within days (see next Section) than missing days, something that was not picked up until well into the study. To try to redress this problem, participants were asked via a pop-up at the end of the study to confirm days for which no data were recorded as genuine no travel (with a reason) or missing. This proved effective for the target group with only one percent of zero travel days remaining unconfirmed. For the control group, the strategy was less effective, something attributed to the general loss of interest/motivation among these participants.

Table 4 – No Travel Days

	Target		Control	
	Before	After	Before	After
Total days of recorded GPS travel	3326	3068	321	393
Zero travel days	523 (14%)	728 (19%)	78 (20%)	72 (15%)
Confirmed no travel days		617 (16%)		18 (4%)
Confirmed missing GPS days		88 (2%)		9 (2%)
Unconfirmed no travel days		23 (1%)		45 (10%)

Missing Trips Within Days and Missing Trip Segments

Detection of missing trips within days for which GPS data had been recorded involved a two-pronged approach. First, the aforementioned missing trip tab enabled participants to self-report problems and second, manual checking using the GIS-based maps was employed. Table 5 provides a breakdown of the number of reports and number of missing trips self-reported by participants. In all, 57 participants reported 192 missing trips in the before period while 52 participants reported 153 missing trips in the after period. Of those who self-reported, around two percent of their trips were identified as missing. These missing trips were more likely to be the first trip of the day, particularly following a period of driving inactivity. This was attributed to the 'cold-start' problem, which refers to the time-lag required by a GPS receiver to detect sufficient satellites to acquire accurate position.

Table 5 – Self-Reported Missing Trip Frequencies

Before Period		After Period	
Number of Reports (Participants)	Number of Missing Trips (Participants)	Number of Reports (Participants)	Number of Missing Trips (Participants)
11 (1)	17 (1)	13 (1)	15 (1)
10 (1)	12 (1)	7 (1)	11 (1)
9 (1)	11 (1)	6 (2)	9 (1)
8 (3)	10 (2)	5 (3)	8 (2)
6 (1)	9 (1)	4 (2)	7 (1)
5 (3)	8 (1)	3 (4)	6 (1)
4 (2)	7 (1)	2 (10)	5 (2)
3 (7)	6 (2)	1 (29)	4 (6)
2 (13)	5 (2)		3 (4)
1 (25)	4 (3)		2 (10)
	3 (10)		1 (23)
	2 (12)		
	1 (20)		
152 (57)	**189 (57)**	**116 (52)**	**153 (52)**

Missing trip segments were primarily attributed to the aforementioned cold-start issue. From the perspective of the study, the main issue here was trying to account for this in some way to get better estimates of VKT. VKT for the missing segment was inferred based on the straight-line distance between the previous trip-end and the start of the new trip using the algorithm for the great circle of the earth:

$$d = \frac{\sqrt{69.1 \cdot (\varphi_a - \varphi_b)^2 + (69.1 \cdot (\lambda_b - \lambda_a) \cdot \cos\frac{\varphi_a}{57.3})^2}}{0.621}$$

Where:

φ = latitude; λ = longitude
a =origin point; b = destination points

Clearly, being a straight-line distance, this will under-estimate VKT, but as long as this under-estimation is consistent across the two periods, in itself this is not a serious issue. Overall, the proportion of missing trip VKT to total VKT inferred using this approach was 1.6 percent for the before period and 1.4 percent for the after period.

VKT Audits

Given the nature of this study, where participants were to be rewarded for reductions in VKT among other things, it was important to check the VKT coming from the GPS against an independent source, namely the odometer. An initial odometer reading was taken at the time of installation by the field-worker responsible for device installation. A second reading was required just before the after phase via a website pop-up stipulating participants provide the reading as part of the eligibility criteria for the incentive-based phase of the study. A final reading was required on completion of the study, which the participant wrote on a pre-attached odometer card stuck to the device, the notion being they would write down the reading as they uninstalled the device. 102 participants provided all three odometer readings – interestingly, it emerged that a particularly effective method for getting the readings was via SMS, where participants could simply reply to the SMS with the odometer reading while in their car, automatically giving the time and date of the reading.

Overall, the GPS-based estimates of VKT were eight percent lower than the odometer-based estimates in the before period and 12 percent in the after period. Viewing this on a participant-by-participant basis (Figure 7) highlights some clear anomalies with readings varying by as much as 90 percent. It must be acknowledged that while the GPS estimates of VKT would be expected to be lower than odometer-based for all the reasons discussed previously, odometer readings themselves are clearly prone to error themselves an several of the larger discrepancies appear to be due to odometer reading problems.

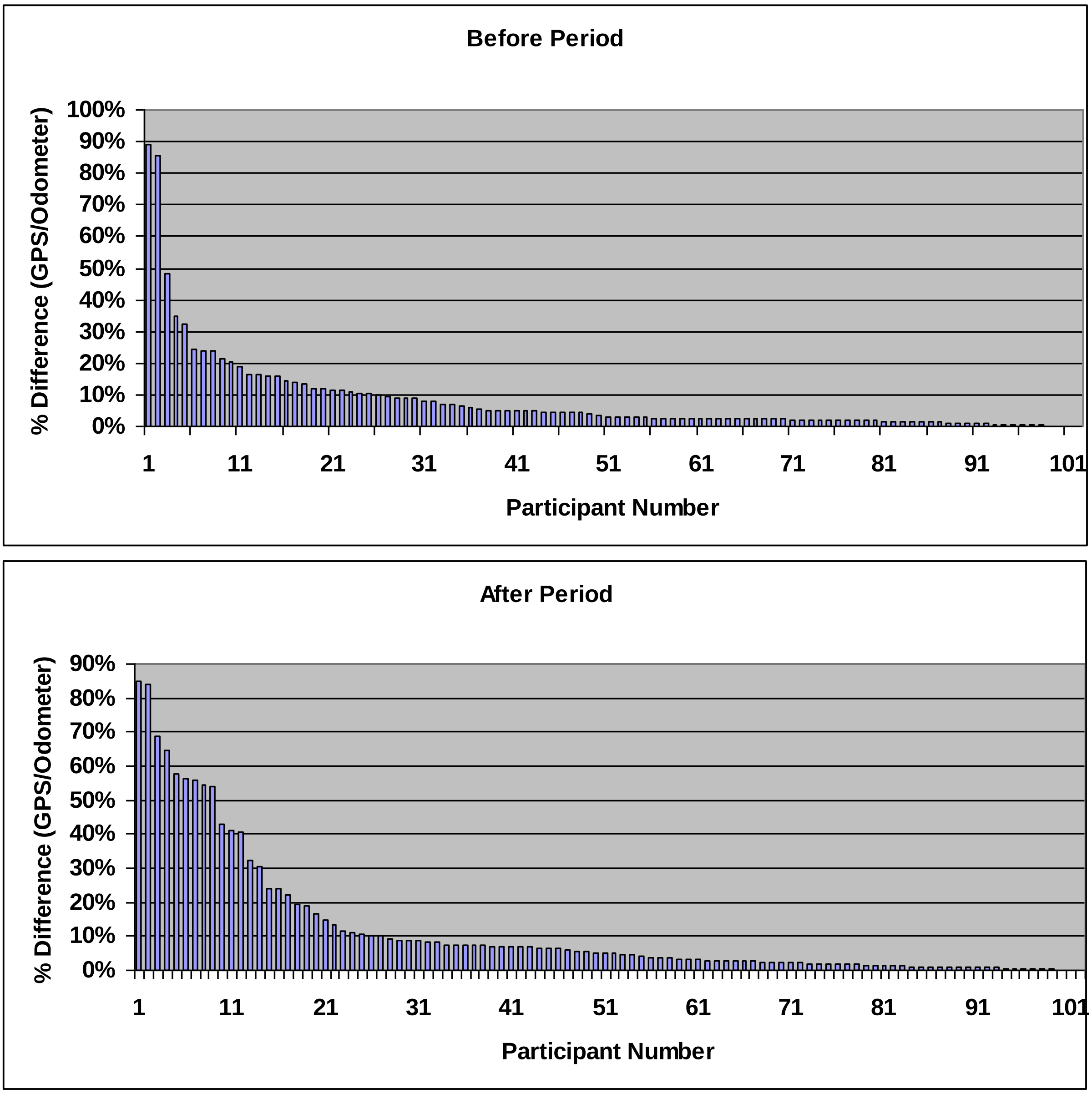

Figure 7 – Percentage Difference in GPS-Based VKT Estimates versus Odometer-Based Estimates

Intentional Misreporting

While most of the data issues identified were due to unintentional problems, clearly there was the potential in an experiment where money could be made for intentional misreporting. The main avenues for misreporting were tampering with the GPS device and the odometer audit. In terms of the GPS device, the simple fact was it could not be proven either way. Rather than focus on this, the wider issue was the reliance on the cigarette lighter for power, which while making the detection of trip-ends easy, made it more susceptible to power loss. Ideally, the device would be hard-wired in to overcome this problem, but this was not permitted by human ethics for this study. An alternative considered during the pilot phase was to have an auxiliary power source (i.e., battery) in the device that would trigger on when the device lost power from the cigarette lighter. However, this involved numerous problems, particularly over the detection of trip-ends. The main check on VKT (the self reported odometer audit) was itself prone to misreporting and ideally the device pick-up and final odometer reading would have been done by trained field staff rather than the motorist. Unfortunately, the experience in the recruitment showed that this could not be done quickly enough, a function of the difficulty scheduling times with participants.

Participant Reaction and Burden

Clearly, the study was demanding, primarily in terms of the time commitment for several weeks on participants and the requirements to visit the website regularly. Unfortunately, unlike the pilot study, the delays in recruitment meant that most participants ended up being in the study for far longer than the intended ten weeks. Undoubtedly this lead to the greater loss of interest compared to the pilot and the higher rates of drop-outs, particularly among the control sample. For the 108 target group participants who did complete all phases of the survey, the reaction gathered though online exit interviews and follow-up telephone calls, was largely positive to both the GPS and prompted-recall components of the survey. Feedback on the GPS device, Table 6 showed that the majority (57 percent) of participants reported no problems with the device. The main complaints were the slow start-up (14 percent), issues with the positioning (10 percent) and problems with the power cord (9 percent).

Table 6 – Exit Survey Feedback on the GPS Device

	Count	Percent
No problems	62	57
Slow to start up	15	14
Inconvenience	11	10
Problems with power cord	10	9
Security concerns	7	6
Needed a new device	6	6
Interfered with radio	5	5
Missing Trips	5	5
Speeding was inaccurate	2	2
Device drained car battery	2	2
Device got very hot	1	1
Not sure	1	1
Total	108	100

Reaction to the prompted-recall website was largely positive, with two thirds of participants reporting no problems or issues (Table 7). The main suggestions for improvements to the website were faster loading speed (which was actually a function of participant browser choice and Internet connection speed) and increased data accuracy. It was clear both from the online and telephone exits that participants had enjoyed the study, particularly the ability to visualize their travel.

Table 7 – Exit Survey Feedback on the Prompted-Recall Survey

	Count	Percent
No problems / easy to navigate	71	66
Sometimes slow / crashed	17	16
Missing / inaccurate data	9	8
Not user friendly / could be improved	7	6
Speeding was inaccurate	5	5
Confused about charging setup	3	3
Liked the maps	2	2
Pop-ups would not close	1	1
Not sure	1	1
Total	108	100

It was also of interest to gauge participant usage of the prompted-recall survey, particularly in terms of burden. The use of a Web server combined with some 'clever' programming facilitated the automatic tracking of usage, providing unique insights into how often they accessed the prompted-recall survey, how long it took to complete, and when they typically completed it. Participants accessed the prompted-recall interface an average of once every 3.2 days (median of 2.5 days) with just under 40 percent of participants accessing the interface at least once every other day. Eleven participants accessed the interface less than once a week. Monday was the most common day for accessing the interface while Saturday was the least common day. The most common time to access the website was in the morning between 8:00 and 11:00 with a relatively consistent pattern of hits until 22:00 (Figure 8). Evidently, the majority of usage of the website was during work hours, probably reflecting the fact that completion does not take long and they may have faster Internet connections at work.

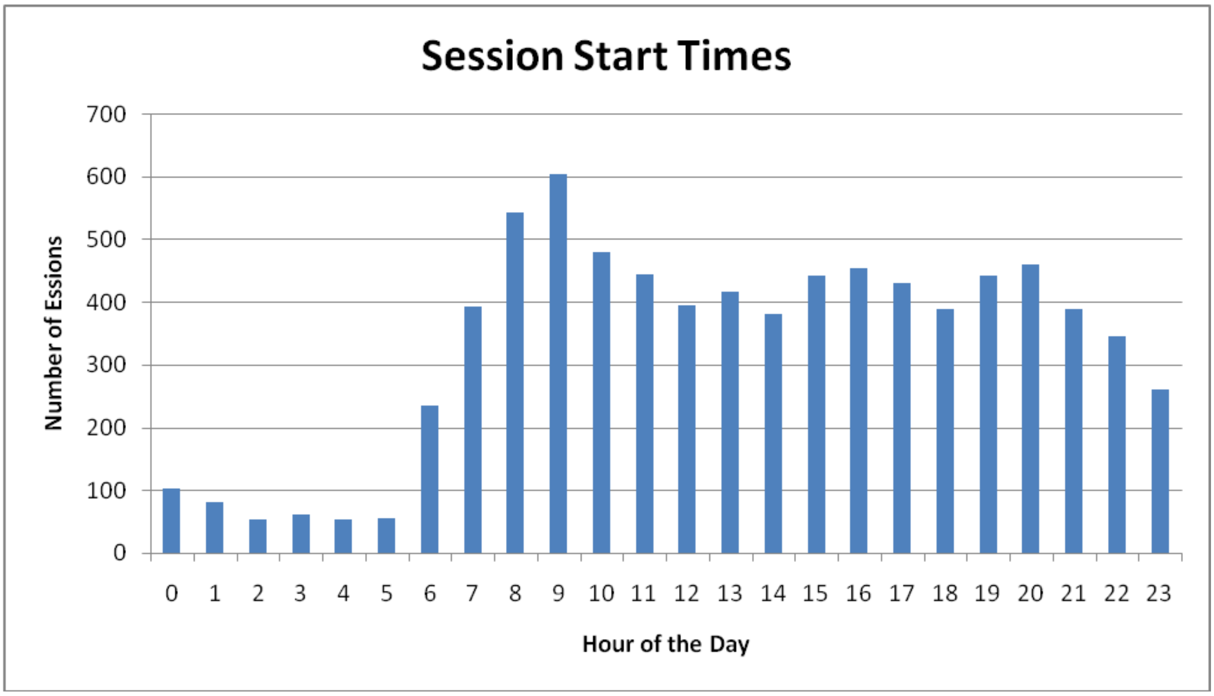

Figure 8 – Session Start times for the Prompted-Recall Survey

The median time taken for participants to enter the details and confirm each trip was 14 seconds. The average time taken was 52 seconds although this was heavily skewed by participants leaving and confirming the trip later, sometimes after several hours. Approximately 80 percent of trips were confirmed in less than 27 seconds with most of the remaining trips confirmed in less than one minute. As Figure 9 shows, the time taken to confirm each trip was highest at the beginning of the study when participants were first using the interface in the weeks leading up to the before period. There was a slight increase in the time taken to confirm each trip after additional trip information (including speeding and cost) was displayed at the beginning of the after period.

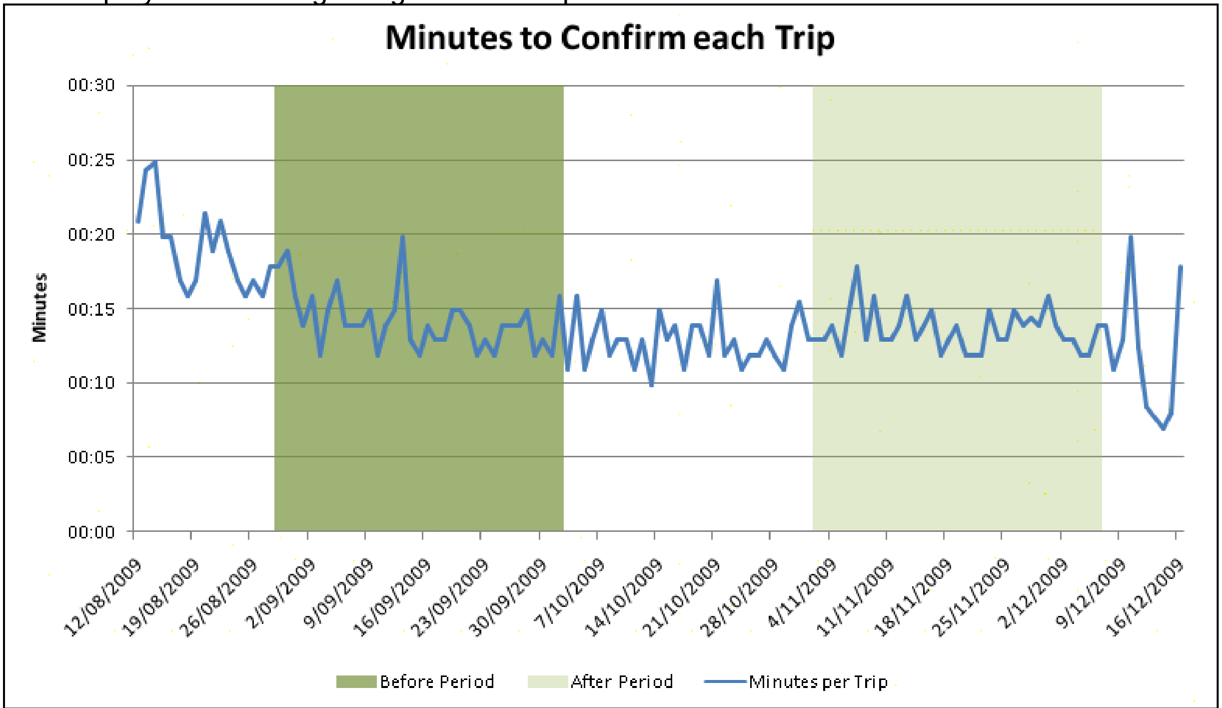

Figure 9 – Time Taken to Confirm Each Trip Over the Study Period

BEHAVIOURAL CHANGE

Although the primary purpose of this paper is to detail the data collection methods used to support the behavioural change study, preliminary results are presented here. Overall, half of the motorists made money (i.e., they reduced kilometres driven and/or night-time driving and/or speeding relative to the five week before period). The average payout for those making money was $82 with the highest payout of $620. Overall, VKT was reduced by 11 percent, day speeding was reduced by 4.3 percent, night speeding by 4.8 percent with no notable change in the proportion of night-time kilometres. Exit surveys and interviews with a cross-section of participants highlighted the difficulties of reducing car travel because of a perceived lack of viable alternatives. Arguably, the most encouraging outcome was that most participants indicated they had become more aware of and motivated to reduce their speeding, supporting evidence from elsewhere (Mazureck and van Hatten, 2006).

One issue that has become clear through the preliminary analysis is that to truly discern the impacts of the money versus other factors lying behind behavioural change, a case-by-case approach is needed (Xu et al. 2009). Even though the study ran for a (relatively) short time, there was a large amount of variability exhibited in peoples driving patterns from week to week. Further to this, the study coincided with many life-events for participants that affected their travel above and beyond the incentive, including moving house, changing job location, and even giving birth. The authors are currently processing this case-by-case information and will publish findings in due course.

CONCLUSIONS

This paper details the development and implementation of a technological solution to support a longitudinal (10 week) study of driving behaviour in Sydney, Australia. Following a successful pilot, the approach combining GPS, GPRS and an interactive web-based prompted recall survey has been extended here to 148 motorists. Recruitment delays early on extended the survey for most participants to four months, but despite this, 108/119 target group participants successfully completed all phases of the study. Reaction to the survey, gathered through exit interviews, was largely positive, particularly in terms of the website and the ability to visualise travel. Usage data, gathered through the prompted-recall survey, suggests that confirming trips typically took no more than a minute or two a day once participants became use to the interface.

In terms of data quality, two percent of days on which no travel was recorded were confirmed as days when participants had gone somewhere with a further one percent remaining unconfirmed. For days on which GPS data were recorded, participants identified around two percent of trips that were missing through the dialogue box on the website - unfortunately, checking/confirming missing trips remains a tedious process, particularly for this amount of data, but algorithms are being developed to try to speed this process up. In addition, around 1.5 percent of data were deemed to be missing from the beginning of trips due to the ‘cold-start’ problem. In this case, VKT (the main issue) was inferred back based on straight-line distance – clearly improvements could be made to these estimates by incorporating network information in the future. Independent checks of VKT from odometer audits showed that 20 percent of participants had a discrepancy of more than 10 percent compared to the GPS-based VKT, attributed to inadvertent or (possibly) deliberate tampering with the device or accidental misreporting of the odometer. Ideally, final odometer readings and device pick-up would have been done by trained field-staff, but for various reasons this was not possible for this study.

While there clearly remain some data challenges, the over-riding conclusion drawn is that this study is one of a growing number demonstrating the possibilities offered by new technologies for conducting (previously impractical) surveys of travel behaviour, with relatively marginal impacts on participant burden. The next logical step could be to take advantage of the proliferation of ‘smart’ devices (e.g., I-phones, Blackberries), which people are increasingly carrying around with them as a matter of course and provide these types of surveys as apps. This would remove the need for having to provide the devices and overcome the time/cost of retrieving devices at the end. Ultimately, the key is to not only make the data collection easier, but to use technology to engage participants in their daily travel-decision making process in a straight-forward and intuitively appealing manner.

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