THE USE OF TECHNOLOGY TO MONITOR FIELD DATA COLLECTION ACTIVITIES

Wende Mix, Gary Shapiro, Richard Huey, Adele Bensur, Westat; and Dennis Utter, Donna Glassbrenner, NHTSA
Westat, 1650 Research Boulevard, Rockville, Maryland 20850

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This paper presents findings and opportunities associated with the implementation of digital technologies in national observational transportation surveys. In the past, the National Occupant Protection Use Survey (NOPUS) has used manual counters and paper forms to collect information on shoulder safety belt use.

Westat has designed an application for a handheld computer known as a Personal Digital Assistant (PDA) with Global Positioning System (GPS) technology to replace the existing data collection method. We describe in detail the technology designed to enhance observational surveys as well as some findings on its impact on cost and data quality. This approach holds promise for home and field interviewer surveys as well as observational surveys. Some of the advantages of the technology are:

- The GPS features validate that the observer is in the right place at the right time and on the right day of the week;
- The timing feature ensures that the observers collect data for the right amount of time;
- The tracking feature of the GPS allows validation of observer movements (while collecting data and traveling between sites), thus providing better information on field costs (mileage and time);
- The data collection software contains validity checks to prevent and correct out of range or invalid responses; and
- Manual coding and data entry are eliminated so errors associated with these activities are removed. Although some data editing is still required, this reduces the amount of calendar time needed for data processing.

This paper is organized as follows. First, some background on what led Westat to develop this PDA/GPS approach to data collection is offered. A brief description of the data collection technology follows. We then propose objective methods to evaluate the use of this approach, in terms of improved data quality and reduced cost. Data from the 2003 National Occupant Protection Use Survey (NOPUS) is used to evaluate the technology.

1. Background

Large surveys, involving numerous field staff spread out over a large geographic area and with short field periods, generally include a basic set of problems that all lead to high, and sometimes extraordinary, costs as well as less than satisfactory data quality. One particular survey, the National Occupant Protection Use Survey (NOPUS) has been conducted by Westat for the National Highway Traffic Safety Administration (NHTSA) on an ongoing basis over the past four years. NOPUS is concerned with the use of shoulder safety belt use. While there are many factors that contribute to the cause and outcome of a motor vehicle crash, one factor that can significantly reduce the injury and fatality consequences of a crash is the use of occupant restraints. Encouraging people to use their shoulder belts and to place their children in child safety seats is a U. S. Department of Transportation/National Highway Traffic Safety Administration (NHTSA) priority. Tracking changes in those use rates is a necessary part of that program. NHTSA began conducting the NOPUS in the fall of 1994 to obtain nationwide estimates of shoulder belt use and of characteristics of their users. It is composed of two separate studies: The *Moving Traffic Study*, which provides information on overall shoulder belt use, and the *Controlled Intersection Study*, which provides detailed information about shoulder belt use by vehicle type, characteristics of the belt user, cell phone use by drivers, and child restraint use.

The survey requires the deployment of field staff to 50 primary sampling units (PSUs) in 137 counties (25 states) within a one-month time period, to collect information on occupant protection. (Each PSU is a set of one or more adjoining counties.) Within each PSU are numerous sites the field staff must visit. At each site, they are expected to collect data from moving or stopped vehicles, for a certain period of time, at a specific time of day, on a specific day of the week. Each time the survey is repeated, the same PSUs with the same sites, with the same data collection rules, are visited.

Over 100 field staff is deployed for data collection. At least six field supervisors travel among PSUs, assisting field staff, checking on their work, addressing any field problems, and coordinating with the home office. This practice is not uncommon in transportation surveys, including metropolitan transit surveys where supervisors show up at scheduled bus runs to make sure the data collector is on-board. Despite the in-depth training of field staff, and the extraordinary efforts by these supervisors and the home office staff, the following types of problems have been known to occur:

- Data are collected at the wrong location (despite the fact field staff are given maps showing the locations of sites and written descriptions of each site location);
- Data are collected at the wrong time of day;
- Data are collected on the wrong day of the week;
- Data are collected for the wrong amount of time;
- Data are not properly reported on data collection forms (generally resulting in item nonresponse);
- Data are not correctly entered into the database (usually due to poor legibility);
- Data collection forms are lost (despite the fact that they are completed in duplicate, and staff is provided preaddressed overnight mail labels and envelopes);
- Unusually high mileage may be billed (compared to prior team submissions and mileage estimates from the maps and schedules); and
- Unusually long labor hours may be submitted (compared to prior team submissions and mileage estimates from the maps and schedules).

If problems such as these are discovered during the field period, generally the sites will be revisited, typically by a new team traveled in from another PSU. This results in higher costs. If some of the problems are discovered after the fact, then a decision is required on whether or not the data should be included in the analysis (and how). Data inconsistent with previous year's data or containing unreasonably low or high counts are not used in the analysis.

PDAs were first used on an experimental basis in the 2002 survey, and were used for half the 2003 survey sample.

2. Data Collection Technology

The PDA/GPS system contains the following components:

- Pocket PC—This variant of the PDA technology uses a Microsoft operating system and includes many features and capabilities similar to those of personal computers including the ability to play and record sounds, display pictures and movies, interface to common peripherals, and perform many typical office operations. Additionally, it is programmable using relatively familiar programming language variants of Visual Basic, C, and others.
- GPS Receiver with a Mobile Accessory Package, includes:
  - GPS Receiver—This receiver is half as big as a cigarette pack and provides the capability to receive and process GPS satellite transmissions in open air situations. It provides processed location, satellite-accurate time, speed, direction, etc. through an accessory slot in the PDA. This information allowed navigation information to be provided to data collectors and allowed Westat to validate and monitor their schedule and whereabouts. GPS accuracy is guaranteed to be within 10 meters 95 percent of the time, but experience has shown much better performance than that for typical tracking;
  - 12VDC automotive power adapter/charger—This accessory charges the PDA and powers GPS; and
  - External magnetic GPS antenna—This accessory provided more reliable satellite reception (especially while collecting from inside a vehicle) by providing a remote, external antenna outside the metallic vehicle compartment.
- DCF-560M CF Modem and phone cord—The modem provided the connection/coding means to allow data to be uploaded to Westat nightly over standard phone lines. Although wireless means might have been easier in some cases, many of the sites would have been unable to access wireless service or might have incurred

high roaming charges for that privilege. With a dedicated toll free number for all the PDAs to access, uploading was reliable, quick, and simple.

- Two Weighted USB charging/synchronizing bases—These provided a reliable charging and storage stand for the PDA's to reside in while not being used to collect data.

- 120VAC power supply/charger—This accessory was used to charge the PDA overnight.

- Display scratch protectors—Scratch protectors were a simple and inexpensive means of protecting the LCD screen on the PDA from wear through normal use.

- Extra stylus for each PDA.

- Simple windshield compass—This compass is used in conjunction with the GPS feedback prior to arrival at an assigned site to direct the data collectors to the proper location (e.g., "You are four miles southeast of the assigned data collection location for the selected site.").

- Camcorder bag—This bag served as a convenient carry bag for all the PDA accessories during data collection and once the units were returned to Westat.

Figure 1 shows the assembled PDA/GPS and the equipment package described above.

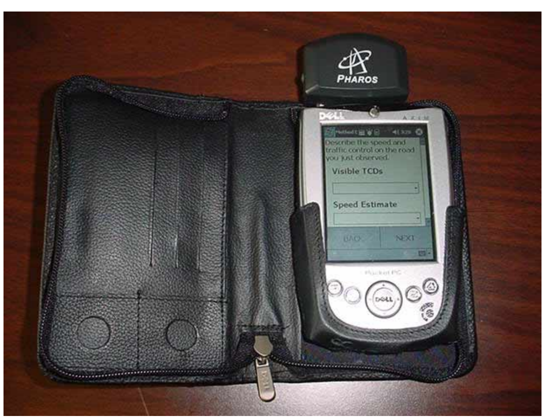

Figure 1. PDA/GPS data collection unit

Development of the application using this technology for NOPUS considered various hardware and software requirements. They included hardware and software features necessary to promote a usable user interface design, data integrity, reliable data collection and uploading, the ability to operate in a noisy, outdoor environment, and the ability to assist in the detective work that often accompanies field data collection. The necessary features are listed below.

2.1 Required Hardware Features:

- Use of vehicle power for PDA and GPS charging;

- Sunlight-readable display;

- Sound output for entry confirmation feedback;

- GPS for location tracking (differential accuracy not necessary);

- Capable of simple, reliable data upload back to office; and

- Hardy device capable of withstanding the rigors of field data collection to a reasonable degree (i.e., dirt, moisture, drops, etc.).

2.2 Required Software Features:

- Operable by finger (without a stylus) for most data entry;

- Capable of high-speed data entry with minimal errors;

- Scripting to provide driving/data collection instructions;

- Feedback to collectors of errors, hardware issues, collection routine status, etc.;

- Logic checks for date, time, number of runs, GPS data integrity;

- Per vehicle data records including:
  - Date/time;
  - Vehicle type;
  - Occupant protection status;
  - Latitude/longitude; and
  - Site/run information.

- "Big Brother" data regarding travel and collection details; and
- Essential software:
  - Active Sync for data upload; and
  - Embedded Visual Basic for custom application development.

Figure 2 shows the screen progression for data collection. The "buttons" are large enough to be manipulated using fingers. With practice, observers "learn" the muscle movements (like playing a piano or typing) without having to look down and take their eyes off the oncoming vehicle. Verbal feedback from the PDA reinforces heads-up data collection.

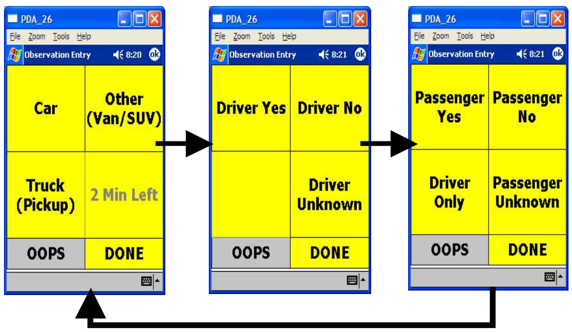

Figure 2. Data collection screen progression

3. Evaluation of Technology

3.1 Improved Data Quality

The GPS technology is used to direct staff to the appropriate data collection site. We have pre-programmed the latitude and longitude of each site into the system. Before data collection may begin, the program displays the distance away (in miles and direction) the data collector is from the right location. We have included positional error in these calculations based on the accuracy and precision of the base maps used to generate the latitude and longitude coordinates

Every time a data item is recorded, the latitude/longitude coordinates and a time stamp are appended to the data entry. In addition, during the moving vehicle study and during travel between sites, the software determines location every 15 seconds.

When downloaded files are received, an operator verifies, using the GPS coordinates, that the data collector was "stationary" at surface street sites, or traveling at limited access highway sites. The location where data collection took place is compared to the given location. If there is a discrepancy in these locations, the operator verifies that alternate site information was provided. If no alternate site information is provided, the data collector is contacted immediately.

The locations where data was collected were mapped against the input site locations and distance was calculated between input and actual locations. Over 70 percent of the pairs were within one tenth of a mile from each other. Eighty percent of the pairs were within two tenths of a mile of each other. Longer distances between these pairs mainly are attributable to the observers picking an alternate site location.

Figure 3 demonstrates the tracking capability of the GPS. The figure simply shows where and when data were collected (green symbols) during a schedule day. We use speed information from the GPS technology to determine if the data collector was stationary or moving during data collection.

The system is preprogrammed with the data collection schedule for each site. Data collectors are warned if they are attempting to collect data on the wrong day of the week or the wrong time of day. They are allowed $\pm$ 30 minutes from the scheduled time to begin to collect data. The system will not allow them to start collecting data at a site after 5:30 p.m. Based on the nature of the site, the program keeps track of the time they start data collection and tells them when the data collection period is over.

Downloaded files are checked to ensure that the data was collected at the right time for the right amount of time. Also, the distribution of time between subsequent vehicle type entries is evaluated. We expect the amount of time between observed vehicles is fairly uniform (with some spikes for signal timing influences) over the 30-minute time period. If we find that a data collector observes a lot of vehicles in a very short time period (say, 10 minutes), then only a few vehicles over a long time period (say, one every two minutes), we can contact the collector to verify that they really were collecting data for the full 30 minutes and that something happened to reduce the flow.

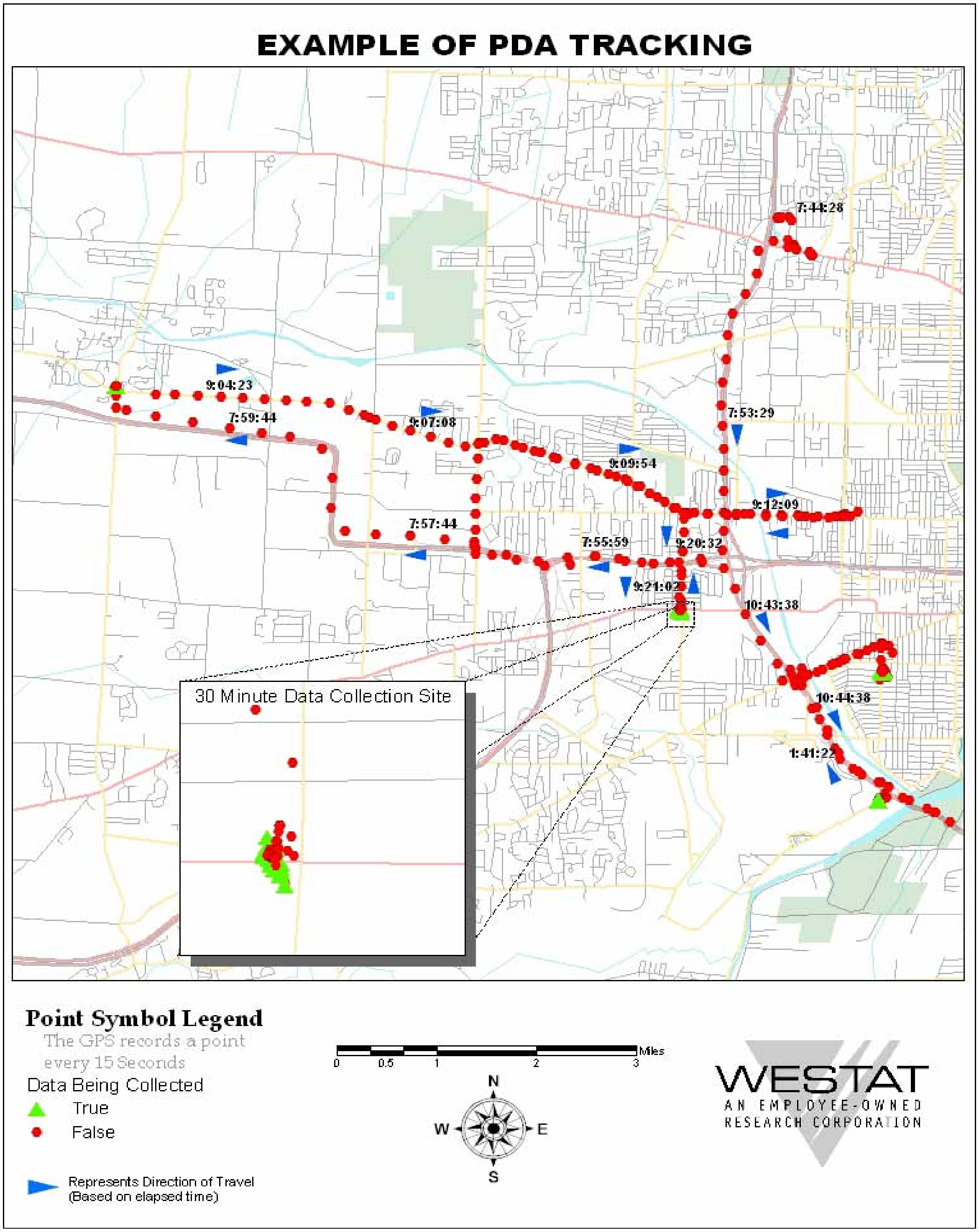

Figure 3. Tracking of data collection activities
(Note: Map labels are excluded on purpose to protect the confidential nature of this information)

Table 1 shows the distribution of the time headway between observed vehicles for the first six days of data collection. Overall, nearly 70 percent of the observations were made less than 15 seconds apart. As expected, these distributions mimic the traditional time headway distributions of vehicle flow. They also demonstrate that a single observer at a site with the PDA can observe all front seat occupants of vehicles passing them in a very short time span.

Table 1. Time headway for observed vehicles

Class	All sites	South	Midwest	North	West
<15 seconds	68.9%	72.2%	64.5%	65.8%	67.0%
16-30 seconds	13.3	12.7	13.9	13.5	12.5
31-45 seconds	5.8	5.3	5.9	6.1	6.2
46-60 seconds	3.1	2.8	2.9	3.0	3.1
61-90 seconds	3.5	2.9	4.2	4.5	4.3
91-120 seconds	1.6	1.3	2.0	1.6	2.5
121-180 seconds	1.6	1.0	2.8	2.3	2.8
181-240 seconds	0.7	0.6	1.2	0.6	0.8
241-300 seconds	0.4	0.3	0.7	1.5	0.3
>300 seconds	1.0	0.9	1.9	1.1	0.4

Data collectors cannot "forget" to observe one of the characteristics of interest (i.e., vehicle type and seatbelt status for front passengers) because the program will not advance to the next vehicle observation until they enter each of these items for the current vehicle observation. During data collection, there is verbal feedback from the PDA after each button is pressed on each screen. There is an "OOPS" button on each screen, that, when pressed by a data collector, flags the vehicle observation as bad. Such bad data is treated as nonresponse. We have also provided observers an opportunity to indicate "unknown" instead of skipping on to the next vehicle as with the traditional approach. An operator monitors the number of bad records per site. If a data collector has an unusually high percentage of bad records, he/she is replaced.

The data collection software contains validity checks to prevent out of range or invalid site parameter settings. The system also allows for an incorrectly entered site parameter to be changed. For example, the observer cannot tell us he/she observed more lanes than the number of lanes in the travel direction.

There are no data coding/entry errors associated with this approach. The digital files are transferred via telephone lines into a central database. Software is run to verify that all files have been transmitted and that they are not corrupt. The centralized database is backed-up nightly. Data monitors are given access to read-only files.

We are comparing data collected with the PDA/GPS technology to data collected using the traditional approach both during the same field period and from prior years.

Table 2 contains a summary, for ten days of data collection, of the proportion of sites where the observers indicated no errors, one error, two errors, etc. Sixty five percent of all sites completed had no errors indicated. As expected, surface streets had a lower proportion of sites with errors indicated.

Table 2. Reported errors by site type

Number of errors	All sites	Surface street sites	Limited access sites
0	65.0%	67.1%	56.1%
1	17.5	16.2	23.6
2	8.1	7.5	10.8
3	4.1	4.3	3.4
4	2.3	2.2	2.7
5	1.1	0.9	2.0
6	0.8	0.6	1.4
7	0.3	0.3	0.0
8	0.0	0.0	0.0
9	0.3	0.3	0.0
10	0.1	0.2	0.0
11	0.1	0.2	0.0
12	0.0	0.0	0.0
13	0.0	0.0	0.0
14	0.0	0.0	0.0
15	0.3	0.3	0.0

We have compared differences in number of observations using the PDA technology and the traditional methodology. Observers with PDAs collected data on fewer vehicles than those without PDAs. About the same number of sites were assigned to and observed with the PDA methodology and the traditional methodology. However, only 41 percent of all observed drivers in 2003 were from the PDA methodology. The main difference was in interstate sites, where only 35 percent of all observed drivers were from the PDA methodology. Observers with PDAs drive up and down a highway segment collecting data. The traditional approach is to observe vehicles as they exit the highway on an off-ramp. This proportion is not necessarily surprising, as driving at only 10 mph less than the prevailing speed on a low flow freeway will result in relatively few observations per minute.

3.2 Improved Field Operations

The use of this technology allows us to collect data in a PSU more quickly. Instead of two people visiting each site, one person is needed at surface street locations. We have scheduled half the number of data collectors for the PSUs thus reducing labor costs. However, we will incur greater travel costs within a PSU since each data collector requires transportation between sites. Further, each team has been assigned two PSUs, one local and one requiring travel.

For surface streets, PDA observers watched two lanes of traffic much less frequently than nonPDA observers. Since there is only one observer instead of a two-person team, this is understandable. For surface streets, adjusted for the number of lanes observed, 46 percent of observed drivers were from the PDA methodology. This is only a little less than 50 percent.

This technology is "big brother" in every sense of the term. We monitor daily the routes taken between sites, the time spent collecting data, and the location of data collection. Problems with staff may be more quickly diagnosed and remedied. Plus, no supervisors are needed to travel to these PSUs.

An investigation into labor requirements and productivity for PDA and nonPDA sites on surface streets produced the following results. The labor requirements for these two methodologies are different. At PDA surface street sites, one person is collecting data for 30 minutes and at nonPDA sites, two people are collecting data for 30 minutes.

Data used in this analysis includes the number of vehicles observed in a work day, the number of sites completed in a work day, the number of completed sites in a day that required a controlled intersection (CI) survey, and the total hours billed by the observer(s) that day. The days selected for analysis were those on which only surface street data were collected; no limited access highways.

Controlled intersection surveys add nearly an hour of data collection time to a site, so we expect that regardless of methodology, fewer sites per day are completed. The analysis was performed on all days with surface street only sites as well as on days with surface street only and no controlled intersection surveys.

The PDA teams were on travel for one of their PSUs. Only some nonPDA observers were on travel. All observers record their hours from the time they leave home/hotel to the time they return to home/hotel. We have not identified if there is a significant difference in travel time (as opposed to data collection time) for PDA and nonPDA observers. The total hours worked includes travel time, data collection time, and paperwork time (downloading or transmitting the day's observations).

For PDA sites there are 138 person days when only surface street data were collected. Of these, there are 25 person days with no CI surveys. For nonPDA sites there are 79 person days when only surface street data were collected. Of these, there are 10 person days with no CI surveys. The average hours per workday for PDA surface street sites is 9.8 and 9.2 for days with no CI surveys. The average hours per workday for nonPDA surface street sites is 22.1 and 18.9 for days with no CI surveys. (NOTE: the nonPDA costs do not include travel and labor costs for field supervisors. PDA PSUs do not require field supervision.)

Three least squares linear regression analyses were performed for both the PDA work days and the nonPDA workdays. Y = total hours billed, X = number of sites completed and the intercept was set to zero. The results are shown in Table 3.

Table 3. Linear regression analyses

	PDA all surface street sites	PDA surface street sites, no CI	PDA surface street sites, 1 CI Survey	NonPDA all surface street sites	NonPDA surface street sites, no CI	NonPDA surface street sites, 1 CI survey
Slope(m)	2.02	2.00	2.25	4.17	4.66	4.23
SE(m)	0.05	0.17	0.21	0.10	0.27	0.31
Coeff. of Determination	-0.33	-0.82	-0.17	-0.28	0.60	-2.08
SE(y)	-34.13	-10.78	-3.36	-16.89	13.73	-6.75
Regression Sum of Squares	-300.46	-147.99	-55.70	-383.96	178.36	-180.27
F	2.97	3.71	4.07	4.77	3.60	5.17
df	137	24	23	78	9	10
Residual Sum of squares	1205.98	329.49	381.06	1772.93	116.91	267.08

As expected, the slope for the PDA sites is around half of the slope for the nonPDA sites. The slope of the PDA lines conforms to the scheduling of the sites (2 hours per site) as does the nonPDA (2 hours for 2 persons = 4 hours).

Chart 1 shows that on nearly 70 percent of all days worked, the nonPDA teams completed 0.3 sites per hour. The PDA teams worked faster; on more than half of their work days they completed more than .5 sites per hour. When days with CI surveys are eliminated the same pattern holds true, PDA work is more efficient than nonPDA.

Finally we looked at unweighted total vehicles observed per hour. This statistic has less to do with the PDA–nonPDA methodologies since volume at an intersection impacts the number of vehicles that may be observed. As expected, the pattern follows a Poisson distribution. This is demonstrated in Chart 2. The tail of the PDA distribution is slightly longer indicating that on a few days the PDA observers actually captured data at a higher rate than the nonPDA teams.

4. Summary

Use of the PDA technology certainly reduced the labor requirements and costs for this survey. Since data entry was not required for half the sites, the results were obtained faster than normal and at less cost. We believe the quality of the data has improved. For the first time, we know exactly where and when the data are collected. Although there is no significant difference in estimates produced from PDA data and nonPDA data, we are still looking into improvements in overall data quality (such as fewer missing observations, more consistent vehicle classification, no incidents of having more front seat passengers than drivers, etc.) This technology has greatly enhanced many aspects of conducting a large, national survey.