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Alternative Methods of Measuring Operating Speed of Electric and Traditional Bikes in China-Implications for Travel Demand Models

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Abstract: Travel survey respondents often over or under-estimate their travel time depending on a number of factors. This research presents two methods of measuring average speed and thus travel time. The traditional method, stated travel times from travel surveys are compared and corroborated against measured implied travel time based on a GPS based floating vehicle study to identify the measurable operating speed. An example of this approach is shown for a survey of two wheelers (bicyclists and electric bike users) in two cities in China. In these cases, survey respondents report up to 32%higher travel times than what is measured on a floating vehicle study, depending on the case. The implication of this is that mode choice models calibrated on respondent stated travel time more than triples the effect of travel time compared with a model calibrated on average GPS speed (and inferred trip travel time).

Keywords: *Travel Survey, GPS, Electric Bike, Bicycle, Travel Time*

1. INTRODUCTION

One of the most effective ways of understanding travel and trip making behavior is through the use of travel surveys. Travel surveys are conducted in a number of ways, such as home based interviews, random telephone surveys, mail-back surveys, or intercept surveys, to name a few(Richardson et al., 1995). In almost all cases, the respondent is asked a series of questions related to their daily transportation choices, including origins and destinations for all of their trips, and the travel time of each trip. While origins and destinations are generally well known and identifiable (such as major landmarks, street intersections, or addresses) the travel time between origins and destinations is often difficult for a respondent to accurately recall, especially in the case of non-regular trips such as shopping trips or non-home-based trips. Travel time is generally a significant and important variable in mode choice estimation, thus it is important to accurately estimate travel time by all modes.

Travel time estimates from survey responses have been shown to produce bias compared to the actual travel time of the trip (Wolf et al., 2003). This bias can be in either direction and can produce biased planning model forecasts. One recent method of measuring and identifying the response bias associated with travel time estimation is to select a sub-sample of respondents to measure their trip patterns by carrying a Global Positioning System (GPS) device with them for all of their trips. This method is certainly the most robust in terms of measuring a number of often poorly reported parameters, including trip rate, trip distance, trip chaining behavior, start time, and travel time. This method has great potential and has been used primarily to validate trip rates (Forrest and Pearson, 2005, Draijer et al., 2000, Wolf et al., 2003), but is also costly and raises questions of adoption and privacy of respondents.

If requiring survey respondents to record their trips with a GPS is infeasible, due to cost, privacy, or institutional constraints; alternative methods of validating travel time are required. One potentially less costly way to correct inaccurate responses related to stated travel time is to measure average mode-specific operating speeds on major travel routes and corridors and identify the travel time based on shortest path distance measurements between stated origins and destinations. There are several intelligent transportation system technologies to measure travel speed that are readily adopted or on the brink of full-scale adoption, such as in-pavement loop detectors, automatic vehicle identification (AVI), remote sensing, in-vehicle GPS, and mobile cellular phone technology (Dowling and Cheng, 1996, Turner et al., 1998, Benz and Ogden, 1996, Eisele and Rilett, 2002). The technology that has the potential to capture the finest detail of data is in-vehicle GPS. GPS also collects data along entire corridors or routes, rather than at specific points along the route, making it more amenable to identifying average travel time or speed along a corridor or over an entire trip. This technology is mobile and can be used to capture instantaneous speed and location data in any vehicle, including non-motorized modes. Current GPS technology is affordable and mobile and has been shown to be an accurate method to capture instantaneous speed and acceleration data of vehicles for the purposes of travel time and delay estimation as well as emission modeling using a floating vehicle methodology . This technology is also very useful to collect data on modes that are not easily instrumented or sensed, like bicycles and motorcycles.

The goal of this study is to identify the feasibility of using GPS to capture average speed data on two “non-motorized” modes in China and identify if respondents of travel surveys report travel time that is consistent with the measured travel time inferred from GPS speed data. If survey responses are inconsistent, what is the effect of this inconsistency on mode choice estimation? This paper outlines a methodology of using a GPS based speed study to verify the time and distance responses to a traditional travel survey. This methodology is illustrated with an application of the measurement of actual average speeds of bicycles and electric two-wheelers in two cities in China, Kunming and Shanghai, using a floating vehicle methodology coupled with a GPS data collection method. The average measured speed is compared with stated trip distance and travel time responses given on travel surveys conducted in the same cities during the same time periods. The distributions of each data collection method are compared to identify the magnitude and direction of inconsistency of survey responses of two-wheel vehicle users in China. Implications of this potential bias are discussed at the end of this paper by comparing the effect of travel time on mode choice by using either stated or measured travel times.

2. METHODOLOGY

2.1 Travel Survey

Two-wheeled vehicles are still the dominant modes in of transportation in China and elsewhere in Southeast Asia. Recently electric bikes and scooters have emerged in many cities to meet the increasing personal mobility needs of Chinese citizens. A detailed background of this new mode is available in the literature and is outside the scope of this paper (Weinert et al., 2007, Jamerson and Benjamin, 2004). A travel survey was conducted in Kunming and Shanghai during Spring 2006 to begin to understand the travel behavior differences between traditional bicycle and electric two-wheeler users in China. A brief description of the survey methodology is presented here, but a detailed description of the methodology and analysis can be found in Cherry and Cervero (2007)(Cherry and Cervero, 2007).

Home-based travel surveys are institutionally and culturally difficult to conduct in China. Because most bicycles and electric two-wheelers share large centralized parking lots, the system lends itself to an intercept survey methodology. In this study, 5-6 large central and multipurpose parking lots were identified throughout both Kunming and Shanghai and surveyors intercepted two-wheel vehicle users (traditional bicyclists and electric two-wheeler users) as they entered the parking facility. A previous day trip diary questionnaire was administered as well as a survey of respondent demographics and attitudes about electric two-wheelers. The survey was carried out during the week, from Tuesday to Friday, to obtain a representative weekday travel diary (Monday to Thursday). The primary questions asked in the trip diary portion of the survey include trip origin, destination, start time, and duration, for each link of a home based trip tour. Between Kunming and Shanghai, 1200 surveys were collected.

2.2 Measurement of Actual Operating Speeds

Survey respondents were told to answer the trip travel time question as accurately as possible, only including the on-vehicle time. The respondents often rounded to the nearest five-minute interval and because of short trip lengths, rounding error could significantly overestimate or underestimate the average speed. A floating vehicle speed study throughout the city, aided by a handheld GPS unit integrated with a geographic information system (GIS) was carried out in both Kunming and Shanghai during the time of the survey. The hardware and software specifications are shown in Table 1.

Table 1 Hardware and Software Configuration Used For Speed Collection

Hardware/Software	*Specifications*
Dell Axim X5 Handheld PDA	Windows Mobile 2003, 300MHz Intel
US Global Sat Compact Flash GPS Receiver	SiRF Star III Chipset
ESRI ArcPad 7.0 PDA GIS Application	
ESRI ArcGIS 9.0 Desktop GIS Application	

A rider floated (allowing the same number of electric two-wheelers to pass as those who passed him) among the electric two-wheelers in the bicycle lane, adopting the median speed of electric two-wheeler users along all major commute routes in Kunming and a subset of commute routes in Shanghai; all likely routes used by survey respondents. Likewise, the same rider floated among the bicycles along the same routes. All measurements were taken in the peak commute periods, 7-10 am and 4-7 pm. Although the terrain in both cities is relatively flat, speeds on all routes were measured in both directions to eliminate any bias as a result of elevation changes. The GPS device collected instantaneous speed measurements every second. Both cities have relatively large blocks and large arterial roadways where segregated bicycle lanes influence high numbers of bike riders on major roadways. Shanghai has several roadways that are closed to bicycles, with parallel alternate roadways open for bicycle traffic. It is assumed that the largest portion of a trip occurs on these major bicycle corridors, though a minority of two-wheeler riders could take different routes than the shortest path. It is important to note that most routes were only measured once for each mode in each direction, so the dataset does not lend itself to drawing inferences of average speed on a specific route because variance in travel times is unknown. Collecting more data along routes would allow for this inference. Rather, one can draw inferences of the average speed of each mode throughout the entire city. An example of the data collected in Kunming is shown in Figure 1.

Figure 1: Example Speed Data Collected in Southeast Kunming

Some observations are missing, because of the urban canyon effect obscuring a large portion of the sky, and thus reducing the GPS signal strength. This could possibly introduce bias into the recorded speeds; but the direction of the bias is unknown. In the urban centers, where observations are missing, the street network is denser than areas with low building heights, causing more intersection and signal delay. Under sampling these points would result in measured average speeds that are *higher* than actual average speeds, that is, one would oversample areas outside of the densest urban areas where operating speeds are higher. However, the urban canyon effect is most pronounced in mid-block sections, where vehicle speeds are higher, thus under sampling high speed sections and oversampling low speed areas at intersections (where the view of the sky is larger). This would result in measured speeds that are *lower* than the actual average speed. These effects should be small since there are few areas where this bias might occur.

Maps of the survey locations and the commute routes on which the speed studies were conducted are shown in Figures 2 and 3. As mentioned earlier, a representative subset of Shanghai's vast transportation network was analyzed for practical purposes.

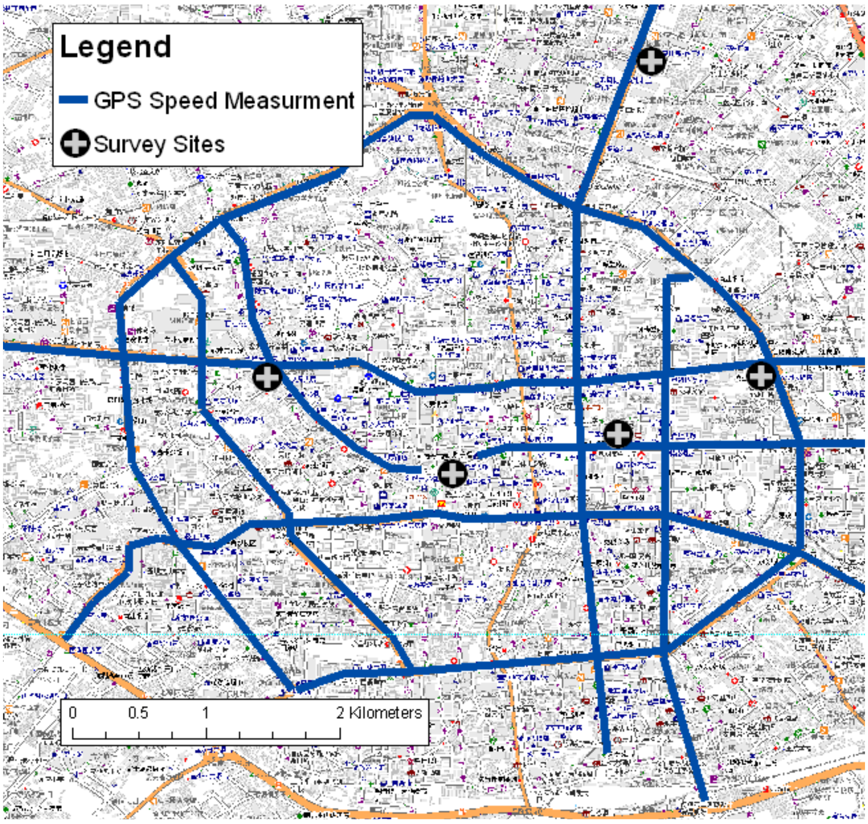

Figure 2 GPS Data Collection Routes and Intercept Travel Survey Sites-Kunming

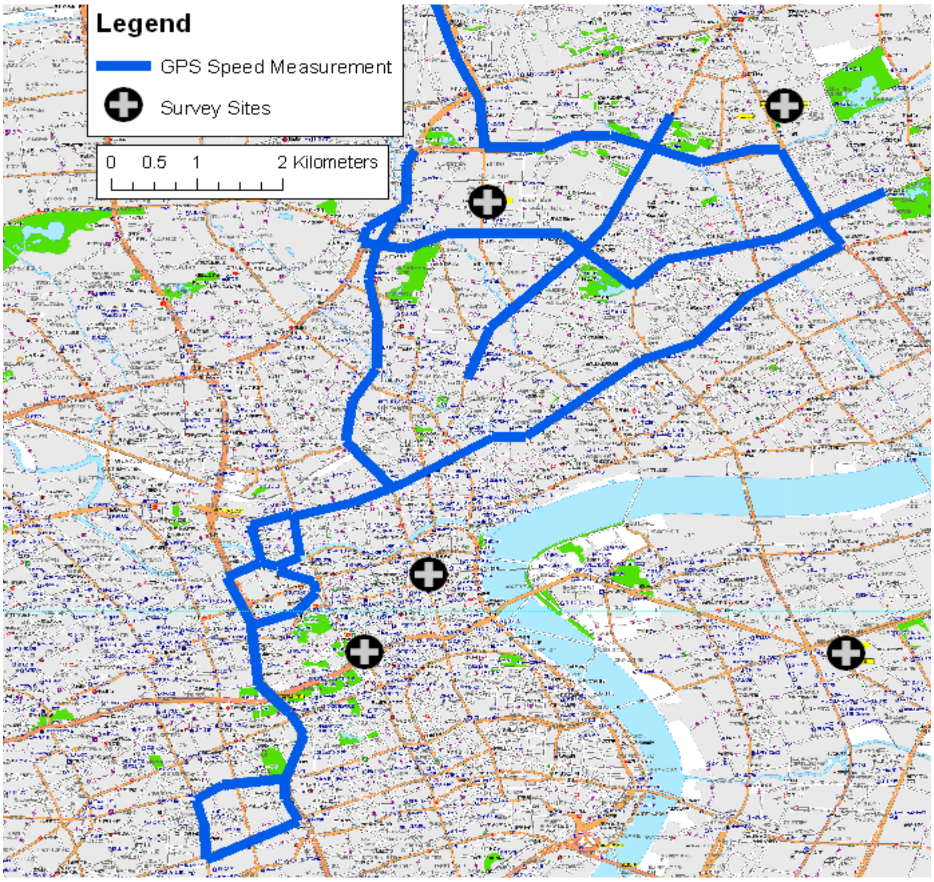

Figure 3 GPS Data Collection Routes and Intercept Travel Survey Sites-Shanghai

3. AVERAGE SPEED INFERED FROM TRAVEL SURVEY RESPONSES

The average speed was not explicitly asked on the survey, nor would it be easy for the respondent to report. The origin and destination of each trip was asked as well as the travel time of that trip. Origins and destinations were often reported as major trip generators, small residential districts, or street intersections. The network distance between each origin and destination was calculated using MapChina (Lingtu, 2005) and TransCAD software packages. The average travel speed over the trip was calculated by dividing the calculated shortest path network distance by the stated trip duration. All calculated average speeds over 50 kph (~30 mph) (about 1.6% of the dataset) were removed given that this is beyond the technical feasibility of electric bikes during the survey period. It is assumed that these were errors in path measurement or data entry. Although this speed is well above the technical limitations of most electric two-wheelers, it is still within reason that response bias could result in speed estimates up to 50 kph. The distribution of responses of bicycle and electric two-wheeler users is shown in Figures 4 and 5. Note that, for illustrative purposes, the graphs do not include values greater than 30 kph, though all statistical analyses include all speed up to 50 kph.

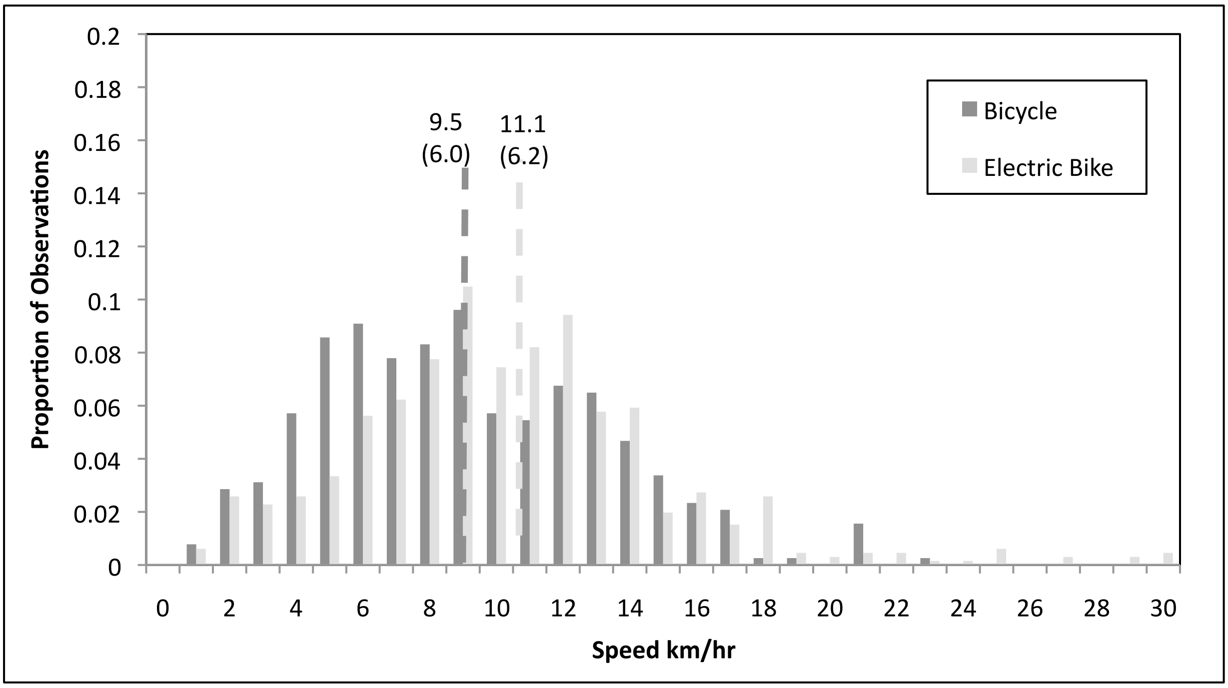

Figure 4 Histogram of Survey Response Speed Data in Kunming

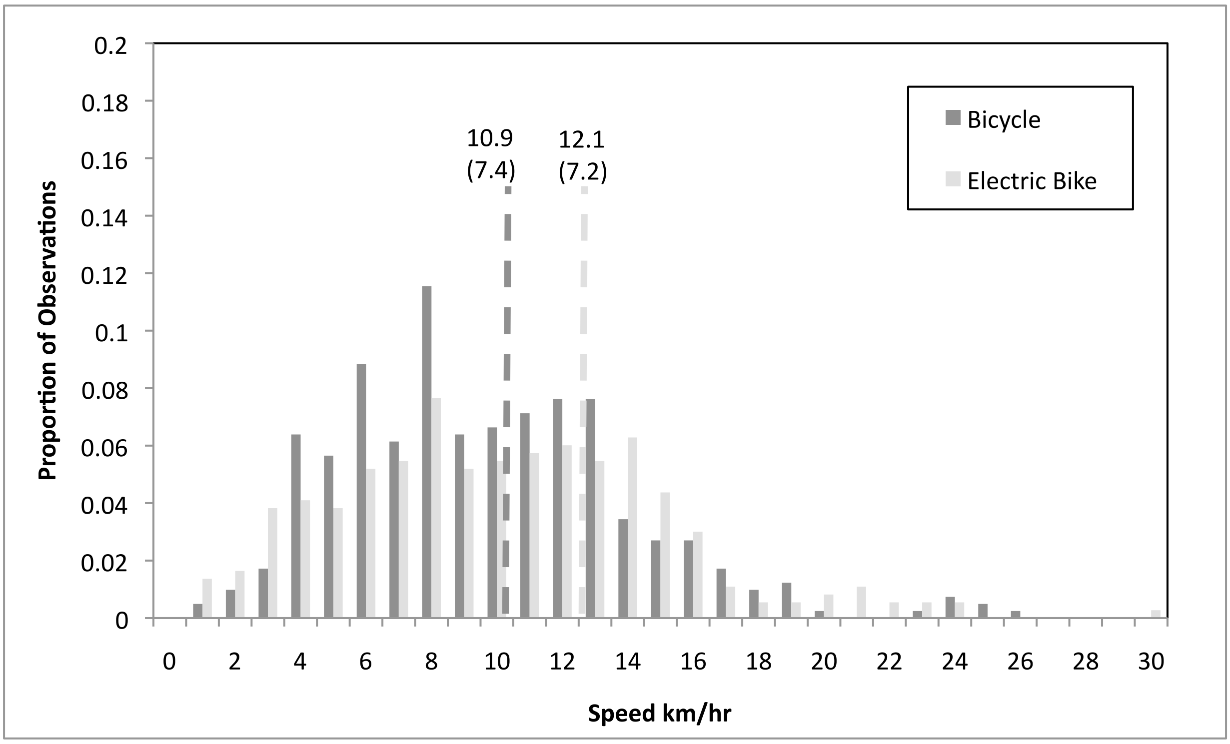

Figure 5 Histogram of Survey Response Speed Data in Shanghai

The mean values of each distribution are shown in the figures, represented by the dashed line, with the standard deviations in parenthesis. Interestingly, the responses are consistent enough to indicate that the average speed difference and thus travel time differences between bicycle and electric two-wheeler are statistically different from one another in both cities, with electric two-wheelers traveling 17% and 11% faster than bicycles in Kunming and Shanghai, respectively. Also, bicyclists in Shanghai travel about 15% faster than fellow bicyclists in Kunming and electric two-wheeler users in Shanghai travel about 9% faster than electric two-wheeler users in Kunming, according to survey responses. All of these differences are statistically different with greater than 95% confidence.

One of the problems with stated travel time responses, especially when comparing two modes with different operating speeds is that respondents could report door-to-door travel time, despite instructions not to. This would have the effect of disproportionately underestimating the operating speed of high-speed modes because a larger portion of the trip time is spent accessing the vehicle. This could be one of the reasons why the average speed differences are relatively small between bicycle and much faster electric two-wheelers. An alternative method of measuring operating speed differences, a GPS based travel time study was conducted in order to confirm or disconfirm the stated travel times.

4. AVERAGE SPEED MEASURED USING GPS

Using the GPS data collection methodology described above, speed measurements were collected on commute routes in Kunming and Shanghai. The frequency distribution of second-by-second floating vehicle speed measurements of bicycles and electric two-wheelers (bikes) are shown in Figures 6 and 7. The solid vertical line indicates the mean of the speed observation, including signal delay. The dashed vertical line indicates the mean speed not including stops (speed<2 kph). Both distributions are left skewed as large portions of the measurements are near the mechanical or feasible speed limits of both modes (20-30 kph), with a long tail toward zero. From these data, signal delay is also measurable. In both cities, electric two-wheelers spend a larger portion of their travel time stopped than bicycles. As expected, vehicles that travel faster spend a larger portion of their travel time stopped (unless the signal progression caters to their speeds). Electric two-wheelers spend about 18% and 20% of their time stopped in Kunming and Shanghai, respectively. Compare this to bicyclists who spend 8% and 16% of their time stopped at signals. Both cities exhibit remarkably similar average speeds of each mode. Bicycles travel 10.9 kph and 11.1 kph in Kunming and Shanghai, respectively. Electric two-wheelers travel 31-35% faster or 14.7 kph and 14.5 kph in Kunming and Shanghai, respectively.

These distributions represent the average speed throughout the city, not necessarily on specific routes. The vast majority of delay was related to signal delay and all signals in this study provided adequate green time for all two-wheelers to progress through the intersection (i.e. the floating vehicle never waited more than one cycle length). Segment or corridor specific speeds and travel times could be measured, but would require a significantly greater data collection effort.

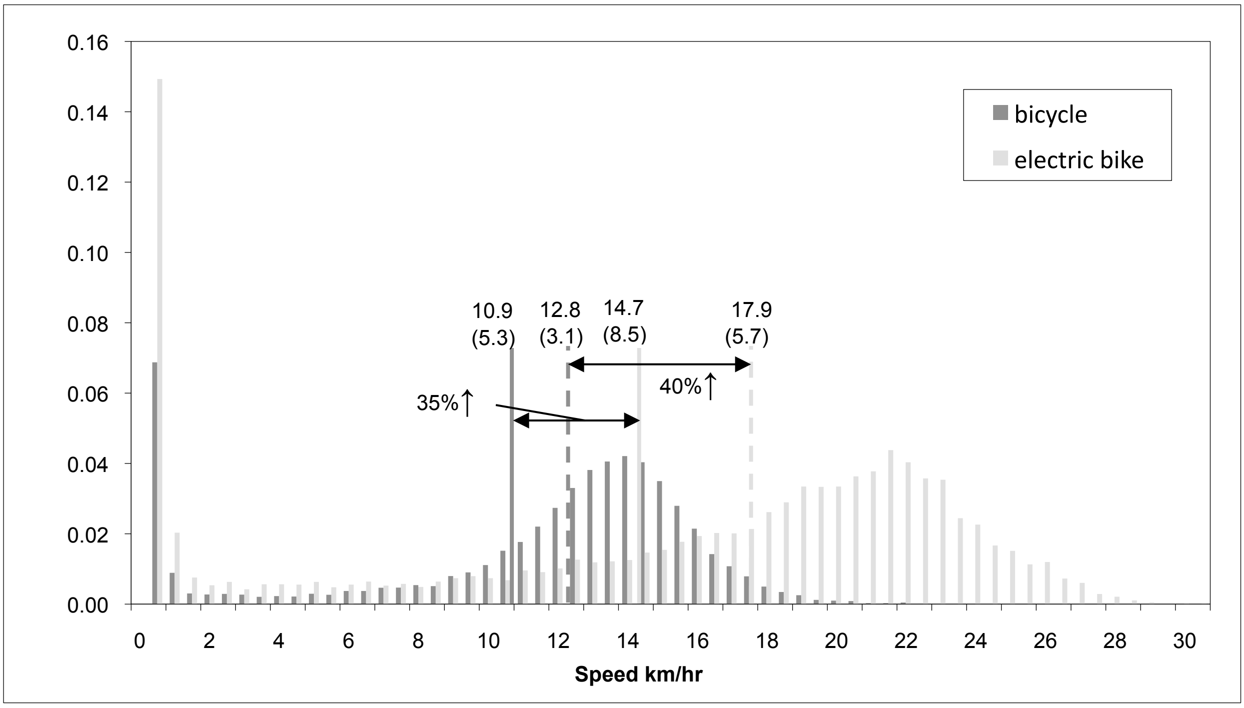

Figure6 Histogram of GPS Measured Speed Data in Kunming

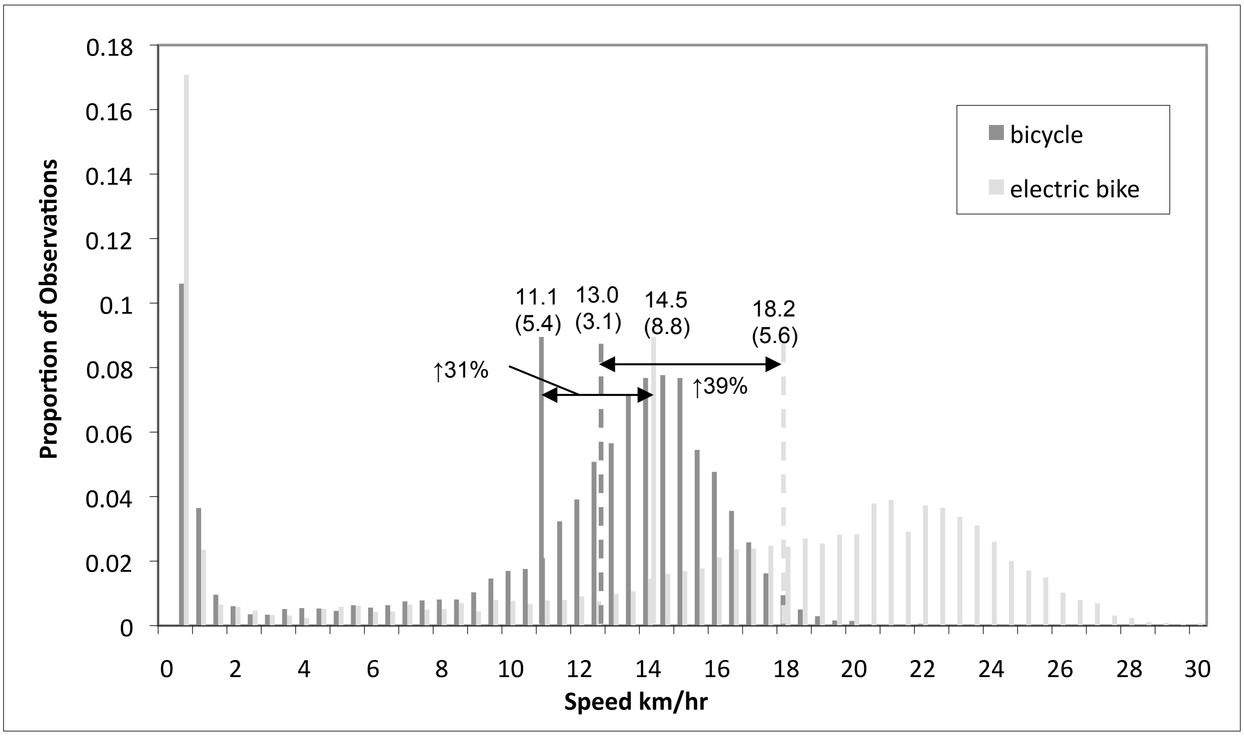

Figure 7 Histogram of GPS Measured Speed Data in Shanghai

5. MEASURED VERSUS STATED SPEED ESTIMATION

The GPS-measured and survey inferred average speeds are shown in Table 2. Bicycle and electric two-wheeler users had a tendency to overestimate their travel time (and thus underestimate their average speed) significantly compared to GPS-measured speed values in all cases except Shanghai bicyclists, whose average speed inferred from stated surveys is not statistically different from GPS estimated speeds. Kunming bicyclists report lower speeds by 13% and electric two-wheeler users report lower average speed by 24% and 17% in Kunming and Shanghai, respectively. While the lower reported speed compared to GPS measurements may seem large, because of short average one-way trip lengths, the survey respondents only report higher travel time by less than five minutes on average. This is well within the range of reasonable survey response error.

Table 2 Measured and Stated Speed Estimations (std dev in parenthesis)

	Kunming		Shanghai	
	Bicycle	Electric Bike	Bicycle	Electric Bike
Survey Speed (kph)	9.5 (6.0)	11.1 (6.2)	10.9 (7.4)	12.1 (7.2)
GPS Speed (kph)	10.9 (5.3)	14.7 (8.5)	11.1 (5.4)	14.5 (8.8)
Average Trip Length (km)	3.4	3.6	4.3	4.8
Trip Travel Time Survey Difference (min)	+2.8	+4.8	+0.4	+3.9
Trip Travel Time Survey Difference (Percent higher than GPS)	+15%	+32%	+2%	+20%

6. IMPLICATIONS FOR TRAVEL DEMAND MODELING

6.1 Mode Choice Model Specification

While the trip travel time difference between stated and measured travel times seem low, this difference could have some significant policy implications. From the same dataset, Cherry and Cervero (2007) estimated a binary mode choice model for the decision to choose bicycle or electric two-wheeler for a given trip tour, where a tour is defined as a series of trips that begin and end at home. While electric two-wheeler users choose this mode for a number of reasons, including user perceptions and demographics, one of the reasons is the travel time saving associated with electric two-wheeler use. The coefficient associated with travel time savings (travel time by bicycle minus travel time by electric two-wheeler in minutes) is 0.027, using the GPS measured speed to calculate travel time by mode. That is, if the difference in travel time between bicycle and electric two-wheelers increases (because of operational changes that cause bicycles slow down or electric two-wheelers speed up), then the probability of choosing an electric two-wheeler also increases. In this discussion, this model will be referred to as *Model 1*.

Using the GPS speed, the mean travel time savings of using an electric two-wheeler, for an entire tour (a series of trips that begin and end at home) is about 11 minutes, whereas that difference drops to between 5 and 8 minutes (depending on the city) when considering inferred stated speeds from survey responses. This effectively reduces the mobility advantage of electric two-wheelers. A new model is estimated with the same specification as *Model 1*, with the only difference being that travel time difference is estimated using travel times calculated from travel survey responses. This model will be referred to as *Model 2*. While it is outside the scope of this paper to explain the estimation of this new mode choice model, the effect on the variable of interest, the difference in travel time between modes, will be discussed. If the average speed by mode that is calculated from survey responses is used to estimate the coefficient of the difference in travel time, the coefficient associated with the travel time savings becomes 0.092, more than tripling its effect compared to *Model 1*. This could be expected as variance in mode choice, explained by travel time, is explained by a smaller range of values. Therefore, any change in travel time would have a larger effect.

The travel time savings using the stated speeds enters the model at a higher level of significance than the GPS measured travel time savings, with corresponding t values of 3.26 and 2.03, respectively. This could be because respondents make decisions based more on perceived travel times than on actual travel times, so their behavior is reflected more significantly by perceived travel time differences. However, it is often difficult to measure perceived travel time changes as a result of changes in the transportation system or policy, so measured travel time improvements are often used, causing a potential bias of the affect of that change.

7. CONCLUSIONS

Using GPS is a powerful and evermore low-cost tool to gather micro-level data on vehicle flow patterns, speed, and delay. It also can help validate average on-vehicle speed, which can be extended to identify travel time savings of alternative modes of transportation. This paper uses GPS to identify differences between travel time that survey respondents perceive and state on survey instruments. The gap between what respondents perceive and report on surveys and what we expect based on average speed measurements is small, but significant. Moreover, the perceived speed gap between competing modes is smaller than one might expect based on what is observed on the transportation network. This could be because both bicycle and electric two-wheeler users both implicitly factor access time into their travel time estimation, which should be the same for both modes and would have the effect of closing the gap between faster and slower modes. In addition, the GPS study showed that electric two-wheelers spend a larger portion of their travel time stopped at signals. To the extent that stopped time is more onerous than time moving, the trip could be perceived to take longer. None-the-less, what users perceive often has more influence on behavior that what actually occurs. Unfortunately, it is difficult to measure perceived changes in travel time when making transportation improvements.

A logit mode choice model was estimated that extended previous work of the author. This model was specified using travel time data calculated from survey responses and showed that perceived travel time predicted mode choice with more significance and also with a greater effect than estimating a mode choice model with GPS measured speed and thus travel time. However, as engineers and planners, it is often easer to measure speed changes of modes using mechanical methods (GPS, remote sensing, microsimulation modeling, etc.) rather than identifying the perceived changes in travel time. Therefore, if GPS-estimated travel time data were used to estimate mode choice from a model specified on stated travel time data, it would result in overestimates of the influence of travel time on mode choice. Therefore, using GPS-estimated travel time, rather than travel times inferred from survey data, to specify a mode choice model would create a model that is more usable with a parameter that can be independently measured. Estimating changes in mode choice as a result of operational or policy changes that change travel time differences between modes could overestimate mode shift if *Model 2* is used in the estimation process, because the travel time changes will likely be estimated using independent measures and will likely be underestimated by users.

Overall, travel time is one of many variables that influence mode choice of two-wheel vehicle users. In fact, many other variables have more explanatory power than travel time, but travel time is something that can be manipulated by policy makers. If independent data are used to evaluate transportation alternatives, it is important to specify mode choice models using the same type of independent data, rather than what users perceive. Additional research that would improve the results of this study would be to collect more corridor specific data so that corridor level speeds can be measured. Reported trips can be mapped to various corridors and more accurate travel times estimated. Moreover, identifying the influence of potentially lower speed routes that access the main corridors would also improve the results of this study.

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