GPS-Recorded and Self-Reported Data in Surveys of Origin and Destination: Analysis of Limitations and Differences

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***Abstract*—GPS technology is available and is being widely used in various scientific fields. The use of GPS in origin and destination surveys is recent, especially in researches of trips and transport. However, a large number of recent studies indicate that its application is feasible and have a great potential in data collection, especially jointly with a Trip Diary. This study explored the potential of data collection with GPS devices, evaluated the differences between data reported and recorded by GPS. For this, it was determined a methodology for collecting data from a GPS device, free software and a subsequent interview with each participant personally. The application of the research was conducted in the metropolitan region of Porto Alegre, in which participants performed 1,225 steps of trips that allowed comparing the information recorded by the device with those reported by participants. Approximately 62% of trips was considered valid. The comparison between reports of respondents and values recorded by the GPS confirmed a significant discrepancy between the values of distance and time of the trips, a result by the application of an analysis of variance for different modes of transport. Since the data collected for transportation planning is commonly obtained through reports, it is important to understand the limits of such information, especially for the reliability of the results and to develop efficient measures.**

***Index Terms*—origin and destination survey, GPS, trip diary, transportation planning.**

I. Introduction

The metropolis is continually faced with the challenge of managing congestion, which requires the adoption of innovative policies and specific interventions that allow mitigating externalities generated in the operation of transport systems. The identification and understanding of the problems are essential to implement efficient measures [1]. However, in establishing the basis for the definition of interventions, transportation data provide information to decision-makers about effective measures to be undertaken. Thus, data quality significantly determines the adoption of effective interventions, implying the choice of investments and policies to deploy.

The methodologies of data trips collection are recent. Traditionally, the surveys of Origin and was composed of Trip Diary [2]. This method obtains trips information from interviewees, which are usually inaccurate and misleading in some cases, particularly in respect of the distance and time of trip [3]. However, a series of experimental studies on the introduction of GPS technology in data collection trips have been held in various parts of the world. Most analyzes merge the GPS and Trip Diary jointly. This procedure allows complement information gathered, minimize errors in duration and length of trip and capture the real routes of each shift [4].

However, the methodology of using GPS technology to collect data is recent and is not consolidated. Thus, it is necessary to understand the benefits and limitations of these methods. The objective of this paper is to explore the potential of data collection with GPS devices and analyze the differences between reported data and recorded data by GPS. The study was conducted in the metropolitan region of Porto Alegre.

This work contributes to the development of research based in GPS in Brazil, determining a methodology for data collection and analyzing the benefits and limitations of their use. The study contributes to the modeling of transport demand. Demand models are based on data obtained from reports of subjects, among others, data time and distance traveled. Knowing the accuracy of this information contributes significantly to the development of efficient measures.

II. The Evolution of Origin and Destination Survey

Traditionally, the trip survey data is performed through Trip Diary, consisting of questionnaires in an interview. In the interview is obtained information about movements made in addition to information on the socioeconomic characteristics. The main goal of a origin and destination survey is to get the information of displacements of a population, being able to formulate models for planning or restructuring the transport network [5].

After the year 2000, GPS devices have been used in origin and destination surveys around the world [3]. Early studies, using the GPS for obtaining travel data, analyzed exclusively cars and public transportation vehicles [6] [7]. But, from 2008, a number of research using GPS and Trip Diary for others modes of transport increased

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significantly. The technology allows obtaining data on short trips, such as the displacements by foot to a bus stop or parking, generally despised in the reports. Studies of the use of GPS devices to collect trip data indicate a great efficacy [7]-[14].

The use of Trip Diary and GPS devices jointly increases the accuracy of the data obtained by supplementing the information and minimizing errors. From the GPS log can be obtained accurately timetables, routes and lengths of the trips. By reporting of the respondent can be obtained the information about mode of transport used and the purpose of the trip [7]-[13].

III. Methodology

In this work, a collection of trip data was performed jointly using GPS and Trip Diary in the metropolitan region of Porto Alegre, in the south of Brazil. The study consisted of four main steps: (i) selection of the GPS device, (ii) determination of softwares to be used and (iii) establishing the methodology of collection and (iv) data analysis. These steps are described below.

A. GPS Device

The choice of the GPS device was based on a study [9] which was checked the performance of a number of existing GPS devices on the market, for applying a origin and destination survey in UK. After the assessment of 32 different GPS, was select three GPS devices that satisfactorily met the requirements imposed on them: The *Atmel MTB-08*, the *Globalsat DG-100* and *i-Blue 747A Transystem +*. The technical characteristics, as the machine's memory capacity, battery life and ergonomics, and data such as the date of product delivery and price were evaluated. From this study, we analyzed some specific features of these three devices, which led to the choice of *Transystem i-Blue 747A +* device.

B. Softwares

The export and processing of data collected with GPS required the use of three different softwares. The configuration and export data from the GPS device were performed using the *BT747 software* supplied by the advice. Data processing was performed using the software *GPS TrackMaker*. The choice of the software involved many graphics programs available in order to draw the best results that among the tested showed satisfactory simplicity, data editing and characterization of trip, besides being free. The final visualization was performed by *Google Earth,* free software that enables the generation of two-dimensional maps and viewing area with satellite images.

C. The Survey

Respondents were instructed to take the device with them on all trips made in a 2 days period in a pocket, for example. Were also instructed to turn on the GPS on early morning of the first day and turn it off at the end of the last day. Therefore, it was not necessary any interaction of the interviewee with the device at any other time, which prevents the manipulation of data or forgetting to turn on or off the device. After the period, an interview was conducted face to face with the participant, in which he was asked about the trips indicating the time, distance, mode of transport used and the purpose of each one.

During the interview the information of the users was not questioned, ie, the responses reports were documented without any discussion. Among the possible methods of interview it was decided to adopt a face to face interview. Alternative methods such as interviews by phone or internet have low response rates and difficulty in obtaining data [7]-[14].

The methodology of data collection adopted consisted in the use of information given by the respondent, through oral reports and information recorded on the GPS on all trips made in two days. This collection period was determined based on the convenient control from the device and by the results of a pilot study, which also pointed out that two days is a maximum permissible to reduce the risk of forgetting the trips made by respondent's time.

It is noteworthy that this study analyzed each trip legs, not just the trip from its initial origin to its final destination. It is understood that each trip, made from an initial origin and final destination, have the reason to satisfy a particular purpose. Trip legs refer to the displacement or trip part made in one mode of transportation. The determination of the beginning and end of each trip leg occurs in changing the mode of transport used. For example, a trip with 2 changes of mode (walk - bus - walk) consists of three trip legs: walk to the bus stop (step 1), bus to the next stop (step 2) and walk from the bus stop to the final destination (step 3). A shift was considered as trip leg if it had a minimum length of 30m, obtained by testing the device. The proposed methodology was applied in order to obtain data on all trips made, including the ones unkempt in traditional origin and destination surveys. These are generally less important in modeling over extensive regions, but useful in micro and behavioral research [15].

D. Data Analysis

The analysis was characterized by two approaches. First, the limitations and difficulties presented by GPS technology were analyzed. After the comparison between the information obtained by GPS and collected by interview was conducted. A comparative analysis was obtained by analysis of variance (ANOVA) and the average comparison of the discrepancies concerning. The ANOVA allowed the comparison of the discrepancies between reporting and recording (distance and duration of each leg trip) in relation to mode of transport. Thus, the existence of significant differences between the different transport modes was investigated, ie, whether respondents had higher discrepancies in transport mode than in another. These discrepancies in distance and duration of trip were represented in absolute and relative form. The discrepancy was obtained by the absolute difference between reported and recorded. The discrepancy was obtained on performing the quotient of the absolute discrepancy and measurement recorded by the device. Thus, it was possible to analyze the discrepancies in absolute terms and also proportional to the distance traveled.

The distance between origin and destination points influences the choice of transport mode. The walk trips are generally used in medium and short distance. This can be observed in different studies, for example, in the survey conducted in Porto Alegre [16]. Therefore, the trips were stratified according to the distance. Analyzing the histogram of the trip distance, shown in Figure 1 was determined the cutoff of 2km. Therefore, the ANOVA analysis was performed separately for lowest and highest trip than 2km, considering in each case the alternative. The histogram (Fig. 1) showed that less than 2km trips were made by public transportation, car and pedestrian. Trips that the distance of origin and destination was bigger than 2km were made by car and public transport.

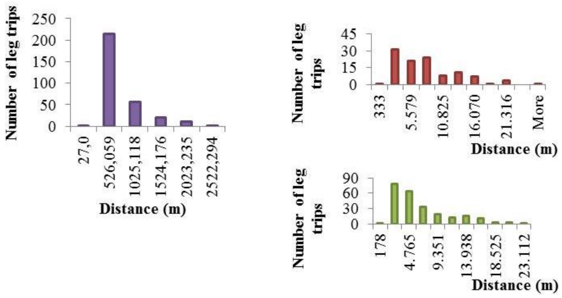

Figure 1. Histogram.

IV. Sample

The sample is contained by volunteer participants living in the metropolitan region of Porto Alegre (RMPA) in the south of Brazil, which have made trips within these cities. The description of the study area, sample size and profile of the respondents are presented below.

A. *Study Area and Sample*

The study area for this study was limited by the RMPA, located in southern Brazil. The sample consisted of 72 individuals. The choice of the participants was performed to obtain diversity among individuals and personal characteristics of the areas frequented by them. Among the issues set for selection, can be cited: gender, age, degree, place of residence and work. Participants took the GPS with them for two days, and the research was in the period of April 2011 to June 2011 and in April 2012 till June 2013. Respondents held a total of 1,225 leg trips.

Much of the displacements involved the central region of Porto Alegre and occurred significantly in avenues in the region. The shifts in local rues generally occurred when the participant was close to a origin or destination. Fig. 2 shows all the legs trips made.

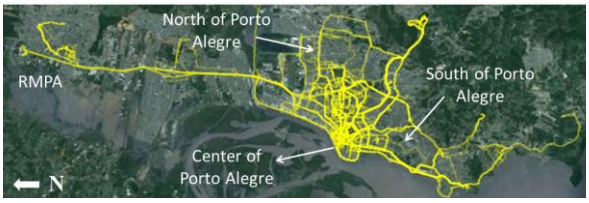

Figure 2. Legs trips collected.

B. *Profile of Participants*

Most respondents (59%) have between 20 and 39 years and 28% have more than 50 years. In total, 55% are female and half are higher education. Currently, approximately 61% do not study, 22% study course in higher education and 4% study another course category, as preparatory courses for competitions, including college entrance examination or vocational courses. Thus, 93% were working and 7% are retired, pensioners or are unemployed. Fig. 3 shows the profile of respondents.

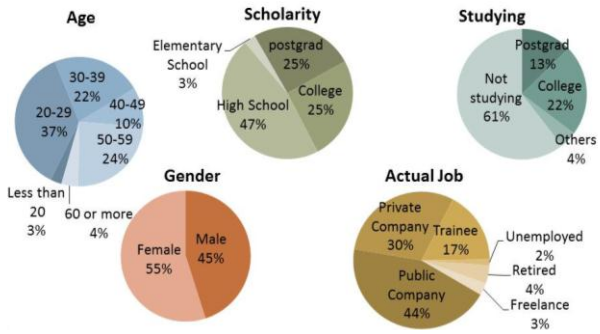

Figure 3. Profile of participants.

V. Problems Identified

The use of GPS devices may represent significant improvements in data collection in origin and destination surveys. But, it was detected a number of difficulties in data collection, due to problems arising from the technology itself. The problems encountered were from two distinct natures: (i) the quality of the signal and (ii) the effect of the cold start.

A. *Signal Quality*

GPS devices have an uncertainty characteristic that varies with the quality and frequency of the antenna gadget and the number of satellites available at the time of data acquisition. Consequently, some points were recorded with a local coordinate very close to it but not to the exact location coordinates. In addition, the GPS did not respond well to urban canyons, ie, to heavily built areas with a large concentration of tall buildings. In the center of Porto Alegre, in particular, the quality of the GPS signal reception proved precarious, making it impossible at times to determine the path of trip. This phenomenon is termed as multipath and is caused by unwanted signal reflection by near or GPS antenna obstacles [17]. Although this inaccuracy, there were not difficult to locate the origins and destination points.

B. *Cold Start*

The effect of the cold start concerns the time it spends GPS to determine the location to be connected or to receive the satellite signal again, in case of losing it [2]. This usually occurred in the first use on the day, or when the person spends a certain period in a closed place, where the device can not define your position quickly. The main problem caused by this limitation was the loss of information relating to early trips. However, once held the loss of information, the impact on the interpretation of the data was not great. Often, the beginning of a leg trip is located at the end of the previous leg strip, if the first day, the starting points is usually home, or even the last trip in the previous day. Moreover, the time interval that the GPS records a point is small, so it is possible to infer the route made by the interviewee.

C. Validity

Of the total of 1,225 legs trips collected, 237 (19%) were invalidated due to technology limitations: battery discharge (11%), loss of signal (38%) and stages of short trips (51%). In the short trips it was not possible to determine the exact location of the exchange of the mode of transport. Participants were asked to report the largest displacement of 30 meters. Also, due to erroneous reports from the participants, for the total number of legs trips collected, 226 (18%) were invalidated because of: legs not reported (52%) legs reported that did not happened (24%) and forgetting to carry with GPS (24%).

VI. Analysis of Reported and Recorded Data

For the total of legs trips collected, 762 (62%) are valid and were considered in analyzes. Analyzes refer to the mode of transport used, obtained through the report of respondents. The legs trips doing on foot represent a significant portion of the collected trips, which are normally forgotten in traditional origin and destination surveys.

A. Analysis of Movements Made

Data analysis showed a modal distribution of movements made by the sample. The movements made by automobile and motorcycles accounted for 40%, by bus, train or mini-bus, 17% and 44% on foot. The number of displacements on foot was superior to displacement by other modes. This is due mainly to the fact that much of the displacement on foot were to access other modes of transport (48% of total), such as commuting to stop public transportation or parking. The walking trips were stratified according to the purpose of the trip. The remaining displacement showed several purposes, mainly shopping or meal and work, as shown in Table I. Through, others purpose were related too.

TABLE I. Purpose of Legs Trips Made by Foot

Purpose	Quantity	%	Purpose	Quantity	%
Personal affairs	24	7%	Work	39	12%
Shopping	40	12%	Others	5	2%
Study	14	4%	Health	3	1%
Exchange mode of transport	160	48%	Family/ Personal errands	6	2%
Recreational	13	4%	Return home	28	8%

B. ANOVA

Several analyzes of variance were performed considering the following sources of variability: purpose of trip, mode of transport, combinations and interactions between them. Variables as distance and duration were analyzed. Several of these analyze one, two and three factors showed no statistically significant results. The results presented are those that showed significant results.

1) Divergence between reported and recorded distance

ANOVA was performed for trips that the distance was less than 2km and for trips bigger than 2km independently, according to the histogram shown in Fig. 1 (Section 3.4). Table II presents the ANOVA results for differences between reported and recorded distances, expressed in absolute terms, relative to the mode of transportation for trips that the distance is less than 2km.

TABLE II. Results of the Analyzes of Trips Less Than 2km

ANOVA	SQ	Gl	MQ	F	Sig.
Between groups	6884274,681	2,00	3442137,341	5,760	0,003
Inside the group	2,109x108	353,00	597550,297		
Total	2,178x108	355,00			

	Statistics	Gl1	Gl2	Sig
Brown-Forsythe	2,482	2,00	77,603	0,070
Levene	23,845	2,00	353,000	0,000

TABLE III. Multiple Comparison of Distance Averages

Test	(I) Mode	(J) Mode	Difference of the averages (I-J)	Standard error	Sig.
Tukey HSD	On foot	Car	-363,606	110,254	0,003
		Transit	65,494	164,605	0,916
	Car	On foot	363,606	110,254	0,003
		Transit	429,100	186,701	0,057
	Transit	On foot	-65,494	164,605	0,916
		Car	-429,100	186,701	0,057
Dunnett t (2-sided)a	On foot	Transit	65,494	164,605	0,851
	Car	Transit	429,100	186,701	0,035

Levene's test for absolute divergence, shown in Table II, shows that it is not possible to affirm the existence of homogeneity of variances (sig=0.000<0.05).The ANOVA analysis assumes that the variances of the groups are statistically equal. Failure to comply with this condition requires the use of a more robust test of the F test commonly used in ANOVA. For this reason, the Brown-Forsythe test was used. This test conducts an analysis of variance transforming the response variable, analyzing data groups with different variance. The result of this test was significant, using a level of significance of 0.10. It is possible to conclude that there are significant differences in the averages of the groups, ie, the divergence between reported and recorded distance is not the same in different modes of transport, and there are ways that individuals overestimate/underestimate the distance more in different modes. To study behaviors in which individuals responses diverge more or less, a multiple comparison was calculated. The multiple comparisons are presented in Table III.

The multiple comparison of averages were performed using Tukey HSD tests and Dunettt. The test results, presented in Table III and graphically in Fig. 4, showed that individuals have different discrepancies of the distance between reported and recorded on GPS in trips made by car than using public transport or on foot. Probably the direction of the tracks, road configuration and the presence of dedicated lanes for buses, let people to think differently in car trips than in other transport modes. This can influence the individual's perception of the distance traveled.

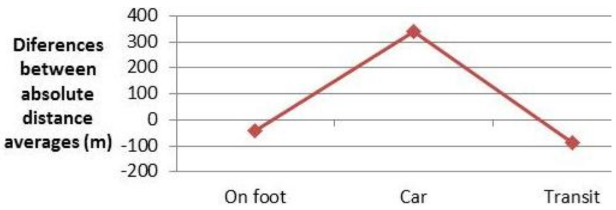

Figure 4. Discrepancies between reported and recorded distances in steps of short trips.

Tukey HSD tests and Dunettt allow analyzing the difference of averages. However, it is interesting to analyze whether there are trends for the individuals to super/underestimate values and to compare the effects of distance and duration. Thus, the average and standard discrepancies relative distance deviation values were analyzed (Table IV). The results indicate a tendency of individuals to overestimate distances on short trips (less than 2km) in all modes. These discrepancies are related to similar shifts in public transportation (39%) and walking (42%), coinciding with the ANOVA analysis performed previously for absolute distances.

TABLE IV. Average Values and Standard Deviations of Discrepancies of Relative Distance

Short trips						
Mode	Related bigger than recorded			Related smaller than recorded		
	N	Average	Standard deviation	N	Average	Standard deviation
On foot	191	42%	0,275	147	-73%	0,824
Car	61	28%	0,185	35	-80%	1,353
Transit	18	39%	0,211	8	-57%	0,721
Long trips						
Car	102	36%	0,243	102	-66%	1,212
Transit	35	22%	0,215	63	-139%	2,471

Table V shows the results of ANOVA for long trips. As in the analysis presented above for short trips, the differences between reported and recorded distances, expressed in absolute terms, relative to the mode of transport are presented.

The homogeneity of variance, Levene's test, was significant (sig=0.00<0.05). So it is not possible to affirm the existence of homogeneity of variances. The test used was the Brown-Forsythe instead of the generally used in the ANOVA, test F. The result of this test was significant, using a significance level of 0.05. The conclusion is that the discrepancy between reported and recorded distance is not the same on car and public transportation (Fig. 5) for displacements bigger than 2km.

The analysis of averages and standard deviations presented in Table IV, shows that individuals underestimate the distance traveled on public transport (139%). Nothing can be said for the car shifts because the overestimated and underestimated displacements coincide in number of hits (102), with no significant trends. Although the discrepancy is slightly larger to underestimate (66% to underestimate to 36% overestimate).

TABLE V. Results of the Analyzes Long Trips

ANOVA	SQ	Gl	MQ	F	Sig.
Between groups	$2{,}613x10^8$	1,00	$2{,}613x10^8$	7,172	0,008
Inside the group	$8{,}635x10^9$	237,00	$3{,}644x10^7$		
Total	$8{,}897x10^9$	238,00			
	Statistics	Gl1	Gl2		Sig
Brown-Forsythe	5,149	1,00	105,696		0,025
Levene	12,455	1,00	237,000		0,001

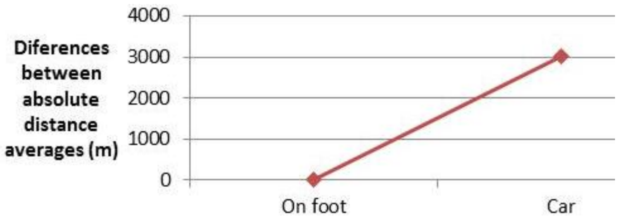

Figure 5. Discrepancies between reported and recorded distances in steps of long trips.

2) Divergence between reported and recorded duration

Analogous to the analysis of divergence in the reported and recorded made for the distance, an ANOVA analysis was performed to short trips and another ANOVA for long trips to study the reported and recorded duration. Table VI presents the results of ANOVA for differences between reported and recorded duration, expressed in absolute terms, relative to the mode of transportation for short trips.

TABLE VI. Results of Analyzes of Durations in Short Trips

ANOVA	SQ	Gl	MQ	F	Sig.
Between groups	454,056	2,00	227,028	6,332	0,002
Inside the groups	12657,133	353,00	35,856		
Total	13111,188	355,00			
	Statistics	Gl1	Gl2		Sig
Levene	4,640	2,00	353,00		0,010

Levene's test verified homogeneity of variances (sig=0.10>0.05), validating the use of the test F for ANOVA. It is marked that the discrepancy between reported and recorded duration differs depending on the mode used. A multiple comparison of averages, performed using the Tukey and Dunnett tests, presented in Table VII, indicates that the error in perception of time is higher in trips made by car than in the other modes. It is similar to the results found in the analysis of distance (Fig. 6).

TABLE VII. MULTIPLE COMPARISON OF AVERAGES FOR THE DURATION OF THE TRIPS

Test	(I) Mode	(J) Mode	Difference of the averages (I-J)	Standard deviation	Sig.
Tukey HSD	On foot	Car	-3,007	0,854	0,001
		Transit	0,109	1,275	0,996
	Car	On foot	3,007	0,854	0,001
		Transit	3,116	1,446	0,081
	Transit	On foot	-,109	1,275	0,996
		Car	-3,116	1,446	0,081
Dunnett t (2-sided)a	On foot	Transit	0,109	1,275	0,992
	Car	Transit	3,116	1,446	0,050

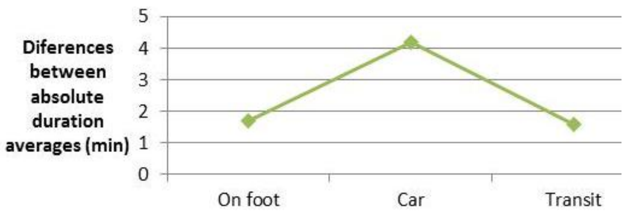

Figure 6. Discrepancies between reported and recorded duration in steps of short trips.

TABLE VIII. AVERAGE VALUES AND STANDARD DEVIATIONS OF DISCREPANCIES RELATIVE DURATION

Short trips						
Mode	Related bigger than recorded			Related smaller than recorded		
	N	Average	Standard deviation	N	Average	Standard deviation
On foot	143	33%	0,212	195	-108%	1,574
Car	18	23%	0,176	78	-140%	1,884
Transit	7	34%	0,239	19	-79%	0,320
Long trips						
Car	78	26%	0,228	126	-44%	0,547
Transit	31	20%	0,230	67	-35%	0,421

The analysis of averages and standard deviations of the relative duration of displacement (Table VIII) shows that individuals tend to underestimate the duration of the displacements in the three modes analyzed. These discrepancies are smaller relative to the shifts in public transportation (80%) and walking (108%), and higher for the displacements Driving (140%).

The difference in the result obtained in short trips is that the result of the divergence analysis of duration for longer trips showed no significant difference between the modes (sig=0.45>0.05). For long trips (over 2km) errors of perception of absolute duration are similar on cars and public transportation. Analyzing the average values (Table VIII) there is a tendency of individuals to underestimate the duration of displacement (44 % car, 35% public transportation).

VII. CONCLUSION

The established methodology for collecting trip data segregated by mode of transport with the joint use of GPS and the Trip Diary showed satisfactory results. The information recorded by the device could be associated to the information reported by the participants in approximately 62% of the legs of trips collected. Some legs of trips are discarded because of technology limitations (19%) and wrong reporting of respondents (18%). Consequently, of the 1,225 legs trips collected from 72 participants, 762 were considered valid.

The majority of the valid listed displacements were performed on foot. The significant observation of dislocations on foot is due to the fact that there is at least one leg trip on foot in the most trips made by car or by public transportation. The displacements performed exclusively on foot till the final destination were mainly due to shopping or work and they had long and varied time.

ANOVA analyzes and analyzes of averages and standard deviations were performed by stratifying according to the trip distance, smaller and larger than 2km. In short trips, the modes considered were public transportation, car and trips on foot. In long trips were considered cars and public transportation. The results showed that all subjects had discrepancies in duration and distance effectively reported and recorded. These discrepancies have been both positive and negative.

The analysis of differences in trip duration showed a clear tendency to underestimate the trip time, both short and long trips as in all modes. The magnitude of the discrepancy between reporting and recording was also higher in subjects who underestimated than overestimated that trip times. The magnitude of the discrepancy for the respondents who underestimated duration was approximately 20% to 30%. However, for those who overestimated, this discrepancy varied between 35 % and 140 %. At long offsets, the gap was proportionally lower than in short.

Regarding the discrepancy between the reported distance and the actual distance of the displacement, significant discrepancies were observed. However, it is not possible to state a tendency to over or underestimate informed of trips distance. In the sample analyzed was possible to observe a greater number of individuals who overestimated, but the magnitude of the discrepancy was greater in those who underestimated.

In transportation planning projects, often information about trip times and distances are obtained from reports of respondents. These data are commonly used in models to estimate demand for transport and other purposes. The understanding of the limits of these data is essential to the reliability of the results of these applications.

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