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# Monitoring travel times in an urban network using video, GPS and Bluetooth

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# Abstract

The travel time is an important measure for the quality of traffic. This paper discusses a few methods to measure or estimate the travel time in urban road networks. First of all, it is important to know that urban travel times display a large variation, so that the measurement of a single (average) travel time is not so meaningful. The travel time distribution is more relevant than the single value of the average. This distribution can be obtained from observations of travel times of individual vehicles, for instance by tracing probe vehicles with GPS. The distribution of travel time can also be measured by Bluetooth scanners that can recognize Bluetooth devices in a car. Travel time over a link can be estimated by comparing passing times at its beginning and end. Automated Number Plate Recognition cameras have a similar possibility to follow individual vehicles from point to point. In the study of travel time measured in urban areas, the quality of data from Bluetooth scanners appeared to be disappointing. The most important reason is that outliers cannot easily be eliminated. This is especially a problem in urban areas. Another reason is the uncertainty about the Bluetooth devices' carriers. It is difficult to identify whether the Bluetooth device belongs to a car or bus passenger, a cyclist or a pedestrian. Probe vehicles with GPS are very well appropriate for the measurements of travel times in urban areas.

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# 1. Introduction

The condition of traffic in a city can be characterized in several ways. Traditional quality measures are total time spent and total distance traveled (e.g. Robinson 1980). The first characteristic can be derived from flow rates and travel times per link, and the second can be measured from flow rates and link lengths respectively. A more recent quality measure is the macroscopic fundamental diagram (Geroliminis and Daganzo, 2008), which is characterized by link densities and flows of vehicles exiting the network. Also here the link travel time is as important as flow counts as an evaluation quantity.

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Flow rates are considered as traffic characteristics that are simpler to obtain directly from vehicle detectors than travel times. Measuring travel times is more complicated. One method to derive travel time is using floating car data. Vehicles that move with the traffic flow can be considered as a representative sample of the population of driving vehicles. For urban traffic the use of only a few floating cars is still full of problems because travel times in urban networks with signalized intersections have a large variation due to stochastic effects (Zheng and van Zuylen 2010). Therefore, a floating car sample has to be sufficiently large in order to obtain a valid and accurate estimation of the travel times.

Methods to measure travel times in urban networks are Bluetooth scanners, Automated Number Plate Recognition (ANPR) cameras, cumulative counts and probe vehicles with GPS. Bluetooth scanners, ANPR and cumulative counts are all techniques based on two or more point measurements and do not monitor vehicles between the observation points. That is a disadvantage, because in urban networks a relative large percentage of vehicles deviate from the straight forwards path between two points along a road. On expressways the fraction 'wandering' vehicles is low, since there are not many places along such a road where vehicles can legally stop or deviate. ANPR has the advantage of high accuracy of the passing moment; Bluetooth does not have that accuracy. On the other hand, Bluetooth can record vehicles on several lanes, even in both directions, while ANPR needs one camera per lane.

The cumulative count method is difficult in practice. It requires a perfect registration of passing vehicles. Standard automated traffic detectors are in general insufficient accurate to serve for this purpose.

The use of GSM to locate vehicles seems to be cheap and convenient, but the accuracy of the measured position of a GSM telephone is rather low and map matching of a sequence of measurement data is necessary to reduce the inaccuracy (van der Zijpp 2002).

For the assessment of the quality of traffic control in the city of Changsha, the link travel times have been used as the evaluation indicator. Different methods to determine travel time have been compared:

- a few probe cars driving through the network, installed with GPS devices with an measuring frequency of 3 Hz,
- 6000 taxis, busses and private cars tracked by GPS devices which can measure positions and speeds with a
  polling interval of 30 s,
- Bluetooth scanners on two positions along one road,
- Video observations of road sections.

A comparison of travel time measurement has been made. The Bluetooth scanners appear to have serious weaknesses due to the difficulty of removing outliers from Bluetooth devices carried by pedestrians or cyclists and from the fact that many vehicles make detours or have intermediate stops. The GPS data from taxis, busses and private cars appear to be very useful for the monitoring and evaluation of the traffic state. Compared with the Bluetooth scanners, it is rather simple to eliminate the effects of intermediate stops and detours from these GPS data.

This paper describes the evaluation of the different ways of measuring travel times. The research was executed in Changsha, the capital of Hunan province in China. Section 2 discusses the verification of GPS by comparing different devices: a mobile telephone with GPS, a commercial GPS receiver with the higher accuracy, and the standard GPS devices as available in about 6000 vehicles in the city. The chapter also shows that travel times obtained by the standard GPS devices could be used to determine link travel times effectively. Even a simplified method of using only the speed data from GPS devices appears to be applicable to obtain an estimation of average link travel time .

Section 3 deals with the use of Bluetooth scanners on urban roads. It shows that the devices that have been tested showed some technical problems that might be solved. A real weakness is that they could not separate travel times of vehicles that deviate from the link or stop somewhere halfway.

Section 4 presents some conclusions and sketches the further research done in this city. The richness of the data that has been collected from probe vehicles with GPS gives opportunities for many more researches.

# 2. The verification of the GPS data

In order to verify the GPS data obtained from 6000 probe vehicles driving in Changsha, the 0.033 Hz (one position/speed per 30 seconds) data from a few probe vehicles were compared with 3 Hz data obtained by a

passenger's telephone GPS. The accuracy of the 3Hz GPS device in the telephone was tested and it appeared that the position determined by GPS has about a variance of 5 m for a fixed position and 7.8 m when driving. The other test shows that the difference between a GPS in a mobile telephone (3 Hz) and a higher quality dedicated GPS receiver (10 Hz) is small.

The data of coordinates obtained by the 3 Hz and 0.033 Hz devices were very consistent, as shown in Figure 1. The road in the test is oriented in the South – North direction and the vertical axis gives the distance to the zero point of the GPS coordinate at 28.00 latitude. This means that, even though the GPS from the taxis is only registered every 30 seconds, the trajectory of the taxi can be extracted rather precisely to estimate the passing of stop lines. Interpolation can be used to estimate the passing moments with an accuracy of 1 second, as visible in Figure 2.



Figure 1 Comparison between 3 Hz GPS positions and the 0.03 Hz frequency of the GPS in a taxi.



Figure 2 Trajectory of a specific vehicle with 0.033 Hz registration

The speed of the probe taxis was also recorded every 30 s. This speed measurement from GPS is in general more accurate than the speeds derived from two consecutive GPS positions. The correlation between the directly measured speed and the speed derived from consecutive positions is 0.89 which indicates that in 30 seconds the driving situation can change a lot, this correlation is quite good. For the measurement of acceleration the low frequency GPS data were not useful.

A further check of the probe vehicle data was made by analyzing video data of a link. The video data were used to count traffic entering and exiting two links, the east second ring road and the third bridge over the Xiangjiang River with length of 600 m and 965 m respectively. The cumulative count method (Edie 1965) was used to determine the average travel time on the link. This method is applicable if there is no overtaking. The delays calculated from probe vehicles passing these links were determined by subtracting the free flow travel time from the travel time and are compared in Table 1. The errors are 1.9 to 3.8 % only. The percentage of probe vehicles in these observed flows was about 6.5%.

The conclusion of this verification is that the GPS data from the 6000 vehicles were sufficiently accurate for the measurement of the link travel times.

Traffic Direction		Distance (m)	Average Delay by Cumulative Counts (s/veh)	Average Delay by GPS Data(s/veh)	Relative Error (%)
The east second ring road	South-North	600	108	106	1.9
	North-South	000	68	66	3.0
The third bridge	East-West	965	107	103	3.8
River	West-East	705	123	119	3.3

Table 1 Comparison of average	delay (= travel time	minus free flow travel	time) estimated b	v two methods
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# 2.1. Comparison of the speed data and travel time

Many cities have GPS data from a fleet of special vehicles, in most cases taxis, and these data are often used for the monitoring of the traffic situation. If on a link low speeds are measured the conclusion might be that this link is congested. However, low speeds are common at a road section close to an intersection and they do not necessarily mean that the road is congested. Congestion can better be measured by average link travel time – or the inverse of the average travel time. In order to verify whether average speeds of probe vehicles on a link and the inverse average travel time. Figure3 shows the empirical relationship between the average link speed and the inverse of the average travel time. The conclusion is that average speeds measured by probe vehicles can indeed be used for the evaluation of the road conditions with respect to travel time.



Figure3 Empirical relation between average speed and travel time (left) and an example of speed measurements in the Changsha network.



Figure 4 Speeds along the Shaoshang road in Changsha; the signalized intersections were at distance 20251 m and 21419. At 20904 t is a unsignalized intersection.

#### 2.2. Elimination of outliers

On urban roads vehicles often do not follow a straight path, but deviate for parking or turn to another link. Later these vehicles can reenter the link. If travel times are simply calculated as the time difference between the entering of the link at the upstream intersection and the exiting at the downstream intersection, large travel times will occur, which has nothing to do with the travel conditions. For GPS observations with sufficient high frequency, the deviations from the direct path over a link can be detected by filtering out all GPS positions outside 10 meters distance from the side of the road. The remaining GPS data from a vehicle which have a gap of more than a certain time interval (1.5 minute in the case of the Changsha data) can be considered as an indication of a detour. Such trajectories are eliminated from the determination of travel time distributions.

The same has to be done for vehicles that stop for a longer time along the road. Such exceptional stops can be found by looking at vehicles with zero speed at positions and times where other vehicles are driving with higher speeds (Asmundottir 2010). In the Changsha study, 2 minutes are taken as the boundary value for such a stop. In Figure 4 some stand still vehicles in the middle of a link can be identify apparently as loading or unloading passengers, not waiting for the traffic signals.

An analysis of the GPS data shows that a large percentage (about 20%) of the trips of the probe vehicles in the investigated urban roads in Changsha cannot be used for link travel time measurements.



Figure 5 Trajectories of some taxis showing the many outliers due to routes that are not directly from start to end of the link

# 3. Bluetooth scanners

Bluetooth scanners are being used now on many places in the world to measure travel times. These scanners receive the signals from Bluetooth devices in a range up to about 100 m radius. Bluetooth devices are recognized with their unique identification number and if two Bluetooth scanners on a certain distance recognize the same device with a certain time interval, it is assumed that this time interval corresponds to the travel time between the two devices.

Two Bluetooth scanners were installed at a height of 2 m in the median area of the Shaoshan road in Changsha. During one hour the Bluetooth data were collected. GPS data were collected during two hours. Figure 6 shows that the Bluetooth data contain many outliers. If we would keep all GPS data from the probe cars the travel time distribution of the Bluetooth and probe vehicles would be similar. For the probe vehicles, the elimination of outliers

is simple. For the Bluetooth data it is very difficult, because the distribution of the valid data and the outliers overlaps: elimination of the large travel times would eliminate the travel times of slow vehicles that still should be counted, as can be seen from Figure 6.

Another problem with the Bluetooth data is the fact that the Bluetooth devices can be carried by passengers of cars or busses. These vehicles are counted multiple times. This can rather easily be eliminated by an analysis of the data. A more serious problem encountered with the Bluetooth data was to distinguish the Bluetooth carrier in a vehicle from a pedestrian or a cyclist. The last two carriers have nothing to do with the traffic situation evaluation. The other problem of the application of Bluetooth data is the moment of detection is not clearly defined. The scanners have a detection range of about 100 m (Granig and Young 2009). A vehicle with Bluetooth device along the route was registered only once when passing the scanner. If this vehicle made a u-turn to make the trip several times, it was still only recognized once. After making the turn the detector did not register the car another time. This is specific in this case for the unconventional route taken by this vehicle, but still illustrates that the setting of the Bluetooth scanner is important to get an unbiased and valid estimate of the travel time. Still most of these technical weaknesses can be solved by a better scanning and recognition mechanism in the scanners. The outlier problem is the remaining and most important aspect of Bluetooth that makes the application in urban areas less suitable.



Figure 6 Travel time measurements by GPS of probe vehicles (taxis) after removal of outliers and Bluetooth

# 4. Conclusions

The use of sensors to detect passing moments of identified vehicles has limited applicability for the measurement of travel times in urban networks. The elimination of outliers is complicated because the distribution of the travel times of the outliers overlaps with that of the valid travel times. This disadvantage limits the practicability of scanners that measure passing moments of Bluetooth devices. Number plate recognition cameras have the same problem of the elimination of outliers. Bluetooth scanners have a few other technical and methodological problems if applied in urban areas: the devices with Bluetooth are often mobile telephones that can be carried by pedestrians, cyclists and passengers of public transport. It is possible that some vehicles have several Bluetooth devices on board. This causes a bias in the estimation of travel time distributions. Furthermore, the exact position where the Bluetooth devices are registered cannot accurately be determined. For longer distance applications like on freeways, such an uncertainty has a smaller impact; on urban roads the relative impact can be large..

The availability of GPS data from probe vehicles gives a rich source of information about travel time. Identification of outliers is relatively simple. Most of the outliers come from vehicles that make a detour, which can be identified by their absence in the area around a link. Waiting vehicles at a link give also outliers, which can be

easily identified as vehicles standing still at places where other vehicles are driving. The processing of GPS data is rather simple and can be done in real time. The average speed data on a link from GPS appears to be closely related to the inverse of the average travel time.

Video recording of traffic gives the possibility to get very detailed information about the traffic state. Counts can be made much more accurate from video recording than from loop detectors. The cumulative count method has been used to verify the accuracy of the travel times obtained from a small percentage of cars provided with GPS. The consistence between cumulative counts and GPS travel times appeared to be very satisfactory.

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