TRACKING AND INTERVIEWING INDIVIDUALS WITH GPS AND GSM TECHNOLOGY ON MOBILE ELECTRONIC DEVICES

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Abstract

More and more transportation surveys use GPS technology, while GSM technology is used only in a few research projects. GPS technology provides very accurate data but is not always applicable due to technical restrictions like open view to the satellites which is especially crucial when participants use public transport. GSM is virtually always available but its spatial accuracy is less accurate. The combination of both technologies is promising more complete spatial data (origin, route, destination) when tracking individual’s routes.

Both tracking technologies can support transportation research in many different ways. This paper explains how either the parallel use of GPS and GSM tracking technology at the same time or the use of GSM tracking technology only, combined with a historic GPS/GSM tracking database can produce reliable tracking results.

Based on the parallel use of GPS and GSM tracking the knowledge of the individual’s location can be used for adapted user response and thus reduce user burden. Portable electronic devices equipped with GPS/GSM can be used to interview the respondents in real time respectively on site. The knowledge of the location will be used to reduce the amount and the complexity of questions asked. Questions about origin/route/destination or transportation mode will be asked only if tracking data are unclear and thus need to be specified.

First test drives provided promising results regarding the combination of GPS and GSM tracking. Based on this tracking some strategies for adapted user response are developed and first dialogues for adapted electronic questionnaires are designed.
1. Introduction

One reason spending so much effort in developing tracking technologies is human inability to report geographic information as precise and reliable as needed for transportation research. It has been reported that people cannot support this kind of data by themselves. In a feasibility study in Germany, information collected in a conventional travel survey (CATI) has been used to geo-code the self reported trips. The results showed that ca. 50% of the trip’s origin and/or destination could not be matched to a street section respectively 70% - 80% to an address (infas, 2001).

The demand for more precise and reliable spatial data is partly derived from increasing microscopic data analysis and modelling. In addition to simple origin/destination coordinates even more complex data about the route is needed. However, route information is too complex to be included into classic paper pencil questionnaires for now and most probably in the future. Facing these problems researchers look for alternatives for conventional travel surveys.

During the last years an increasing number of GPS based transportation research projects have been carried out to meet the required tracking data quality. Under certain conditions tracking technologies provide the means to improve the spatial information of the whole trip. Due to technical constraints like power supply or weight most of the early research projects focused on vehicle-based transportation mainly by private car. Recent feasibility tests on tracking in public transport produced poor results which leads to further research in this field.

At the same time the introduction of electronic questionnaires on mobile devices allow new approaches in transportation research. This technology provides the opportunity to adapt flexible questionnaires to complex research designs.

Since tracking technologies can not provide reliable data in every situation this paper will describe how the parallel use of mobile electronic questionnaires and GPS/GSM tracking technologies can be used to collect missing or to specify inaccurate tracking data.

2. New technologies in transportation research

Two major technologies had large influence on travel surveys in transportation research during the last ten years. At first, these are the tracking technologies GPS and, more recently, GSM. Secondly electronic questionnaires both offline/online as well as stationary/portable are used.

Tracking vehicles and individuals with GPS and GSM technology can be divided into two main approaches. The first is passive tracking without direct user response. The second approach is active tracking where user response is used to add additional information to the recorded GPS/GSM-tracks. Both GPS and GSM have advantages and disadvantages in different ways. GPS is highly accurate regarding its positioning data but has problems with availability under enclosed conditions, e.g. in tunnels and buildings. GSM is less accurate but it is literally always on hand. Active tracking with user response became more popular since the mobile equipment like personal digital assistants (PDA) provided the necessary performance and user friendliness.

2.1 Tracking with GPS technology

The first approach to use GPS technology for transportation research has been passive tracking along with traditional reported travel data like it has been done in Austin (Casas, 1999). This study focused mainly on the comparison of traditional (PAPI, CATI) and GPS based surveying. Bachu et
al. used passive GPS data collection to carry out a Proof-of-Concept Study (Bachu, 2001). They used printed maps showing the determined travel path to support prompted recall after the respondents finished the GPS survey.

Many of the current active GPS studies use some kind of user interface like a PDA attached to the GPS device to collect further information about the trip. One of the earliest surveys using this technology was the Lexington study carried out by the Battelle Institute in 1996 (Battelle, 1997; Murakami, 1999). This study was followed by a number of other studies mainly focusing on vehicle based and in particular on car based transport. This restriction on vehicle based surveys is due to the fact that early GPS equipment was limited by the power supply provided in vehicles. At the same time it was heavy and bulky.

The first GPS pilot project focusing on the examination of all travel modes was done by the Dutch Transport Research Center (AVV) in 1997 (Draijer, 1999). They used active GPS equipment that could be carried outside a car but which was still heavy (2Kg weight). Looking at the quality of the results, the pilot study demonstrated that it is possible to monitor individuals in different travel modes. But, comparing the different modes, there is a big difference regarding the tracking availability. Car users where tracked on 90% of their trips while tram and rail passengers where tracked only on 50% of their trips. The results of this research project also show a resistance to use the GPS equipment during walks, bicycle drives and public transport as well as for some travel purposes such as shopping or visits. This might have been caused by equipment’s size and weight.

De Jong et.al. carried out a feasibility study tracking individuals in public transport, in this case on different commuter trains in Sydney (Jong, 2003). This data show similar results in terms of tracking quality in public transport, especially in trains. Good tracking results were detected only in special trains with overhead windows or on seats directly at the windows.

One ambitious goal using GPS technology is the “Elimination of the Travel Diary” like Wolf and others expressed it in their paper for the Transportation Research Board (Wolf, et al, 2001). Ideally, not only the track of each trip but also the travel mode and even the trip purpose should be detected automatically just by analysing the tracking data. Looking at the results of Draijer and de Jong, need to be much improvement will be necessary to reach this goal.

### 2.2 Tracking with GSM technology

The literature reveals only very few reports on GSM tracking technology as an alternative for tracking in transportation research. Besides projects dealing with location based services mainly focusing on location based services, only two projects are reported that applied GSM tracking technology for transportation research purposes.

The TeleTravel System (TTS) project was carried out in 2000 in Germany (Wermuth, 2001). This project combined GSM tracking technology and an electronic travel diary to determine the travel behaviour of the respondents. In this project the GSM tracking technology has been proven for an accuracy of about 100 meters with the highest precision in urban or densely populated areas.

Hato et. al. used GPS tracking technology to collect time-space activity data (Hato, 2001). They used a passive approach to collect the time-spatial activities of 10 individuals for a two week period. In addition, the subjects were asked to fill out a simple paper pencil form for both weeks.

Both surveys demonstrated the general applicability of the GSM tracking technology for traffic research. It has been shown that the error level of GSM tracking at the highest accuracy level is approximately 100 meter in dense areas.
2.3 Complex questionnaires on mobile electronic devices

In order to apply the active tracking approach, there needs to be a man-machine-interface to communicate with the respondent. For this purpose most of the active tracking surveys used electronic questionnaires on personal digital assistants (PDA) to meet these requirements.

Starting with easy to use adaptations of paper pencil questionnaires on standard cellular phones up to complex activity-based diaries on PDAs, the use of mobile electronic questionnaires gained increasing interest and use in transportation research.

Doherty et.al. developed their activity based electronic questionnaire (CHASE) on stationary computers and transferred this tool on PDAs (Doherty, 2000). This activity-based approach with extended activity planning functionality (Ex-ACT) is also applied in a German study carried out by Rindsfüser et. al. (Rindsfüser, 2003). Recently they have done a feasibility study with the aim to include GPS tracking into their research approach.

Sommer developed a very easy to use basic approach to collect mobility data on standard cellular phones (Sommer, 2002). He designed a tool which can be used to collect the basic trip information like mode, purpose and time on every cellular phone.

2.4 Bring it together

Accuracy and availability of spatial information provided by GPS and GSM technology as it has been discussed in the literature can be summarized as shown in Table 2.4.1.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Information accuracy</th>
<th>Information availability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Origin</td>
<td>Route</td>
</tr>
<tr>
<td>GPS</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>GSM</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Questionnaire</td>
<td>++</td>
<td>-</td>
</tr>
</tbody>
</table>

+++ = good, ++ = sufficient, + = poor, - = no data

Provided a clear view to the sky, GPS will produce the most accurate data. But the availability suffers from its technological restrictions. The expressed accuracy and availability level of GSM technology is true for cities or densely populated areas only.

Due to the technological restrictions and advantages of both technologies it is quite clear that GSM tracking can complement GPS tracking in many situations. But up to now there are no known reports in the literature where both tracking technologies have been used at the same time for transportation research. Even with parallel use of both tracking technologies there might be some situation where user response is necessary to generate survey results.

All tools discussed above do not integrate the actual tracking data into their questionnaires in real time. This might be due to the large amount of data which needs to be processed or stored on the PDA. Using GSM technology for tracking provides also the opportunity to transfer data in real time and thus the usage of remote computer power for calculation and data storage. With this technology real time integration of tracking results parallel to user response becomes an opportunity.

The following analysis describes recent results with parallel GPS/GSM tracking. Based on this analysis several approaches for GSM tracking improvements will be proposed and how real time integration of tracking results can reduce the complexity of questionnaires and thus user burden.
3. Tracking with GPS/GSM technology in practice

As described above, due to the constraints of GPS technology such as power consumption, weight, etc. most of the GPS tracking projects in the past focused on vehicle-based transport mainly by private car. When tracking individuals in all transportation modes, the participants were asked to wear the equipment in a special manner. Most of the projects used a GPS antenna placed on the shoulder strap of a bag. The bag was used to store a passive data logger, power supply and sometimes a portable computer, when user response was required. One can imagine that this equipment has impact on the respondent’s behaviour and on the willingness to participate in such a survey (Draijer et al., 2000).

The aim of the research described in this paper is to track individuals in an “every day” situation on all modes. Due to the conditions at the study site Berlin, a large share of trips done by public transport has to be considered (22% in Berlin). Thus, the design of the equipment should be as handy as possible to minimize the influence on the respondent’s behaviour. To meet this requirement we have chosen two devices (GSM, GPS) which can be carried easily. Size and weight of the devices are similar to a standard PDA or cellular phone.

The equipment used in this test drive has the following specifications:

<table>
<thead>
<tr>
<th>Cellular phone/PDA</th>
<th>GPS device</th>
</tr>
</thead>
<tbody>
<tr>
<td>- data storage capacity (128 MB RAM + variable SD-card memory)</td>
<td>- data logger functionality</td>
</tr>
<tr>
<td>- programming capability (Windows CE System)</td>
<td>- data storage capacity 8MB (expandable)</td>
</tr>
<tr>
<td>- GPRS functionality</td>
<td>- independent runtime: ~10 hours continuously</td>
</tr>
<tr>
<td>- independent runtime: ~15 hours continuously</td>
<td>- weight: 100 g</td>
</tr>
<tr>
<td>- weight: 190 g</td>
<td>- size: 110x53x24 mm</td>
</tr>
<tr>
<td>- size: 130x70x20 mm</td>
<td>- bluetooth port</td>
</tr>
<tr>
<td>- bluetooth port</td>
<td></td>
</tr>
</tbody>
</table>

Given the fact, that a large proportion of inhabitants in the study area own a cellular phone (80% in Berlin), we assume that carrying similar devices with comparable size and weight does not bother people too much. The devices do not need to be connected with a separate power supply and thus can be carried independently in different pockets.

We further assume that people do not like to carry a GPS on top of the shoulder. For this reason we tested in this study some other positions to find out whether these positions provide reliable GPS tracking data especially when these data can be complemented with GSM tracking data.
Two major goals are pursued:

- To develop tracking equipment which will reduce the user burden in terms of carrying comfort as much as possible and, at the same time, to provide accurate and reliable tracking data in an acceptable quality. To this end two tasks have been carried out.
  - Test the GPS tracking capabilities of the used equipment in different positions at the body to determine the best compromise of tracking capability and convenience for the respondent.
  - Test the GSM tracking availability parallel to the GPS tracking.
- Develop routines for an electronic diary which will use the tracking data for an adapted, situation-based user response.

Real time adaptation of tracking results can be used to reduce the complexity of questionnaires and thus user burden.

### 3.1 Simultaneous tracking with GPS/GSM technology

The following example will show how the use of both tracking technologies simultaneously will increase the data availability and accuracy. These examples are results of a series of test drives during the years 2002/2003. The study site was Berlin.

Tracking accuracy and reliability is highly dependent on the position where the survey participants carry the GPS device (Jong, 2002). This analysis is based on a test drive with eight participants at the same time. The eight participants are divided into four groups which took different, predefined routes in commuter trains (S-Bahn) in Berlin. Each participant carried five GPS devices on predefined positions at the body (one at each shoulder, two at the belt or in pockets of the coat, one in the backpack or breast pocket). At the same time, each participant carried a cellular phone in the backpack which has been tracked during the test drive (Kracht, 2003).

In the following, data of the two GPS receivers placed on the shoulders and the two at the belt (two participants carried the devices in cases in their coat pocket next to the belt) are analysed with respect to data availability during the trips as well as accuracy. Figure 3.1.1 depicts the recording of signals during each journey and for all GPS devices. Device 13 and 19 where configured incorrectly and thus did not provide usable data.

Figure 3.1.1 shows that only 10 out of 36 GPS devices (6, 9/10, 17/18, 22, 26, 29/30) provide constant tracking results with less than 10 minutes gaps at a time - except tunnel times. All these devices were placed on the shoulder of the participants. This was expected due to the characteristics of GPS technology and the chosen test environment.
But there are also some GPS devices not carried on the shoulder that show fair results (20, 23/24, 31/32). Especially those devices carried in the pockets of a coat, basically at the same position like those on the belt but not covered by heavy clothing, showed good results.

Comparing the GPS tracking on each of the four routes (group 1-4) separately, the pattern plotted in Figure 3.1.1 show some similarities. The presence and absence of GPS signals on different routes show some characteristic “waves” for each route. The pair of GPS devices placed on the shoulder or on the belt (pocket) of each respondent show similar results on most routes. When the signal on a test drive is not available at one of the paired devices the other device shows similar results. These “waves” might be caused by external conditions like build environment close to the rail tracks.

The analysis over time shows that the position shoulder or belt is more crucial than the left or right hand position at the body. The GPS devices on the shoulder show the best results followed by the devices in the pocket. The devices on the belt show the poorest results on all routes and persons. With respect to the analysis over time, the position in the pocket might be a place where tracking requirements and user burden respectively convenience comes to a good compromise. Due to the small number of devices this needs to be confirmed in further tests.

The GSM devices of all four groups showed constant connection to a base station over the complete travel time. Assuming that the tracking accuracy of this technology in areas with dense population can reach about 100 meter as it has been reported, this will close the gaps left by the GPS tracking.
Figure 3.1.2 shows an example how GSM tracking can fill the spatial gaps when a GPS signal is missing. The map shows the tracks of two GPS devices 22 and 24 (see also Figure 3.1.1). In addition the sites of the GSM base transceiver stations which are connected to the GSM device during the same drive are plotted to indicate the proximity and thus the potential tracking accuracy to the real track. The test drive starts in the south-east corner of the map, turns right (up north) onto the ring structure and comes back to the starting point.

**Figure 3.1.2 Spatial pattern of GPS/GSM Signals on commuter rails**

As Figure 3.1.1 already indicates, the GPS device 22 provides good tracking data. This is confirmed by the spatial pattern of Figure 3.1.2. There are only few gaps left at the northern part of the test drive. Device 24 shows very poor GPS tracking results. Only the first part of the test drive (in the south/east part, done by walking to the rail station) provides good GPS results. The largest part of the trip driven by commuter train is documented only by very few GPS tracking points.

The GSM track outlined by the plotted GSM transceiver stations on the map shows, that in an urban area like Berlin the distance of GSM transceiver stations to the real track is relatively small. Both GPS tracks can be complemented by GSM tracking to fill the gaps. The GPS tracking of device 22 is nearly complete and the GSM tracking have to fill only a few gaps in the north. On the other hand, the GPS tracking points of device 24 can serve as reference points to adjust the more inaccurate GSM tracking.
The red GSM base transceiver station (tunnel) indicates that the respondent used a rail tunnel which is equipped with GSM functionality. This is the case for most of the rail and subway network in Berlin as well as in other large cities.

The analysis of the GPS tracking data leads to the conclusion that tracking individuals in commuter trains does not provide reliable data in all situations. At the same time the GSM tracking can close the gaps left by GPS tracking in some environments. It is expected that the development of the GPS/GSM database, as it will be described in the following chapter will further improve the GSM tracking capability and accuracy.

4. Concepts for adapted data collection

Automated data collection and analysis based on passive GPS tracking approaches strongly rely on good data. For example the determination of traffic mode derived from GPS tracking data will only work with very accurate data. As discussed in 2.1 and proved in 3.1, tracking data is often not in the appropriate condition to allow this kind of analysis. In this case other active tracking approaches with user response are needed to ensure data quality and reliability. The following chapters will explain how incomplete or inexact data can be used for adapted data collection.

4.1 GSM tracking with a historic GPS/GSM data base

A GSM network consists of serving cell areas structured by cell borders (A) (see Figure 4.1.1). In addition to the cell borders there are field strength borders (B) within each cell which divides the cell into concentric zones around each GSM station. The determination of the actual position will be done by measuring the field strength or TA level of each base transceiver station in sight of the cellular phone. The intersection of all measurements will be the actual position of the phone. Figure 4.1.1 shows an ideal situation not influenced by the “real world” like landscape, buildings and other factors affecting the signal spreading and thus the shape of a cell border. Neglecting those environmental effects GSM tracking would provide distorted results. Thus the knowledge of the “real world” cell borders and field strength borders would increase the GSM tracking quality.

![Figure 4.1.1 Schematic figure of GSM-tracking (ideal tracking conditions)](image)

Once the in 3.1 described approach of parallel GPS/GSM tracking has been used for a longer period, a historic GPS/GSM data base can be established. This data base will consist of the GSM
transceiver station ID, the transceiver station location and the GSM field strength at every logged GPS position.

This information reflects the cell borders and field strength borders influenced by “real world” conditions like landscape and built environment. GSM tracking with this “real world” cell borders might be much more realistic than measuring the theoretical position assuming there would be a homogenous space with no interferences.

GSM tracking based on the described GPS/GSM database concept can be done for different accuracy levels.

1. The (average) border of each GSM serving cell will indicate the area in which the participant stays. Tracking the moving participant over a time period will provide a sequence of all cells and thus a trajectory.

2. As outlined in Figure 4.1.1 the field strength or TA-level can increase the tracking accuracy. The signal strength within each serving cell can be understood as a virtual border subdividing each serving cell. These smaller areas will increase the tracking accuracy.

The described database will provide the opportunity to track only with GSM technology when GPS tracking is temporarily not available or GPS equipment is not available and a less precise accuracy level can be accepted.

It is well known that the spatial spreading of field strength is influenced by a number of effects like shadows of buildings, weather and mirror effects. Since some of these effects are not stable over time the described GSM tracking approach is - compared to the accuracy of GPS tracking - still only an approximation of the real position. But even when the tracking accuracy of GSM tracking might be sometimes inaccurate, the tracking results can be used for adapted data collection as described in the following chapter.

4.2 Adapted data collection with user response

All tracking technologies discussed above can be used for location-based respectively situation-based data collection. Each accuracy level in terms of tracking can be used to adjust questions asked in an electronic questionnaire to an appropriate level. This can be done by reducing the written context menu (Figure 4.2.2) or by providing adequate graphical support like maps (Figure 4.2.3). With respect to the origin/destination and the track of individuals, the interaction intensity with the respondent will vary as shown in Figure 4.2.1

**Figure 4.2.1 Influence of tracking quality on respondent interaction needs**

<table>
<thead>
<tr>
<th>Tracking data quality</th>
<th>Interaction with respondent</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS signal</td>
<td>no interaction</td>
</tr>
<tr>
<td>GSM signal</td>
<td>reduced interaction</td>
</tr>
<tr>
<td>No signal</td>
<td>complex interaction</td>
</tr>
</tbody>
</table>

A GPS Signal with good quality will provide all information needed to find out the track and sometimes even the mode of the trip. Thus, in this cases an interaction with the respondent is not necessary. Tracking at the following quality level with GSM signal might cause some interaction...
with the respondent assuming that the tracking data needs to be more precise than provided by the GSM technology. The interaction with the respondents can be reduced as follows:

An inexact knowledge of the location given by GSM tracking can be used to present a reduced menu content. This can be done when asking for origin/destination information like street name. Having a rough knowledge of the location of a respondent all streets within a certain vicinity (e.g. a GSM serving cell, see Figure 4.1.1: A) can be selected and presented on the screen (see Figure 4.2.2) and thus reduce the interaction with the user. The same procedure can be applied for other spatial information like public transport stations or zip codes.

Figure 4.2.2 Respondent interaction with reduced menu content

![Image of reduced menu content]

Sometimes respondents feel more comfortable when their response is assisted by maps (Figure 4.2.3). Even with incomplete or inaccurate tracking data the origin or destination of a trip can be specified by presenting the estimated area on a map and asking the respondent for specification. The knowledge of the actual GSM cell ID for example can be used to present this area on a map at the mobile device. The same approach can be used when the information about a route is incomplete or the accuracy level is less precise than required. In this case the estimated route will be presented on a map and the user will be asked to confirm or adjust the route.

Figure 4.2.3 Respondent interaction with graphical support

![Image of graphical support]
The described concepts for adapted data collection are currently under development. The establishment and test of a GPS/GSM data base is ongoing. First tests have been done and show good results.

5. Conclusion

Getting data in good quality is one of the major demands in transportation research. One attempt to increase data quality and thus data accuracy and availability is using new technologies. A lot of research has been done on GPS/GSM tracking technology and electronic questionnaires in transportation research. This paper focussed on parallel GPS/GSM tracking and adapted data collection with electronic questionnaires on mobile electronic devices.

It has been shown that parallel GPS/GSM tracking is a good opportunity to fill incomplete GPS tracking data. The proposed GSM tracking approach based on a GPS/GSM database might work in cities or dense areas only because of the sufficient density of GSM base transceiver stations. Ongoing tests will prove whether the proposed concept will be suitable on a larger scale and under everyday conditions as it is intended. Further research will be done on this topic.

Asking people to wear technical equipment over a long time can always cause non-response or drop out effects, which will influence the research results. These effects are even stronger if the equipment is heavy or bulky. Using GSM tracking technology in combination with adapted user response as described might enable researchers to provide more user friendly equipment. The loss of tracking data accuracy might be compensated from information collected with adapted user response. However, the influence of higher user burden due to active user response in comparison to passive tracking data with no user response needs to be examined in future research.

The application of the proposed approaches depends on the research goal in mind. Both tracking technologies provide data on different accuracy levels. At the same time it is assumed that up to now GSM equipment is more handy and user friendly than GPS equipment. Researchers have to decide which accuracy level is applicable according to their research requirements.

New technological developments will provide further opportunities for transportation research. UMTS technology is promising better tracking capabilities than GSM. Additional satellite tracking services like GALILEO might increase the tracking accuracy and availability. There is strong evidence that GPS and GSM technology will merge into one single device in the future.

However, GSM tracking is still a very new approach in transportation research. The test showed promising results but there are still many open questions to be answered.

7. Literature


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