CAPABLE GPS report

Draft 2

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Abstract

This report outlines the methodologies of the Children's Activities, Perceptions and Behaviour in the Local Environment (CAPABLE) project, with particular focus on how GPS (Global Positioning System) receivers have been utilized in the data collection phase of the project. The CAPABLE, which runs from 1 August 2004 to 31 December 2006, is a joint research initiative between four UCL departments and four non-academic partners.

The aim of the CAPABLE project is to understand current situation of children’s usage of their local environment and to examine the interaction between children and the environmental factors such as space configurations and socio-economic characteristics of neighborhood areas. By synthesizing several approaches to children’s activities, this project tries to identify the barriers in physical activity amongst children in the environment with a view to making recommendations about how they can be improved.

GPS is one of the research tools we employed in this project. A number of previous studies suggested the potential of using GPS for collecting detailed information on human spatiotemporal activity patterns. However not so many studies have been made on the application of this technology to observe actual spatial behavior of children in conjunction with other traditional travel survey methods to collect necessary datasets to reconstruct the whole picture of children’s lifestyles. The paper provides details of how we select, use our GPS equipment for tracking approximately 200 children’s spatial movement in Hertfordshire, U.K, over 4 days as well as an overview of technical specification of GPS positioning technology.

Firstly the background, the aims and the research tools of the CAPABLE project are briefly explained. Following the technical specification of GPS, methodologies regarding GPS tracking surveys in the project are explained. As the scope of this paper is within the methodological aspects of the project, more specifically within the use of GPS, details on the results drawn from the actual analyses of the data is not included in this report.

Introduction

What is CAPABLE project?

Obesity amongst British population, especially amongst children has become one of the most serious social problems in the UK. Physical activity promotion has been put high on the health policy of British government. In response to this, there have been several efforts to tackle this problem across British government departments. These efforts and relevant policies are reviewed in a report by The National Audit Office (NAO) and it is pointed out that “declining rates of participation in physical activity within the general population have been linked to... greater use of the car leading to a decline in walking (NAO, 2000).” Subsequently, several initiatives were taken that try to promote walking to school. For example, the Department for Education and Employment (DfES), the Department of Transport, Local Government and the Regions (DTLR) and the Department of Health (DoH) have produced guidance for local authorities, schools and parents on building a safe environment for pupils to walk or cycle to school (EPPI 2001).
In this context, Children's Activities, Perceptions and Behavior in the Local Environment (CAPABLE) project was launched in August 2004 as a joint research project between four departments of University College London (UCL) and four non-academic partners:

UCL departments

- Centre for Transport Studies
- Bartlett School of Architecture
- Department of Psychology
- Centre for Advanced Spatial Analysis (CASA)

Partners

- Hertfordshire County Council
- Children's Play Council
- Groundwork UK
- The Young Foundation

Funded by the Engineering and Physical Sciences Research Council (EPSRC), this project studies the behavior and perceptions of primary school children in an effort to understand how they currently use their local environment and what can be done to make it easier and safer for them to move about on foot. Previous studies highlighted that the characteristics of built environment and people’s perception of it have significant influence on people’s walking behavior therefore human activity and travel patterns can be approached from social, demographic, economic characteristics (Ewing 2005, Li, Fisher et al. 2005). Thus, in this project we synthesize spatial analyses on children’s actual movement patterns and transition of their physical activity level with socio-economical studies of children’s households and neighboring areas. By this synthesized approach, we have been exploring:

- the types of activities that consist children’s lifestyle
- the relationship between children’s car use and their physical activity level
- the nature and structure of routes, spaces and networks as used and perceived by children
- the spatial extent of children’s area of activities
- the impact of the local environment on children's behaviour and spatial understanding

In order to collect all the datasets which are necessary to conduct a series of analyses on the topics listed above, several research tools were employed in this project. In the next section, all the data collection methods we have used in the CAPABLE project are briefly explained.

Research tools for the CAPABLE project

Fieldworks

In the CAPABLE project, a series of field works was carried out from November 2004 to March 2006 in two contrasting areas: Hertfordshire, a wealthy leafy suburb that is located at the north of London, and Lewisham, one of the boroughs of Inner London that has more urban environmental setting with busier streets and dense residential blocks（Figure 1）.

(a) (b) (c)

Figure 1 Neighborhoods in Hitchin, Hertfordshire (a) and in Lewisham, Inner London (b and c)

We collaborated with seven primary schools in total, five in Hertfordshire and two in Lewisham, for conducting our field work surveys:

1. The Holy Family RC Primary School (Wellwyn garden city, Hertfordshire)
2. St Paul's Walden Primary School (Hitchen, Hertfordshire)
3. New Briars Primary School (Hatfield, Hertfordshire)
4. Flamstead End Primary and Nursery School (Cheshunt, Hertfordshire)
5. The Burleigh Primary School (Cheshunt, Hertfordshire)
6. Kilmorie Primary School (Forest Hill, Lewisham)
7. Perrymount Primary School (Forest Hill, Lewisham)

Figure 2 shows the location of each of the seven schools by a red dot that is overlaid onto the map of administrative boundaries around London at county level. The area highlighted in yellow is Hertfordshire and the one in blue is Lewisham borough. As described earlier, Lewisham is one of the boroughs that constitute Inner London (the area within the light blue line). All schools are within 50km radius from central

London and therefore can be easily reached by train and car in less than 2 hours. Amongst these seven primary schools, only Holy Family School is Catholic and the other schools are publicly funded community schools. Religious schools tend to have larger catchment area compared to the other non-faith schools, which could leads more children travel to school by car.

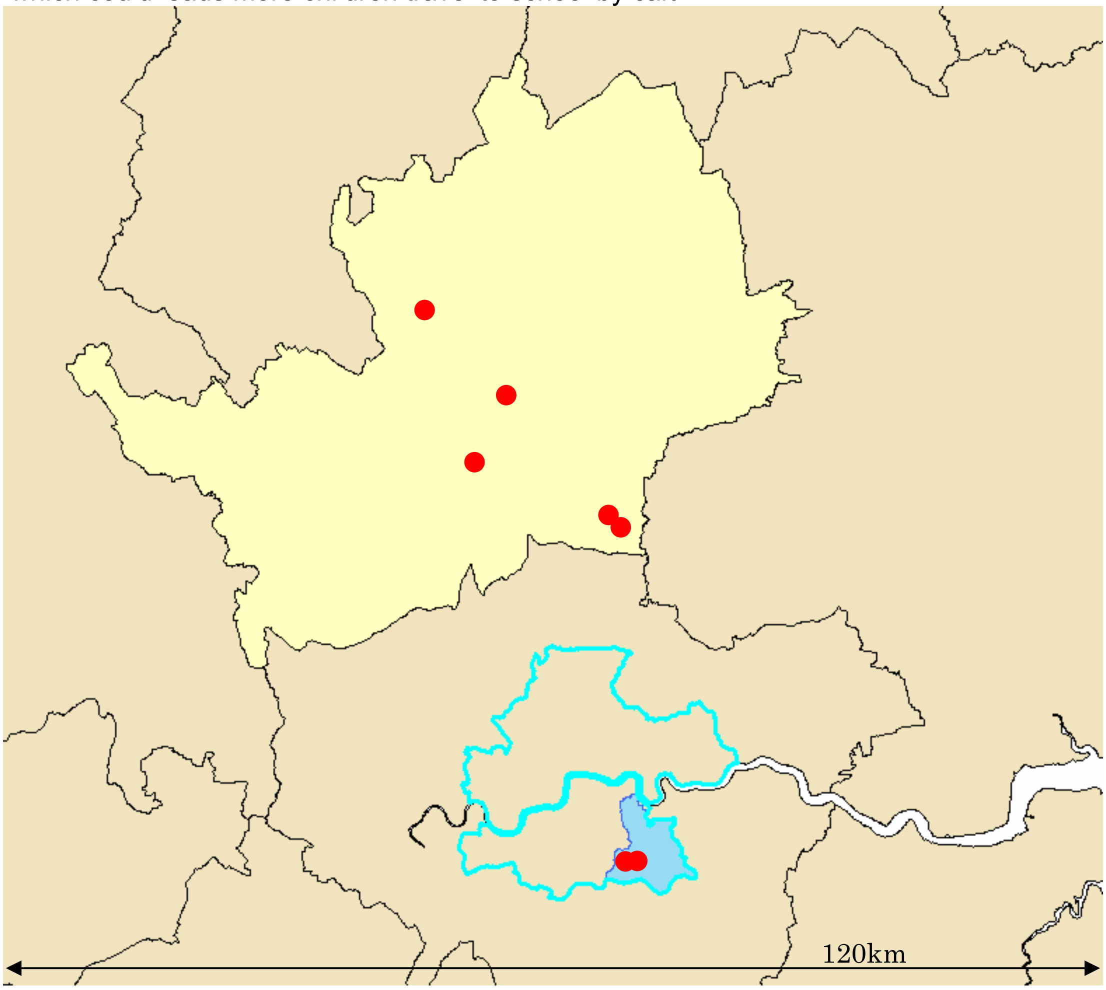


Figure 2 Seven primary schools (red dots) that participated in CAPABLE fieldworks. The area in yellow shows the Hertfordshire and the one in blue shows the borough of Lewisham of Inner London (the area defined by the light blue line)

The primary school children who took part in the field works are in Years 4, 5 and 6, which means that they are aged 8/9, 9/10 and 10/11 respectively. Approximately 300 children in total (200 in Hertfordshire and 100 in Lewisham) participated in our fieldwork surveys.

The prime aim of the fieldwork surveys was to collect detailed information of the lives of primary school children such as where they play, how long they spend their spare time with their friends, perceptions of their local environment, and parental attitudes towards children's autonomy when they let their children play without adults. Such information is crucial when we try to understand an overall picture of children's lifestyle and to investigate possible environmental factors that have some influence on children's behaviour. For this purpose, we employed several data collection methods for the field works that include:

1. Monitoring surveys using GPS (Global positioning system) receivers, RT3 (Tri axial

accelerometer) monitors and Travel and activity diary

2. Questionnaires surveys of children and their parents
3. A battery of tests and drawing map exercises which investigate children’s environmental knowledge, including two types of sketch mapping tasks to test children’s recall of the local environment, direction estimation tasks, landmark recognition tasks, and a test of spatial reasoning.
4. In-depth interview with children and their parents including mapping exercises

Tool 1: Monitoring surveys

The first data collection method, monitoring surveys, provides detailed information which allows CAPABLE project researchers to reconstruct almost every single activity that the children were engaged over four days. Three different types of equipment, GPS receivers, RT3 monitors and Travel and activity diary were employed in this method. All the equipments were fitted or handed to the children by CAPABLE researchers in the classroom with the detailed instructions on how to handle them.

GPS is a satellite-based positioning system. By picking up signals from these satellites, a GPS receiver can tell the user position over the ground with relatively high accuracy up to several metres. Each week of the survey period, a set of the children (15 on average) is selected to wear wrist-watch type GPS equipment Figure 3) from Wednesday to next Monday. They were asked to keep putting the equipment all the time except several occasions such as while they are asleep and when GPS might get wet.

Figure 3 a child wearing GPS equipment on his wrist

The data obtained from GPS subsequently is superimposed on a local area map in GIS to allow the researchers to track the children's spatial movement （Figure 4）and the type of activities. Further details of GPS equipment we used for this project are explained in the sections of GPS and GPS surveys.

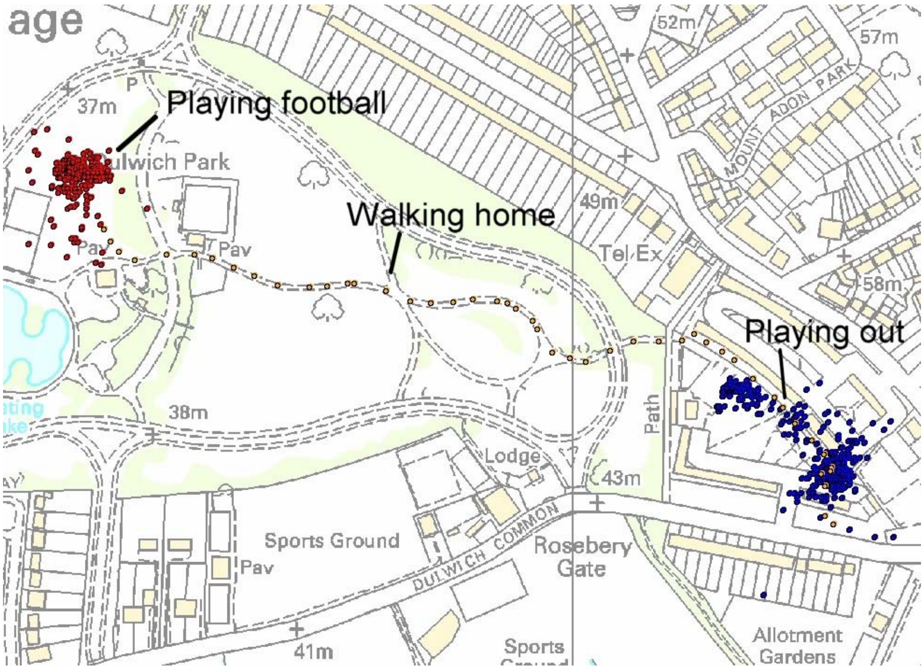
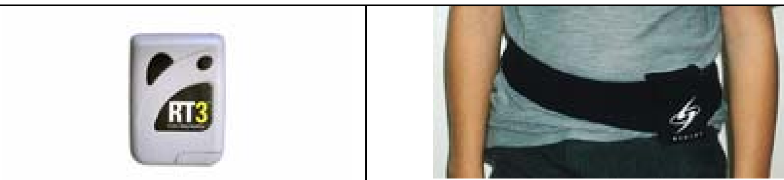


Figure 4 sample data of GPS showing that a child played football in the park (red dots), walked back home (orange dots) and then played outside of his house (blue dots).

RT3 is an activity monitor which detects and records 3-Axis motion. This unit measures the amount of energy expended during the periods of activity and rest by computing caloric energy necessary to accomplish motion. In this project, children are fitted with RT3 around their waist (Figure 6). Figure 6 and Table 1 shows the data obtained from this device provide us with the information about the calories consumed per minute, in other words, how active the child was at given point in time. The transition of children's physical activity level is measured continuously over four days. Using the RT3 data in conjunction with that from GPS and Travel and Activity diary, the type of the place where children become active as well as the type of activity they are engaged can be identified.



(a) (b)

Figure 5 RT3 monitor (a) and a child wearing the monitor around his waist (b)

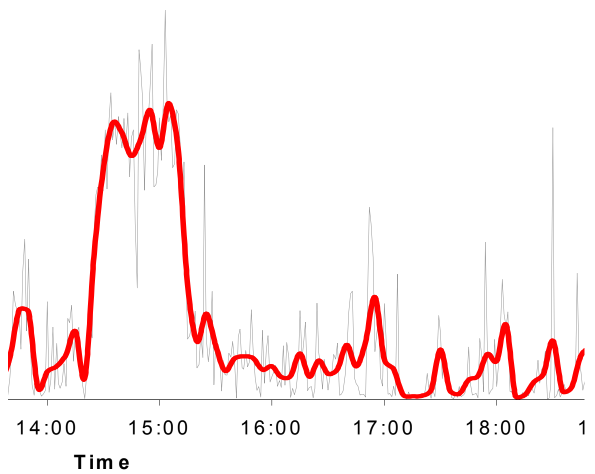


Figure 6 a sample graph showing the transition of Vector Magnitude (the intensity of the activity) in one day. The smoothed line (red) is overlaid onto the original data (grey). The peak showing vigorous activities around 15:00 was identified as the child walking his dog when analyzed with the data from Travel Activity diary.

Table 1 sample data of RT3 showing the calories consumed and the activity level per minute

				Physical activity level				
				Very light	Ligh t	Moderate	Vigorou s	Very Vigorou s
07/13/2005	10:07:00	1.9105	1.0321	0	1	0	0	0
07/13/2005	10:08:00	1.1868	0.3084	1	0	0	0	0
07/13/2005	10:09:00	1.9105	1.0321	0	1	0	0	0

Travel Activity Diary is used to record the details of each activity during the survey period such as approximate timing, transport mode, attributes of the place and the type of companion (with adults, with other children, alone).

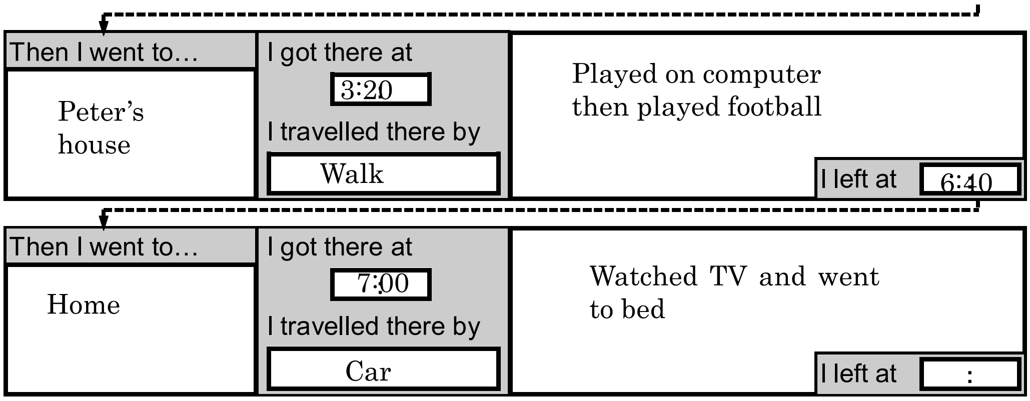


Figure 7 a sample of Travel Activity Diary. The children were asked to fill in the details of each activity including what they did, how they traveled and who they were with.

The data from each of the three types of equipment (GPS, RT3 and Travel and Activity diary) is linked up with each other using the time stamp so that the location, physical activity level and information of the activity at any given point in time can be easily identified. In other words, every GPS point that shows the location of a child at certain time has got the detailed information of the activity that he or she was then engaged in (___).

Table 2 a sample of the information that describes the type of activity

Reference	*Event& Number*	*Details*	*Date*	*Start Time*	*End Time*	*Activity Calories per minute*	*Accompanied by*	*Broad*
FE5-012	13 Own Home (In Home - Own Home)	Read a book	2005/11/4	7:00	8:45	1.95		In Home
FE5-012	14 Travel to School (1-1) Car		2005/11/4	8:45	8:50	3.79	Adult	Travel
FE5-012	15 Before lessons started (School activity - informal)	Ran around the playground	2005/11/4	8:50	9:00	4.35		School

Tool 2: Questionnaire surveys of children and their parents

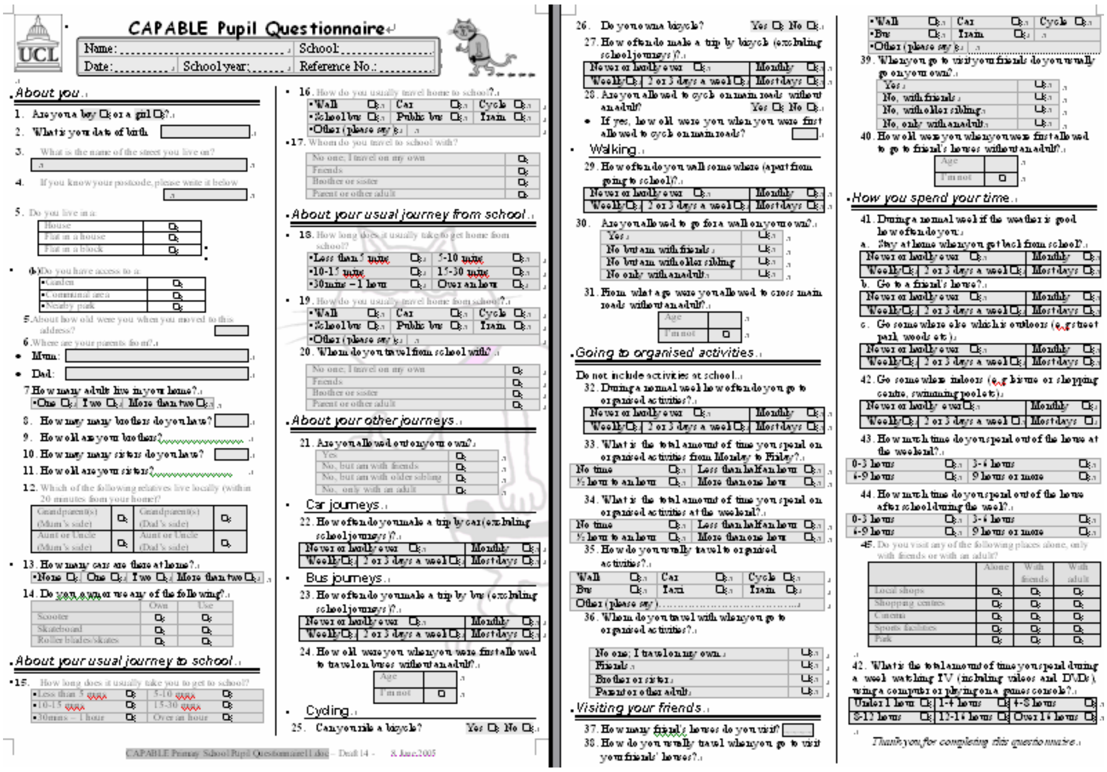
In this project, we used two types of questionnaire: Pupils questionnaire and Parents questionnaire. They are designed to gain information about the socio-economic background of the children's household as well as that about basic behaviour patterns e.g. how often the child go to organized activities and how they normally travel to and from school. Both questionnaires were printed onto a one side of an A3 paper (Figure 8) and were handed to children at school with a cover letter attached in order to explain the aim of the surveys as well as to give parents detailed instructions on how to fill in the form. The completed questionnaire sheets were collected through the school then returned to the CAPABLE research team.

The Pupils questionnaire can be split into 7 sections.

- About the child (e.g. family members and where he or she was born.)
  - About his or her usual journey to school
  - About his or her usual journey from school
  - About his or her other journeys (e.g. how often he or she goes out)
  - Car journeys (e.g. how often he or she travels by car)
  - Bus journeys (e.g. how often he or she travels by bus)
  - Cycling (e.g. ownership of a bicycle, how often he or she uses it)
  - Walking (e.g. how often he or she walks)
  - Going to organised activities (e.g. Does the child take part in any after-school organized activities such as a swimming club)
  - Visiting friends
- Playing (e.g. how often the child play outside)

The Parents questionnaire can be split into 6 sections.

- About the household (e.g. ownership of a car, the type of residence, and the address)
  - About their child's journey from school
  - (e.g. how the child travels to school and what are the factors the parents consider most important when they decide how their child should travel to school)
  - About their child's other journeys (e.g. how their child travels when they goes to places that are within a mile)
  - About their child's autonomy(e.g. whether they allow their child to travel alone)
  - About your child's play (e.g. where the child usually plays)
  - About the parent's travel as children (e.g. how they traveled to school when they were at the age of 8/9/10)


CAPABLE Pupil Questionnaire

Name: School:

Date: School year: Reference No.:

About you

About your usual journey to school

About your usual journey from school

About your other journeys

Car journeys

Bus journeys

Cycling

Walking

Going to organised activities

Visiting your friends

How you spend your time

Thank you for completing this questionnaire.

Figure 8 Pupil Questionnaire sample

Tool 3: A battery of tests and drawing map exercises

In order to investigate children's environmental knowledge, a battery of tests and drawing map exercises were employed. These tests and map exercises were carried out in the classroom with helps from the teachers at each primary school.

In the landmark recognition tasks, we asked the children to identify a number of landmarks taken from the area around their school. The landmarks include large shopping centres, sport facilities, characteristic buildings, and parks (Figure 9). A map on which the position of each of the landmarks to be identified was indicated by a numbered arrow was presented to the children. The number of the arrow corresponded to the question number on a worksheet. On the worksheet, a photo of the correct landmark is presented for each question mixed with three distracters. The children were asked to read the map to find the location of the landmark for each question, and then to choose the appropriate photo of the place from the worksheet. A point is given for each correctly answered question.


(a)


(b)

Figure 9 sample photos used for the landmark recognition tasks, (a) the Galleria shopping centre and (b) the swimming pool in Hatfield

In the area mapping task, each child is asked to draw a map of the area around the school. We handed each child an A4 sheet of paper on which a plan view of the school was printed in the middle. Following the explanation by a CAPABLE researcher on how to use the sheet including which direction in the classroom corresponds to North or upwards on their sheet, the children were requested to draw as many objects and places around the school as they could remember onto the sheet to make his or her own map of the vicinity. The objects can be parks, houses, shops, other buildings, roads, junctions or any other things that the children think characteristic in the area. The children were encouraged to draw the map as accurately as they could and to name as many objects as possible. Figure 10 shows an example of an area map in which several main roads around school and landmarks such as a super market, a wood and roundabouts are placed in relation to the school location.

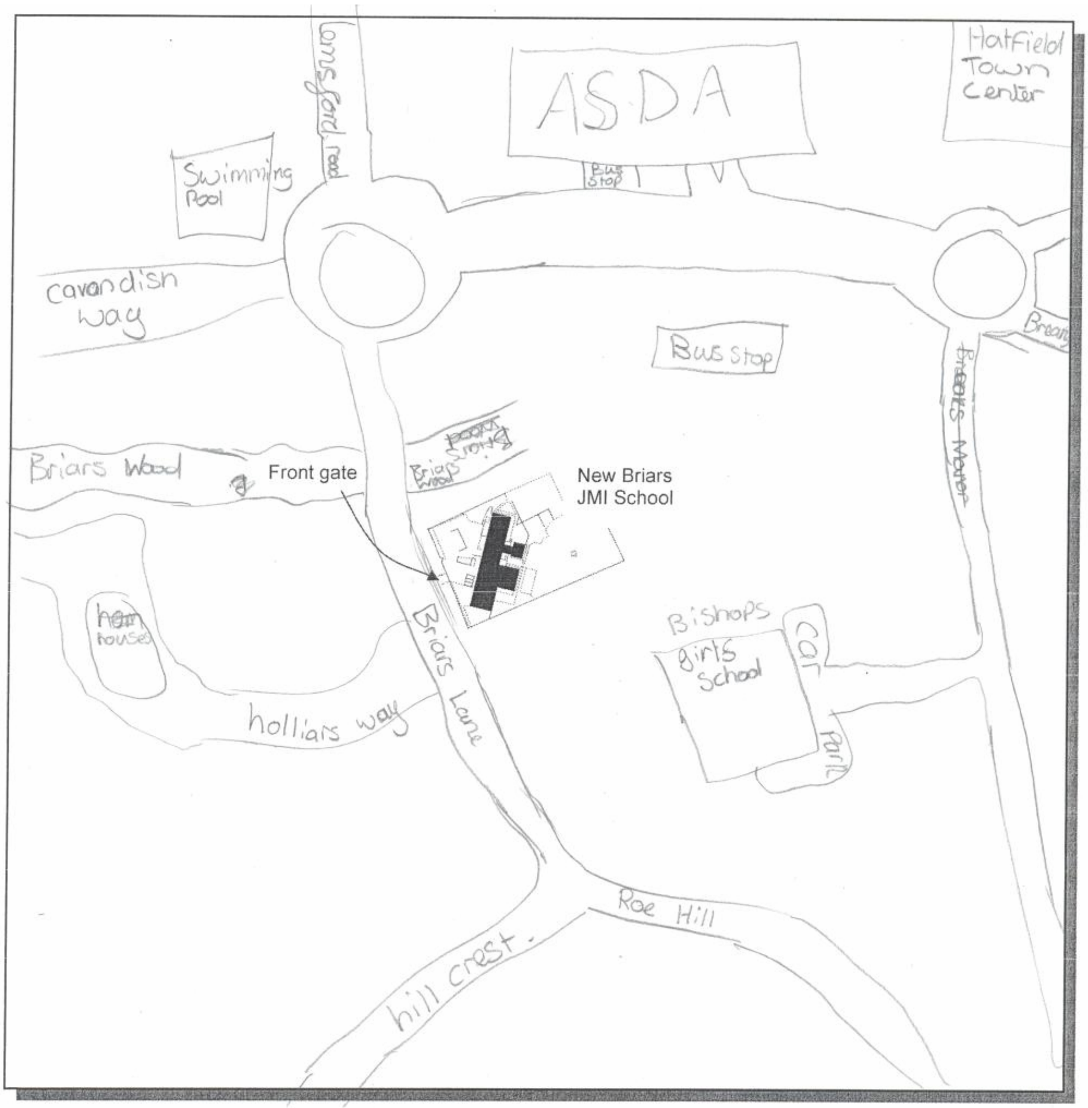


Figure 10 sample of the area mapping test

Following the area map drawing exercises, each child is again asked to draw a map on an A4 sheet of paper. This time, however, the sheet is blank and the children were told to use the sheet as they like. The children were then asked to draw a map of the route they took from home to school that morning. The instruction was given by CAPABLE researchers that the children should try to make their map as clear as possible so that it would allow someone to follow the same route and to navigate him or herself all the way down to school. It was also requested that the children should try to include as many landmarks on their way from home to school or in the vicinity or the school as they could remember. Figure 11 shows an example of a route map in which the route that a child followed to school is indicated by a set of arrows. Several landmarks such as his or her friends' houses as well as the name of each road are also shown in the map.

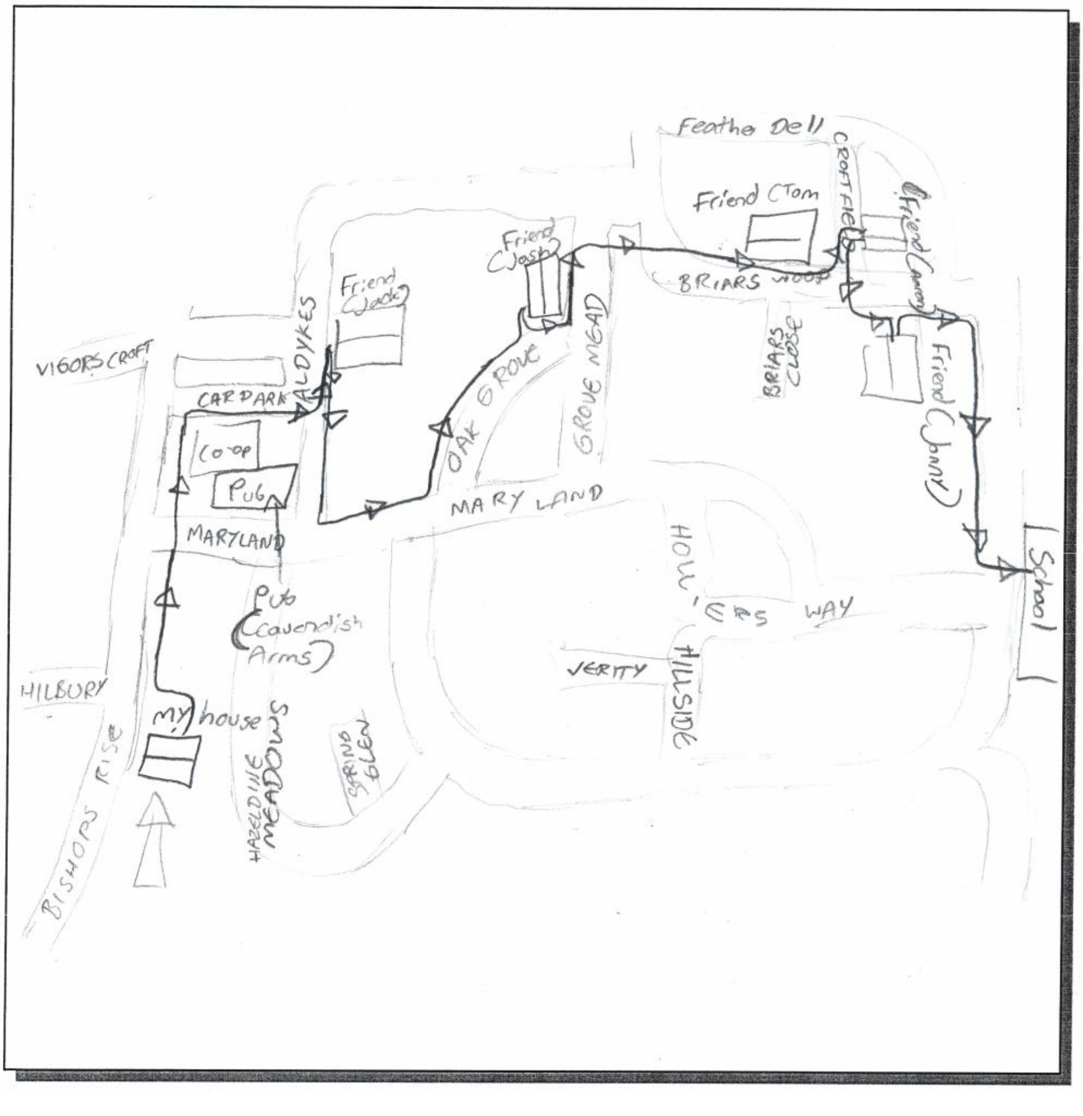


Figure 11 a sample of the route mapping test

Several sessions of the direction estimation tasks were also carried out in the classroom. CAPABLE researchers asked each child a series of questions regarding the direction of a landmark in the local area. It involves the child pointing by hands to the direction of a landmark. As all the landmarks are distant and therefore can not be seen from the classroom, each child needs to guess the relative direction of the landmark from where he or she currently is. The pointed direction was measured by a magnetic direction sensor. The data from the direction estimation tasks was used as another measure of spatial understanding to complement drawing exercises.

We also used spatial reasoning test method to obtain the information on children's ability to in spatial recognition. The material used for this method was a test published by NFER Nelson, which provides a standardized measure of spatial reasoning ability. The test consists of a number of questions that enables its users to assess children's ability to think and manipulate shapes and patterns in three dimensions. Such tests can provide an objective measure of children's spatial ability that does not rely on their drawing ability.

Tool 4: In-depth interview with children and their parents including mapping exercises

The last tool we have employed in out field works is in-depth interviews with parents and with children, including mapping exercises. This method aimed at revealing the nature and extent of parent's and children's social networks that might have a huge influence on children's independence and mobility in the local environment. For example, children's independence was measured through a series of questions such as whether they are allowed to do the following without an adult:

- Go out
  - cross the main road
  - travel to organised activities
- cycle on main roads

Then the data of the presence of family members or relatives in local area was collected. Both datasets were then correlated and the percentage summaries of the table are presented below (Table 3). It clearly illustrates the effect of having lots of relatives in the local area on the chances for children of being allowed to do something only amongst their cohort.

Table 3 Presence of relatives in area and level of independence ((Brown and Paskins 2005)

	NO local kin	1-2 types kin	3-4 types kin
Allowed out	61%	66%	81%
Allowed cross main road	51%	57%	75%
Allowed travel to organised activities	28%	33%	65%
Allowed cycle on main roads	25%	27%	53%
Number of the children	102	110	21

Other types of information collected through the in-depth interview include:

- Number of friends the child usually visit
  - How the child travel to school (transport mode, with or without adults)
- The age at which the child was first allowed to go out without adults

All the datasets collected by four disparate types of methods were linked in a database using a unique reference number assigned to each child. It enables CAPABLE researchers a series of cross-cutting analyses. ___ shows the key statistics of the datasets that we have obtained from the fieldworks.

>>>>>>>> Insert basic statistics of CAPABLE <<<<<<<<<<<<

Primary School	Participants (total)	Data for full-analysis	Participants in the monitoring surveys			
		Those who have all the data (1), (2), (3)	(1)total	GPS	RT3	Diary
Holy Family	7			7		
St Paul's Walden	22			22		
New Briars				0		
Flamstead End				100		
The Burleigh				96		
Kilmorie				0		
Perrymount				0		
TOTAL						

Primary School	Participants (total)	Participants (gender)		Participants (year)		
		Boys	Girls	Year 4	Year 5	Year 6
Holy Family	7				0	
St Paul's Walden	22				0	
New Briars						
Flamstead End						
The Burleigh						
Kilmorie						
Perrymount						
TOTAL						

GPS

How GPS works

This section summarizes the basic principles of how GPS system works. Global Positioning System (GPS) is a way of pinpointing the exact location of a receiver with high accuracy up to a few metres in three dimensional space anywhere on the planet. A constellation of about 24 GPS satellites placed by U.S. Department of Defence (DoD) orbit around the earth at altitudes of approximately 11,000 miles. Each satellite continuously broadcasts a specific radio signal. This signal contains satellite ID, its location in space and codes. The signal is received by GPS receivers and the code is analyzed by the software contained in receivers to identify the time that the signal took to travel from the satellite till it reach to the receiver. In order to do this, GPS satellites and receivers use very accurate clocks which are synchronized so that they generate the same code at exactly the same time. The code received from the satellite is compared with the code generated by the receiver. By comparing the codes, the time difference between when the satellite generated the code and when the receiver generated the code can be determined. This interval is the travel time of the code. Multiplying this travel time, in seconds, by 186,000 miles per second gives the distance from the receiver position to the satellite in miles. Using signals from at least 3 (4 or more if elevation is desired) different GPS satellites, the GPS software calculate the location of the receiver by a technique called trilateration i.e. triangulation

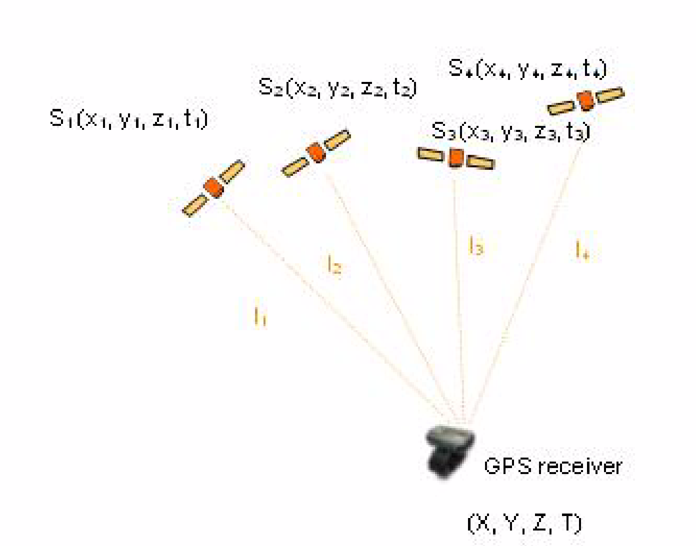


Figure 12 a GPS receiver computes its location using signals from 4 satellites

The designers of GPS system at DoD originally had a military application in mind such as navigation and troop deployment. Since 1980s GPS has been available for civilian use and quickly became much more valuable tools for non-military use.

The dramatic drop in equipment prices over the past 10 years, from approximately 20000 Euro for a civilian receiver to about 100 Euro for the least expensive hand-held receivers today, have lead to an enormous growth in the number of GPS users. New applications emerged; for example, car navigation systems, fleet management, aircraft approach and landing, bridge deformation monitoring, offshore drilling research, and the navigation of agricultural field machinery. These multiple applications increased the need for improved accuracy, availability, and integrity in the systems (Lechner and Baumann 2000).

Still the accuracy of GPS signal that can be obtained by civilian GPS receivers were intentionally downgraded by U.S. government by a technique called Selective Availability (SA). Uncorrected positions determined from GPS satellite signals under SA produce accuracies in the range of 50 to 100 meters. High-tech firms and hobbyists had been keenly lobbying for access to the full satellite data, but until May1st 2000, the U.S. government was too worried that possible abuse of accurate GPS data could lead to national threat to allow more accurate GPS data flow into civilian areas. After SA removal, the positioning accuracy increased up to 10 times more than before, 20m on average. However, its accuracy and availability can on occasions leave a lot to be desired. This is because while Ranging Signal Accuracy was improved with the removal of SA, there are other factors which affect Positioning Accuracy and Time Transfer Accuracy. The latter two types of accuracy vary with:

1. GPS receiver configuration especially with its antenna, and receivers
   The hardware configuration can affect the accuracy of GPS positioning as the intensity of GPS signal from satellites is very weak. "... a standard 100 watt light bulb is 10^{18} times more powerful than a GPS satellite signal at the receiver's antenna (Major David Hoey and Paul Benshoof 2005)". Expensive survey-grade GPS receivers are generally be more accurate than the consumer-grade receivers.

2. Surrounding objects
   A GPS signal can be easily refracted by both ionosphere and troposphere. This causes the difference in the speed of the GPS signal from the original one. Consequently, the estimated distance from the satellites and receivers will include some errors for the portion of the GPS signal path that passes through these spheres. Objects such as tall buildings and tress possibly block signal reception or cause multi-path reception (see below)

3. Atmospheric conditions
   Objects such as tall buildings and tress possibly block signal reception or cause multi-path reception (see below)

4. Noise
   Errors in the clock which GPS systems rely on and in orbital positioning of satellite location can add up to 0-10 metres of positional error.

5. Multipath
   Multipath is referring to a phenomenon that a GPS signal is bounced off a reflective surface prior to reaching the GPS receiver antenna. This caused the difference in the speed of the GPS signal, therefore errors in the estimated distance between the satellite and the receiver. It is hard to remove errors caused by multipath and it remains yet to be solved.

The chart below lists the most common sources of error in GPS positions. This chart is commonly known as the GPS Error Budget.

Table 4 GPS Error Budget(Information source: (http://www.cmtinc.com/gpsbook/index.htm#chap6)

Source	Uncorrected Error Level
GPS receiver configuration	30 meters
Atmospheric conditions	0-30 meters
Measurement Noise	0-10 meters
Clock Drift	0-1.5 metres
Multipath	0-1 meter
Selective Availability(removed in 2000)	0-70 meters

Total	0-30 meters without SA

GPS augmentation systems

As described in the last section, the accuracy, availability and integrity of the stand-alone GPS sytem can not always meet the required performance. To improve the data accuracy, several GPS augmentation systems have been developed.

DGPS

In Differential GPS system(DGPS), the base receiver computes of which location is fixed and known computes timing errors using several GPS signals. It transmits the information on this error with appropriate correction messages to other GPS receivers in the local area via FM radio wave of around 300kHz (Czerniak 2002). Typically, the positional error of a DGPS position is 1 to 3 meters.Sources of real time differential correction data are available over many areas using:

Local Area Augmentation System (LAAS)

LAAS consists of a reference station of which location is fixed and known and mobile user receivers. At the reference station, errors within GPS signals are computed and then the information on the data correction is broadcasted to users in sight of the station. Generally, within a 200km circuit of the reference station, users receiver is able to obtain quite high accuracy up to 50cm - several metres.

Wide Area Augmentation System (WAAS)

WAAS is a widely used DGPS service especially for navigation for airplanes. This service is operated by the Federal Aviation Administration (FAA). In order to cover large areas, the system requires a network of 24 wide-area reference stations on the ground where GPS errors are computed as well as geostationary satellites which broadcast the differential correction information. The advantage of this system is that it is available for any WAAS-enabled GPS receiver. These days most commercial handheld GPS are equipped with this function.
European Geostationary Navigation Overlay Service(EGNOS)
EGNOS is a space-based augmentation system and covers a region including Europe, Africa, the Middle East, some Asian countries, and even parts of South America (Lechner and Baumann 2000). This system consists of three geostationary satellites and a network of ground stations. The ranging augmentation service is provided by these three satellites which broadcast GPS-like signals so that users' receiver can get two additional GPS signals.

RTK-GPS

RTK is another GPS augmentation method for GPS in which a reference GPS receiver at a known location calculates the errors in GPS signal and transmit the information to other receivers. The use of RTK-GPS can compensate most errors and increase the accuracy up to within a centimetre. This method is mainly for engineers and surveyors who require very precise location information.

Pseudolite

Pseudolite is a contraction of the term "pseudo-satellite". Small transmitters that create a local GPS-like signal are placed in the area where they system users would like to receive GPS data correction service. Users' GPS receiver calculates its location using signals from both satellites and Pseudolite, which helps improving the positioning accuracy.

GPS with GIS

It is argued that GPS has found its greatest utility in the field of Geographic Information Systems (GIS). GIS are computer programmes for capturing, storing, checking, integrating, analysing and displaying data that is spatially referenced. It combines relational databases with spatial interpretation and its visualization tools enables making the outputs of analysis in form of maps. Since GPS provide the precise location of any point on earth, the descriptive database of the place that GIS provide is ideal complementary data to analyze any geographical phenomena. As Czerniak (2002) pointed out “the combination of digital mapping with an underlying digital spatial database, a GIS, provides a range of flexibility in mapping and spatial analysis capabilities”. Also, using both GPS and GIS for mapping can increase positioning accuracy. Imran, Hassan et al (2006) have reported an integrated GPS-GIS system to track vehicle paths on highways. By matching each original GPS point to an appropriate road segment which was analyzed by GIS extension software, they proved that the GPS-GIS based system can provide accurate information of the lateral placement of a vehicle in a relatively inexpensive and simple way.

Previous studies on tracking spatiotemporal activities

The use of GPS receivers is not a novel method in some fields. Surveyers who produce maps, which are the very base of any kind of spatial analysis, use GPS to improve survey accuracy and to complement conventional survey methods by reducing data collection time. It has also been used as a base technology of guidance and navigation tool for aircrafts and vehicles. Lee, Park et al (2004) and Hardesty, Conner et al. (2006) suggest the use of a GPS-based tracking and guidance system for aircrafts to which very precise position data and accurate flight tracks are indispensable. Bell (2000) explained how GPS is utilized for automatic tractor guidance in the field of agriculture. However, GPS equipment used in these fields are very high-end products for specialists, which are not appropriate for general users.

Price barrier has been a biggest issue. According to (Kumar and Moore 2002), the first commercial GPS receivers, introduced in the mid-1980s were priced at over $100,000 and it was only after the introduction of the first handheld receiver priced below $1000 in 1992 that GPS-related industry entered a new phase. After the introduction of cheap commercial GPS receivers which cost around $100 in 1990s, saw the rapid increase in demand for associated applications. Although the most well-known application of GPS technology these days might be in-car navigation systems, the number of applications that were designed to track human behaviour has been dramatically increasing.

Significant amount of research have been made to collect and analyze people’s movement using GPS, most of which can be seen in transport studies and tourism. GPS surveys were employed to collect a large amount of spatial data for every individual who carries equipment so that certain areas that have different characteristics from other areas such as where people frequently use can be identified. (Hagena, Kramera et al. 2006) investigates the spatial behaviour of visitors to Görlitz city in Germany. Figure 13 illustrates the percentage of the tourists who visited a certain area to a total number of the tourists to this city. A colour map is assigned to each area (represented as a grid cell) show the different level of the percentage that indicates the area’s attractiveness for tourists. Through this visualization, they identified several parts of the city that do not function well as tourist destinations.

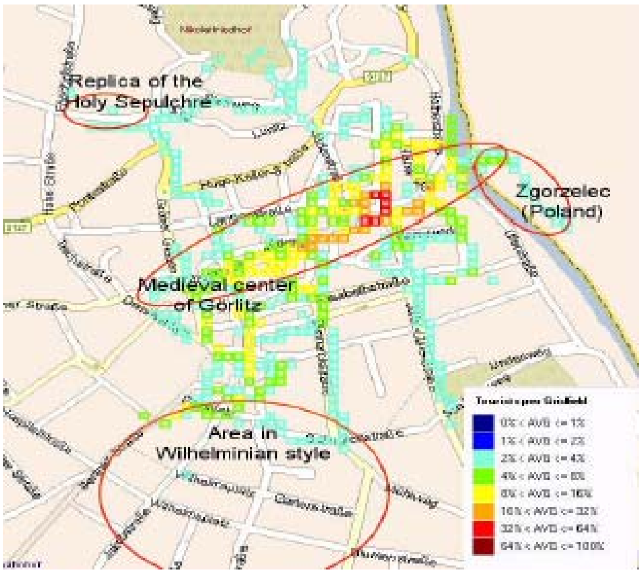


Figure 13 Spatial distribution of tourist (Hagena, Kramera et al. 2006)

Understanding current situation of people's use of certain space, it is necessary to gauge the possible impact of any changes to the space. It is because any plans to achieve successful built environment are difficult to draw if little is known about what kind of environmental factors have influence on the users' behaviour. (Mountain and Raper 2001) and(Dykes and Mountain 2003) proposed to introduce exogenous information into the analyses of people's behaviour. They look at tourist behaviour with a prospect of utilizing location data as base information of Location-based services. In their tracking system, a GPS receiver is combined with a mobile phone to make up their tracking devise that sends the GPS location information to the system server over the telecommunication network. By this solution, the location of each tourist who carries the tracking devise is collected at real-time, which enables the system an instant analysis of the general behavioral tendencies of tourist. Data mining methods are applied to extract characteristic movement patterns and to infer the context of certain behavior from external factors such as land-use attributes of the neighborhood. Figure 14 illustrates the constraint on tourists' spatial movement posed by the location of ports and ferry routes.

Figure 14 weekly spatio-temporal log with exogenous information such as background map showing the extent of island (dirk grey) and sea (light grey)from(Dykes and Mountain 2003)

Another approach that uses GPS positioning to analyze people's bahaviour is called Time Geography. It is an effort to analyze people's activity patterns from the perspective of time. As GPS tracking data can provide information of "when" a certain event occurs at significantly higher accuracy than conventional methods such as activity diaries, it quickly became a useful data collection tools in this research field. The frequently used method in this field for visualizing people's movement is spatial-temporal prism which is similar to the Minkowski Diagram that is used in Physics (). Basic concept of this diagram is to represent space and time by light path. X-Y plane of the diagram represent space and another axis is used for time. Light rays are drawn at a 45 degree angle to the plane representing space to make up two three dimensional light cones that represent our world in past and future. This means that if the time axis is measured in seconds, then the space axes are measured in light-seconds (the distance light can travel in one second). The events in the world can be illustrated by a combination of its location (x-y coordinates) as well as the timing and the length of the event inside of these cones. The events that happen outside of the cone cannot be experienced. Although spatial-temporal prism follows the basic concept of Minkowski diagram, the extent of its space and the measurement unit of its axes can be determined at the discretion of users without any restriction of light cones as shown in Figure 16.

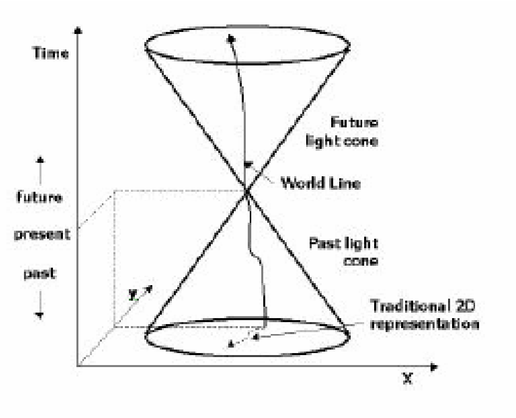


Figure 15 Minkowski Diagram from (Mountain and Raper 2001). The movement of the object in real world is represented as a line inside two light cones defined by light paths. The events that happen outside of the cone cannot be experienced.

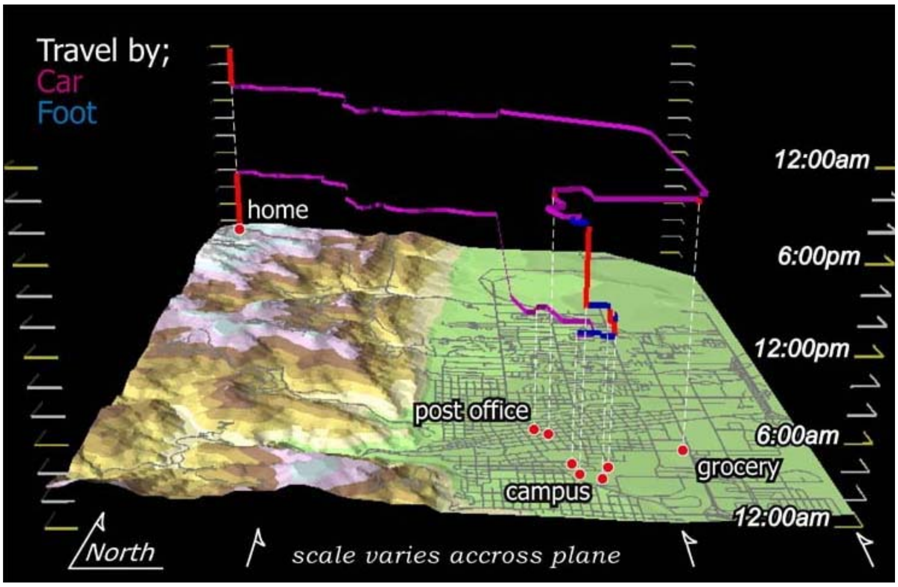


Figure 16 spatial-temporal prism of one person's movement over 24 hours. The plane that represents spatial extent and the measurement unit of time axis are defined by the user. (http://www.colorado.edu/geography/cartpro/cartography2/spring2001/dettloff/time/prism_map.html)

According to (Corbett), Torsten Hägerstrand, professor in the Department of Social and Economic Geography at Sweden's Lund University, first proposed the need to examine the spatial and temporal coordinates of human activity and introduced the concept of Time Geography. Since then there have been significant amount of research based on this concept to analyze people's bahaviour focusing on the interrelationship between activities in time and space, and the constraints imposed by these interrelationships (Lenntorp 1976);(Janelle, Goodchild et al. 1998; Weber and Kwan 2002); (Kim 2003);(Kim and Kwan 2003); (Miller in press)). By providing a large quantity of detailed spacio-temporal information, GPS enables such analyses at finer resolution level.

Because of this capability of GPS in tracking spatial-temporal movement of individuals at very microscopic level, there has been a tendency amongst transport community to use GPS for augmenting and auditing traditional travel survey methods. In traditional travel surveys, information about daily travel patterns are generally captured using self-reported diary, questionnaires and telephone interviews. According to (Bricka and Bhat 2006), “the transportation community began in earnest an investigation into the application of global positioning system (GPS) technology to travel survey data collection efforts” with its immediate focus being “to improve the quality of travel survey data, with a long-term goal of eventually replacing respondent-reported data with travel details collected passively through these devices.” The first attempt to use GPS as a part of a large scale travel survey was made in Lexington by U.S Federal Highway Administration in 1996 (Wagner, Murakami et al. 1997). In this study, people carried a unit of Personal Digital Assistant (PDA) of which serial port a GPS antenna/receiver is attached. This hardware was connected to the electrical system of the vehicle of the survey participants via a power cord so that vehicle positions and time information were automatically collected at frequent intervals. Other information "such as trip purpose and vehicle occupancy (Wagner, Murakami et al. 1997)” were manually entered by the vehicle drivers. 100 household vehicles in Lexington, Kentucky took part in the six-day survey conducted September through December 1996. The survey result proved that the combination of computer-assisted self-interviewing (CASI) and GPS technology can not only improve the quality of travel behaviour data but also enables researchers to collect the information that was previously very hard or almost impossible to obtain such as accurate departure time and travel speed. However, the attempt to reduce unreported trips was incomplete in this survey.

Since then a number of travel surveys have been made that employed GPS for auditing trip reporting. In the early period, most surveys dealt only with vehicle trips (McNally, Marca et al. 2002); (Marca, Rindt et al. 2002); (Ohmori, Muromachi et al. 2002). This is because GPS receivers require continuous power supply and the relatively large size of the hardware. The real-time positioning data obtained by GPS is constantly transmitted to a central data processing system through cellular telephone networks or wireless networks via vehicle electronic system. This type of GPS tracking is called ‘active’ as opposed to ‘passive’ tracking, a technology that was enabled as technology advanced, by which location data is collected and stored in built-in memory of the GPS unit or in a data logger connected to the GPS receiver. The device for passive GPS tracking was used in (Draijer, Kalfs et al. 2000) to examine the use of GPS records to track multiple travel modes. The custom-made device called GeoMate weighed approximately 2 kg with a built-in battery, a computer for data logging, and a GPS antenna. Although GeoMate was able to track any type of travel of the respondents including walking and cycling in addition to vehicle trip, its bulkiness and weight was reported to have often caused inconvenience amongst survey participants and the device was consequently left behind on a significant number of trips.

These days both active and passive GPS tracking can make use of small handheld units. For the examples of active tracking, there has been a lot of research on travel data collection using GPS and GSM cellular phone network to track multiple travel modes (Asakura and Hato 2004); Arimura and Takano 2004; OHMORI, HARATA et al. 2005). The examples of passive GPS tracking include the project commissioned by British government in 2002 to explore the possibilities of passive GPS tracking technology as a cost effective travel data collection method. A subset of participants in the London Area Transport Survey (LATS) was equipped with passive personal GPS devices that consist of a GPS antenna and a data logger (Gleave 2002). (Bachu, Dudala et al. 2001) also used a commercial passive GPS device to collect travel data. In this study, the GPS data over a couple of days was logged onto pre-installed memory of the device.

Now that tracking individual’s travel by GPS has been widely accepted, there is a possibility to replace traditional travel survey methods with GPS-based data collection methods. (Wolf 2004) presents that “GPS logging devices are a powerful tool for collecting multi-day and multi-period survey data with little or no respondent burden.” However it also states that “it seems unlikely that GPS methods will replace traditional methods anytime soon", mainly because there are still rooms for improvement of the size, power demand, wearability and price in GPS devices. Another crucial issue for GPS-only travel survey is the details of each trip such as the purpose of the trip, the number of companion(s) can not be automatically logged by GPS. Since such factors can affect travel patterns, we should avoid missing them out in travel surveys. Therefore, it can be concluded that the current best solution for collecting travel data of individuals is the combination of passive GPS tracking and travel activity diary or other paper-based methods.

Why we used GPS for CAPABLE?

The methods that traditional travel surveys have been used include questionnaire, interviews and travel diaries. Although progress in information technologies has enabled researchers to make use of computers as a part of data-collection tool in electronic diary surveys, it is only when positioning technologies such as GPS were introduced that a whole new dimension for travel surveys opened up. There are two main advantages of using GPS to collect trip-making data.

Firstly, a large amount of detailed location data can be obtained by GPS surveys. Shoval and Isaacson (2006) identifies two significant challenges in the field of human spatial behaviour research; (1) how to record spatial activity in retrospect; (2) how to pinpoint the location of said activity in space. They also pointed out methodological flaws of a data collecting procedure using activity diary arguing that it requires "the subject to actively record his or her actions in time and space during the entire experiment". In other word, it is solely depends on the log of subjects' accounts of where they were and for how long. Because of this reliance on people's memory, short and "insignificant" trips can be missed out in traditional trip diary surveys. In addition, "the added survey response burden associated with activity and time use surveys can not be ignored (Pendyala and Bhat 2004). In this context, introducing GPS-based data collection has a clear advantage. Moreover, as the positioning interval of GPS is up to 1 second, the spatiotemporal resolution of GPS data is significantly higher than those from other methods.

Secondly, using GPS enables us to measure and record the precise time at which each event happens. As Harvey (2003) pointed out, "activities occur in time and space". In order to fully understand children's lifestyle, we need to look into not only the types of activities they are engaged and their spatial movement patterns but also the timing and length of each activity. In addition, such precise time information is very useful when we link up several different datasets some of which contain inaccurate time stamps, providing us with a key to infer when certain events actually took place.

In the next section, technical specification of GPS positioning followed by previous studies on tracking human spatiotemporal activities is explained.

Selection of suitable GPS equipment for CAPABLE

In the CAPABLE project, GPS equipment was used to collect detailed information of approximately 200 children on:

1. Where children went
2. how long they stay at certain place
3. speed at which they moved

For these purposes, each child wore GPS all the time with several exceptions (bed time, when they take a bath or shower, etc) through 4-day survey period. Therefore, there were a number of factors that must be considered before choosing GPS equipment used in this project:

1. Price
2. Bulk
3. Resolution

4 Battery life
5 Capacity
6 Availability
7 Fieldwork time
8 Casing
9 Interface

Firstly GPS units should be reasonably priced. The price of each unit determines how many children we could monitor simultaneously. Originally we were planning to monitor 20 children in each week during the survey period. Consequently if the 20 GPS units cost more than our budget limitation, it decrease the number of children we can observe per survey.

Secondly, the GPS units should be reasonably small and light-weight so that children can easily wear it all day long without feeling discomfort. The physical size and weight of the unit might prevent children to do their normal everyday activities. As previous study (Draijer, Kalfs et al. 2000) suggested, if wearing GPS cause any inconveniences or discomfort, the device is likely to be left behind.

As for resolution of the positioning data, the frequency with which the unit can take and store position information should be 30-second or smaller. Location data with larger resolution may miss small trips or events such as dropping into local shops.

Battery life and capacity of memory are the most important factors when we selected our equipment. The battery of GPS units should last at least 12 hours to cover all activity for a whole day. However as each of our monitoring survey lasts four days, preferable battery life would be 4 consecutive days. The logging memory of GPS data must be able to record all data points for four days. If we collect and record the location of children at the interval of 1 second, resulting GPS points will be roughly 9000.

As we need to purchase at least 20 exactly the same units for our surveys, the product should be already available in the market and can be purchased in time, in the UK, in the right quantities.

Set up routines, changing or charging batteries or other operation methods of the GPS unit all have fieldwork implications. Therefore, the product equipped with simple interface is preferable.

The unit must have a robust casing that can endure hard weather conditions and other unexpected events, given that the GPS units will be used by primary school children for four days.

All of the GPS derived location data will be downloaded to computers for data cleaning and analyses. For this purpose, the GPS unit should be equipped with at least one of the major PC interfaces such as RS232C, USB or Bluetooth.

In the next section, the details of comparative studies to assess the feasibility of using currently available commercial handheld GPS products for our monitoring surveys are explained.

Comparative study

This section gives some information about the availability of suitable GPS units and compares some of their features. After some research on currently available GPS products, we selected several units from Garmin, the largest producer of consumer GPS unit along with the GeoLogger from GeoStats, a wearable GPS datalogger, and Followit Locator from Followit UK Limited for for closer examination and comparison.

Consumer GPS units (Garmin)

The handheld units produced by Garmin aim at the consumer market and therefore are widely available in UK. As Garmin has very wide range of products, we selected units that advertise a battery life of at least 12 hours. This is the minimum required to track on a school day; assuming that a unit that was fully charged over night at children's home would track the journey to school around 9:00am, the movement at school during the daytime, then the journey home and the subsequent journey in the evening.
The list below (Table 5) includes handheld GPS units with a battery life of 18 hours or over. The quoted battery lives on the Garmin site are for units in battery saver mode. The eTrex LegendC has the longest battery life. Battery life estimates are apparently based on the unit being on, but in battery saver mode without the gps on. With the gps unit collecting data the battery lives are somewhat shorter, for instance the 36 hour battery life of the eTrex legend C falls to around 22-24 hours with the gps unit on and collecting data (according to Garmin UK customer support).All units have a 12 channel GPS receiver and are encased in waterproof plastic casing (that is in accordance with IEC 60529 IPX7). All units can be connected to computers via RS232C cable.

Table 5 Garmin commercial handheld GPS units with a battery life of at least 12 hours. Where the table cell is highlighted in grey, the unit does not meet the selection criteria for the CAPABLE project. This table was produced based on that made by James Paskins on 23/11/2004)

Product	Battery Life	# of Tracklog Points	Unit Weight	Unit Size (H x W x D)	WAAS capability	MSRP (as of 23/11/2004)
eTrex	22 HR (2AA)	1536	5.3 oz.	4.4 x 2.0 x 1.2	N/A	$106.24
Geko 201	12 HR (2AAA)	10,000	3.1oz	3.9 x 1.9 x 0.96	Yes	$149.99
Foretrex 201	15 HR (rechargeable battery)	10,000	2.75 oz.	1.7 x 3.3 x 0.6	Yes	$182.13
eTrex Summit	22 HR (GPS) 13 HR (GPS and Compass)	3000	5.3 oz.	4.4 x 2.0 x 1.2	Yes	$214.27
eTrex Legend	18 HR (2 AA)	10,000	5.3 oz.	4.4 x 2.0 x 1.2	Yes	$182.13
eTrex LegendC	36 HR (2 AA)	10,000	5.5 oz. w/ batteries	4.2 x 2.2 x 1.2	Yes	$374.99
eTrex Venture	20 HR (2 AA)	2048	5.3 oz.	4.4 x 2.0 x 1.2	Yes	$149.32
eTrex VistaC	20 HR (2 AA)	10,000	5.5 oz. w/ batteries	4.2 x 2.2 x 1.2	Yes	$428.56
eTrex Camo	22 HR (2 AA)	2000	5.3 oz.	4.4 x 2.0 x 1.2	N/A	$116.86
GPS 12	24 HR	1024	9.5 oz.	5.8 x 2.1 x 1.2	N/A	$231.80
GPS 12XL	24 HR	1024	9.5 oz.	5.8 x 2.1 x 1.2	N/A	$309.07
GPS II Plus	24 HR	1024	9 oz.	5 x 2.32 x 1.62	N/A	$309.07
GPS V	25 HR	3000	9 oz.	5 x 2.32 x 1.62	Yes	$374.99
GPSMAP 60C	30 HR (2 AA)	10,000	5.4 oz. w/o batteries	6.1 x 2.4 x 1.3	Yes	$482.13
GPSMAP 60CS	20 HR (2 AA)	10,000	5.4 oz. w/o batteries	6.1 x 2.4 x 1.3	Yes	$535.70
GPSMAP 76C	30 HR (2 AA)	10,000	7.6 oz. w/ batteries	6.2 x 2.7 x 1.4	Yes	$535.70
GPSMAP 76CS	20 HR (2 AA)	10,000	7.6 oz. w/ batteries	6.2 x 2.7 x 1.4	Yes	$589.27

The Advantages of Garmin products include its robust casing, small and light-weight units , reasonable price and their availability in the market. On the other hand, their battery life tends to be short, which means regular charging or replacement of batteries would be necessary during the fieldworks.

(a)

(b)

Figure 17 Garmin handheld GPS (a) GPS 12XL and (b) eTrex

Wearable GeoLogger

The GeoLogger is a wearable GPS unit from GeoStats. GeoStats was set up by Jean Wolf, an expert in the field of transport research and GPS tracking. The unit uses a Garmin aerial/receiver unit, tracking 12 satellites (WAAS enabled), combined with a datalogger and battery pack (Figure 18). The pack is designed to be worn over the shoulder, as the aerial is on the strap the view of the GPS aerial will not be obstructed by the child's arms or legs.

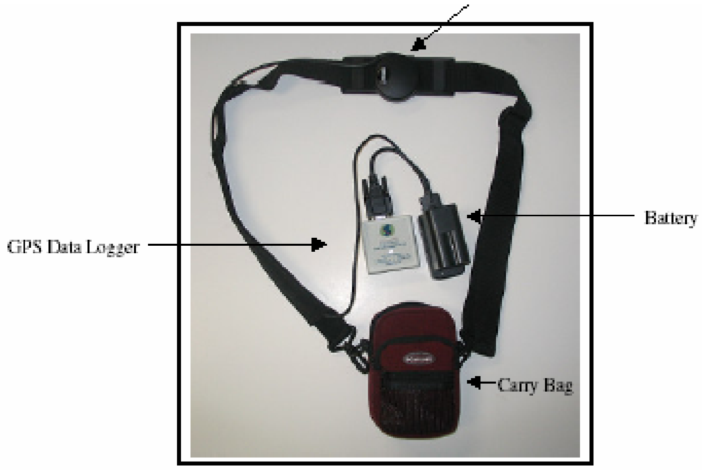


Figure 18 GeoLogger from Geostats (http://www.geostats.com/)

A newer unit was then being developed and should have been available in due course (as of November 2004). The newer unit will be lighter, slightly smaller and have a higher battery capacity than the current unit. The current unit is too bulky and heavy for children to carry around for whole day. The main advantage is the large battery that the unit comes with; according to the website the current unit will record for up to 3 days and a newer unit (as yet unavailable) will have a 5 day battery life (Table 6). It has 8MB memory capacity, which is claimed to be large enough to record a GPS point every 1 second over a week.

Table 6 Specification of Geologger (current unit and new unit)

	Battery life	Size*	Weight (including batteries)	Price	Availability
Current unit	<3 days	89x 140 x 191 mm	740g		Current
New unit	>5 days	Slightly smaller	450g †	$800	1-2 months (as of 23/11/2004)

Followit Locator from Followit UK

The Followit Locator was originally produced by Swedish Followit AB and Finnish Fastrax Ltd. In the UK, the units were distributed through Followit UK ltd. The device shown in Figure 19, about the size of a small mobile phone, includes programmable GPS receiver and a GSM modem for two-way communication.

Figure 19 Followit (http://nordicwirelesswatch.com/wireless/story.html?story_id=1673)

Using the programmable GPS receiver, the device can collect location data and to send it either in real-time, or on specific time intervals, or depending on pre-set conditions for location, speed or direction. Positions are stored in the memory of the Locator and when the memory is full, the oldest positions will be overwritten with new ones using the FIFO principle (First In First Out). The communication with the Locator web-server takes place remotely via an SMS message to transfer all the positioning data obtained by the device. Users can retrieve the positioning data by logging onto Followit's web based mapping solution. Communication can also take place locally through the serial interface provided through the hardware serial port located on the unit.

According to the Followit website (http://www.followit.co.uk/), the Followit Locator is the smallest GPS, GSM (GPRS enables early 2004) location device on the market today. The advantage of the device is its size (it is as small as a matchbox) and the ease of fitting. However, the battery life and positioning resolution are major drags when we use this device for tracking children's behaviour. Fastrax CEO Kim Kaisti was quoted in (Poropudas 2002) claiming that "the power demands of the GPS receiver of this device is only one third to one fifth of the off the shelf-competing GPS products." The power usage and battery performance depends on how often the device transmits the location information to the system via GSM. According to the product brochure, the device can make 400 SMS text messages (Table 7); in other words, it can collect the location information 400 times from single charge of the pre-installed rechargeable battery. It would be an equivalent of collecting location information every three minutes over 10 hours per day. This does not provide detailed enough information to track all spatial behavioural patters of children.

Table 7 Specification of Followit Locator

	Battery life	Size*	Weight (including batteries)	Memory	Availability
Followit locator	It depends on the frequency of the communication (400 SMS text messages)	79 mm x 41 mm x 29 mm	80g	Small The data need to be transferred to the server	Current

GPS equipment chosen for CAPABLE project

As explained in previous sections, the GPS equipment for CAPABLE project should be small and light-weight so that children can easily wear it on their wrist all day long without feeling discomfort. After testing several types of GPS equipment in order to decide the best in terms of precision, battery life and acceptability to the children, we chose Garmin Foretrex™ 201 GPS receiver (Figure 20)because of its characteristics listed below:

- Wrist-top mount design --- its wrist-top mount frees up hands for outdoor activities
- Lightweight compact design: 2.75 oz, Unit dimensions: 3.3" W x 1.7" H x 0.6" D (8.38 cm x 4.32 cm x 1.52 cm). --- it doesn't give children any discomfort
- Waterproof: IEC 60529 IPX-7 standards (submersible in one meter of water for up to 30 minutes)--- it can deal with rain, any accidental event
- Internal rechargeable lithium battery for 15 hours --- it can cover travel behaviour for whole day and can be relatively easily recharged at the children's home
- User-friendly interface ---- six dedicated buttons (GoTo, Page, Enter/Mark, Up, Down and Power) make it easy for children to operate by themselves when necessary
- Relatively high accuracy: 15 meters or less
- Track log: 10,000 trackpoints ---- its internal memory can easily record the children's location information for 4 days

Figure 20 Garmin Foretrex 201 (Garmin)

GPS surveys in Hertfordshire

As described in the Fieldwork section, a series of fieldworks including 17 GPS surveys were carried out from November 2004 to March 2006. The primary schools who took participate in our GPS surveys are as follows:

- The Holy Family RC Primary School (Wellwyn garden city, Hertfordshire)
- St Paul's Walden Primary School (Hitchen, Hertfordshire)
- New Briars Primary School (Hatfield, Hertfordshire)
- Flamstead End Primary and Nursery School (Cheshunt, Hertfordshire)
- The Burleigh Primary School (Cheshunt, Hertfordshire)

Procedures

In each tracking survey, approximately 10-20 children were chosen to wear this GPS receiver for five days (the first day is only for testing equipment. The data from the first day is not used for the analysis), starting in Wednesday morning and finishing in Sunday evening. The first day, CAPABLE staff briefed the children on the survey in the classroom and gave them a set of GPS equipment:

- GPS receiver (with unique ID number label)
- Battery charger
- Instruction on how to use GPS receiver (e.g. re-charging, switching On/Off)

The children were instructed to wear the receiver on their wrists like a watch, with the top face of the unit oriented towards the sky using the wrist strap. They were requested to wear the unit all day and through the surveys except when they are asleep, when they are engaged in water-related activities (e.g. having a bath and swimming) and whenever they feel uncomfortable to continue wearing it. It is also requested to recharge the battery of the receiver every night, perhaps when they go to bed. This is done by turning the unit’s power off and connecting it to a power plug with the Battery charging cable. Next morning, the unit should show the message “The unit is charged successfully” on its display if it was fully charged without any problems. The unit must be turned on and be worn again before they leave home for school. All the instructions were given by CAPABLE researchers in the classroom as well as by an instruction note for parents.
CAPABLE staff would come back to the school on the third day (Friday) to get the feedback from the children as well as to check whether all receivers are working without problems. GPS unit consecutively monitors children's location and record all data for 6 days on its pre-installed memory in chronological order. On the sixth day (next Monday), CAPABLE staff returned to the school to collect the equipments and to download recorded data. Although the GPS units recorded data for whole 5 days and the part of Day 6, the data from Day 1 is discarded as we assume children need some time to get themselves accustomed to the unit i.e. to get back to normal behavior.
All the GPS units used in the fieldworks were set to use the system properties listed below:

- Time format – 24 hour (HH:MM:SS)
- Time zone – London (with daylight saving when necessary)
- Position format – H D M.M
- Map datum – WGS84
- GPS mode –Normal

Problems in data collection

We encountered several difficulties and unexpected problems through our fieldworks. The main problems include:

- Problems with charging the battery
- Loss of cradles
- Problems with the GPS unit
  - GPS unit stopped responding
  - The wrist belt detached
  - Missing control buttons

Problems with charging battery were derived from defected power adopters. Close examination revealed that 12 power adopters were not in proper working order. Such problems seem to have caused by imperfect contact between AC/DC adopters and cradles.
Another frequent reported problem was regarding missing cradles. Seven cradles were lost during the GPS surveys. The cradle is a crucial component of GPS power adopter without which one can not charge the unit. Although we purchased additional cradles and power adapter units in order to deal with these problems it caused serious delay in our fieldwork schedule.

Figure 21 Three components of GPS power adopter unit (cradle, AC/DC adopter, UK socket from left to right)

In addition, 9 GPS units were reported to be out of order. 3 units that had stopped responding to any input were sent back to Garmin to overhaul maintenance. Amongst other 6 units, 2 units were fitted with a new wrist band. The other 4 units were in bad condition with several missing control buttons, and consequently ceased to be used in the survey.

Data

GPS data was downloaded from each GPS unit after CAPABLE researchers collected equipment from the school. GPS units and PC were connected by the attached serial cable and a cradle to PC's RS232C port. For data transferring, we used Garmin Mapsource software. As GPS data was recorded in Latitude and Longitude (WGS1984), we appended British National Grid coordinates (Easting and Northing) using the software called Grid Inquest. The Grid InQuest software provides a means for transforming coordinates between ETRS89 (WGS84) and the National coordinate systems of Great Britain, Northern Ireland and the Republic of Ireland. It provides a fully three dimensional transformation incorporating the latest geoid model. This software is available for free at their website ((http://www.qgsl.com/software/gridiq.php).

Table 8 shows the format of the location data recorded by Garmin unit is latitude and longitude with the Easting and Northing coordinates appended to each data point. Data fields include:

- Header --- it shows whether this is a track point
- Position --- Space delimited two values (Latitude in Decimal minutes, Longitude in Decimal minutes)
- Time --- dd/mm/yyyy hh:mm
- Altitude --- current altitude from 4 or more GPS data triangulation, shown in feet
- Depth --- N/A
- LegLength --- distance travelled since the last recording
- LegTime ---the time elapsed since the last recording
- LegSpeed --- the current speed being travelled at time of recording, shown in mile per hour (mph)
- LegCourse --- current direction in angular velocity ("true"
- appendix means the GPS unit uses the real North direction obtained by
- its compass as the fixed origin of clock-wise rotation)
- Latitude ---- Latitude in Decimal minutes
- Longitude --- Longitude in Decimal minutes
- E --- Easting in Ordnance Survey Grid
- N --- Northing in Ordnance Survey Grid

Table 8 GPS data sample (British National Grid coordinates were appended to the original Garmin format)

Header	Position	Time	Altitude	Depth	LegLength	LegTime	LegSpeed	LegCourse	Latitude	Longitude	E	N
Trackpoint	N51 48.748 W0 10.834	13/07/2005 10:54:01	21 ft		24 ft	0:00:05	3.2 mph	0? true	N51 48.748	W0 10.834	525520.2	214212.5
Trackpoint	N51 48.744 W0 10.826	13/07/2005 10:54:13	29 ft		37 ft	0:00:12	2.1 mph	129? true	N51 48.744	W0 10.826	525529.5	214205.3
Trackpoint	N51 48.744 W0 10.826	13/07/2005 10:54:14	29 ft		0 ft	0:00:01	0.0 mph	0? true	N51 48.744	W0 10.826	525529.5	214205.3
Trackpoint	N51 48.751 W0 10.820	13/07/2005 10:54:28	30 ft		46 ft	0:00:14	2.2 mph	32? true	N51 48.751	W0 10.820	525536.1	214218.4
Trackpoint	N51 48.752 W0 10.824	13/07/2005 10:55:06	30 ft		17 ft	0:00:28	0.4 mph	298? true	N51 48.752	W0 10.824	525531.5	214220.2
Trackpoint	N51 48.748 W0 10.829	13/07/2005 10:55:26	37 ft		30 ft	0:00:20	1.0 mph	219? true	N51 48.748	W0 10.829	525525.9	214212.6

Sample GPS map

OS MasterMap data that covers Hertfordshire area were used as a basemap to analyze GPS datasets. The map data was imported into ArcMap, with British National Grid projection (Northing and Easting). Figure 3 shows the GPS data superimposed on OS Mastermap using ArcGIS.

Figure 22 GPS points superimposed on OS MasterMap

Data Processing

Data cleaning

The GPS datasets obtained from our monitoring surveys contain a number of positioning errors.

shows the original GPS point dataset that consists of 4-day tracks of 102 children from Flamstead End Primary School in Hertfordshire. The number of GPS points 97437 in total.
As you can see, the original dataset contains obvious positioning errors. For example, several GPS points are located at places where is unlikely to be visited by children such as in the middle of North Sea. For the first step of data cleaning, we deleted these obvious errors. Most of the obvious errors can be detected by speed value analyses. Figure 24 shows the speed values (mile per hour) that obtained from 2 GPS units at each location. Given that plausible vehicle moving speed is 20 to 50 miles per hour in urban areas and around 80 miles per hour on motorways, several data points with the speed value over 100mph are likely to be positioning errors. Similar criteria were used for more detailed analysis to judge the transport mode:

- Walking - 2-4 mph
- Bicycle -9-20mph
- Train –up to 160mph (Intercity high speed train)

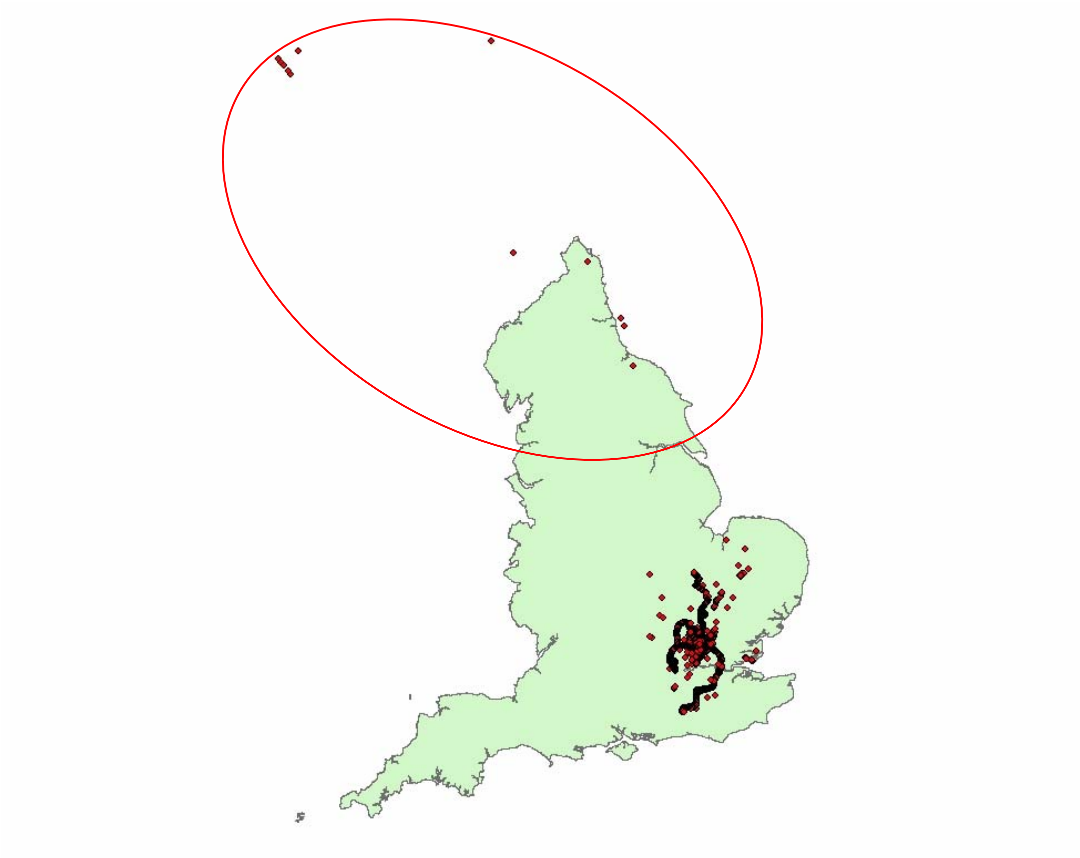


Figure 23 Original GPS data superimposed on a map of England (the dots within a red circle are possible positioning errors)

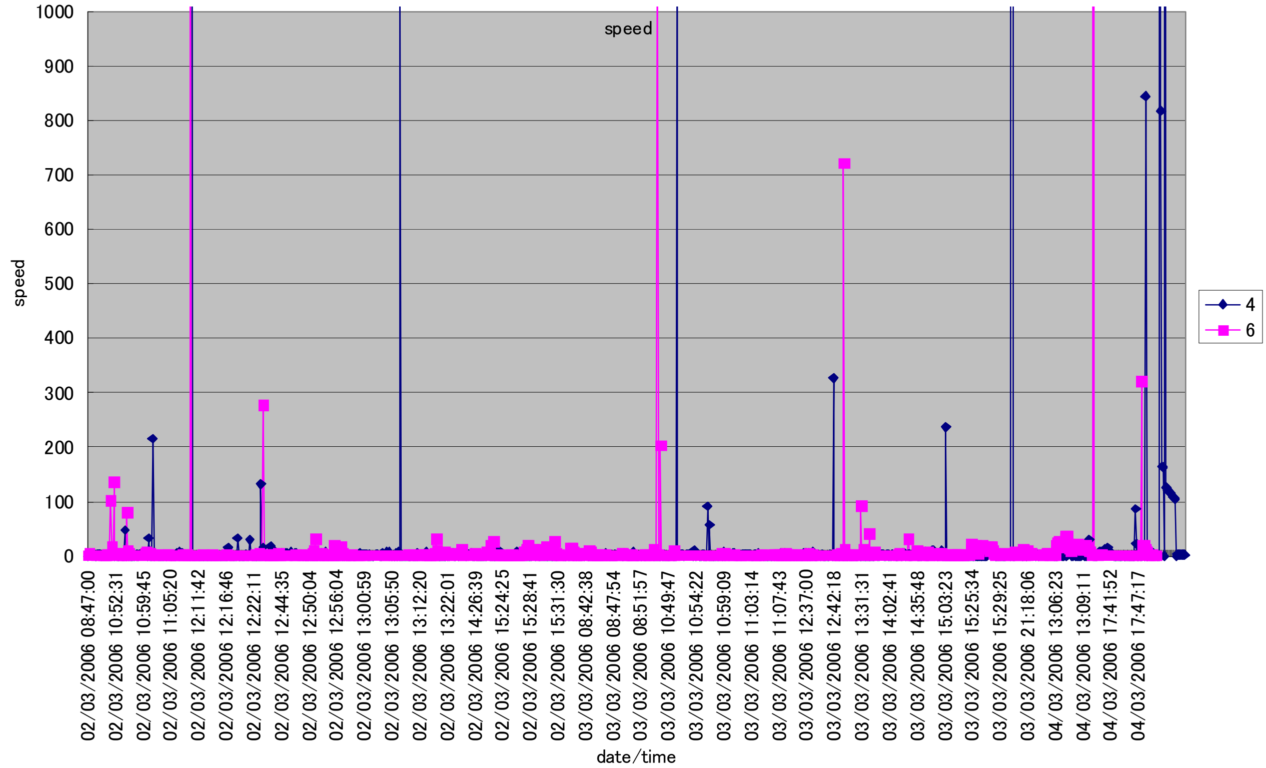


Figure 24 a graph of the speed values (mph) from two GPS units

We used the moving speed of 90mph as our criterion for the data cleaning. In other word, if the moving speed calculated by the distance and time difference between two points is greater than 90 mph, we assume that the second GPS point is possibly a positioning error. Such "blips" can also be seen at other locations. This problem seems to occur whenever GPS unit is turned back on again after being off for a while as it is when the unit tries to get first location fix, thus often accompanies decrease in positioning accuracy. Table 9 shows the details of the eight GPS points including time and location of each point. The first three points were obtained in the evening of December 10th 2005 and the other four points were from late evening (early morning) of December 11th, 2005. When we look at the data on the map (Figure 25), there is a huge jump in location when the child turns the unit few hours later. Such problem seems to be caused by loss of GPS signal. When GPS units lost the signals from satellites or when they are switched on, it takes quite a long time to get a location fix again and first several points tend to be errors.

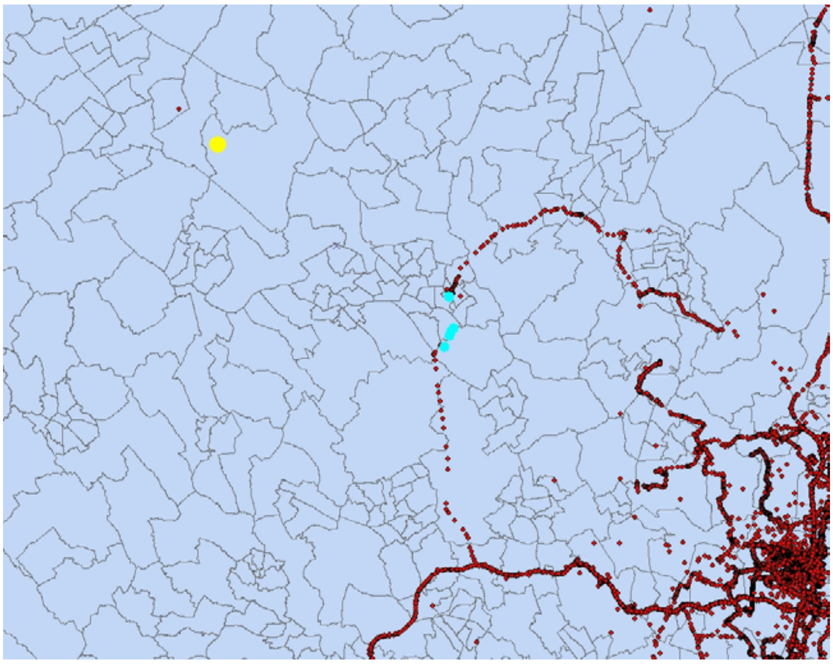


Figure 25 Sample of GPS positioning errors (close-up)

Table 9 GPS data of around blips

childRef	rt3DT	easting	northing	gpsDate	gpsTime
FE6-031	FE6-031 10/12/2005 1142	509844.4375	222433.3438	2005/10/12	19:02:12
FE6-031	FE6-031 10/12/2005 1142	509866.4375	222424.5469	2005/10/12	19:02:17
FE6-031	FE6-031 10/12/2005 1142	509809.4688	222458.5469	2005/10/12	19:02:44
FE6-031	FE6-031 11/12/2005 51	493274.6563	233306.7188	2005/11/12	00:51:05
FE6-031	FE6-031 11/12/2005 51	510176.5313	220163.3438	2005/11/12	00:51:12
FE6-031	FE6-031 11/12/2005 51	509956.3438	219943.4063	2005/11/12	00:51:28
FE6-031	FE6-031 11/12/2005 51	509853.4375	219609.2188	2005/11/12	00:51:45

In addition, the GPS units often failed to achieve 15metre accuracy during the survey. In Figure 27, several GPS points fall onto somebody's gardens or other non-street places. Judging from Activity diary data, it is likely that GPS could not pick up the journey of the children who walk or drive along the roads for these "suspicious" data points.

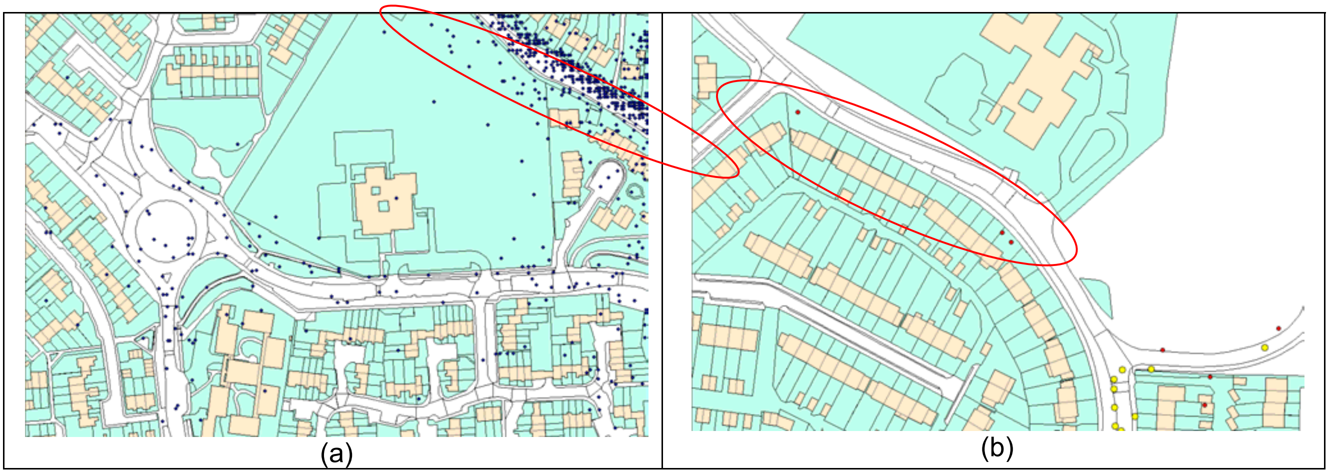


Figure 26 sample of GPS positioning errors (the dots within red circle are supposed to fall onto roads)

It's important to note that although the location information calculated and recorded by GPS has relatively high accuracy (20 m on average in the survey area) it can't avoid positioning errors that occur time to time. Amongst a number of major causes of these positioning errors, unavailability of satellite signals is the single most influential factor on the accuracy of GPS data. There are a number of places in urban areas where tall objects such as buildings and trees block the GPS users to access to the satellite signals. Under such situation, the accuracy of GPS positioning could easily decrease up to several hundred metres. For example, even when several dots are recorded in the area of playground, we can't conclude that this playground was visited by the children because these points could be just error values. Although obvious outlier values have already been eliminated, GPS points need to be tagged with other information such as activity types and transport modes so that some corrections can be made based on the context in order for the location data to have better reliability.
In order to investigate the accuracy and precision of GPS units, a series of tests were conducted in May and June 2006. A CAPABLE researcher wore four Garmin foretrex 201 units and 1 Geologger to test the reliability of their data.

The first test was conducted at Cheshunt railway station, the closest train station from one of the survey area. CAPABLE researchers turned on all the 5 GPS units for 15 minutes. Although the sample accuracy obtained from GPS unit (GeoLogger's accuracy was calculated from DOP value) were around 15 metres (Table 10), GPS points seem to disperse on the map (Figure 27 and Figure 28).

Figure 27 GPS points data from GPS accuracy test (stationary)

Table 10 Results of GPS accuracy test

	Geologger	Garmin 1	Garmin 2	Garmin 3	Garmin 4
First data	06/16/06 14:48:58	16/06/2006 14:53:29	16/06/2006 14:54:50	16/06/2006 15:02:55	16/06/2006 14:56:04
Last data	06/16/06 15:04:10	16/06/2006 15:04:26	16/06/2006 15:04:45	16/06/2006 15:02:55	16/06/2006 15:04:15
Number points	858	5	7	1	8
Sample accuracy	15 ±2.6	14.0208	15.8496	34.1376	14.0208

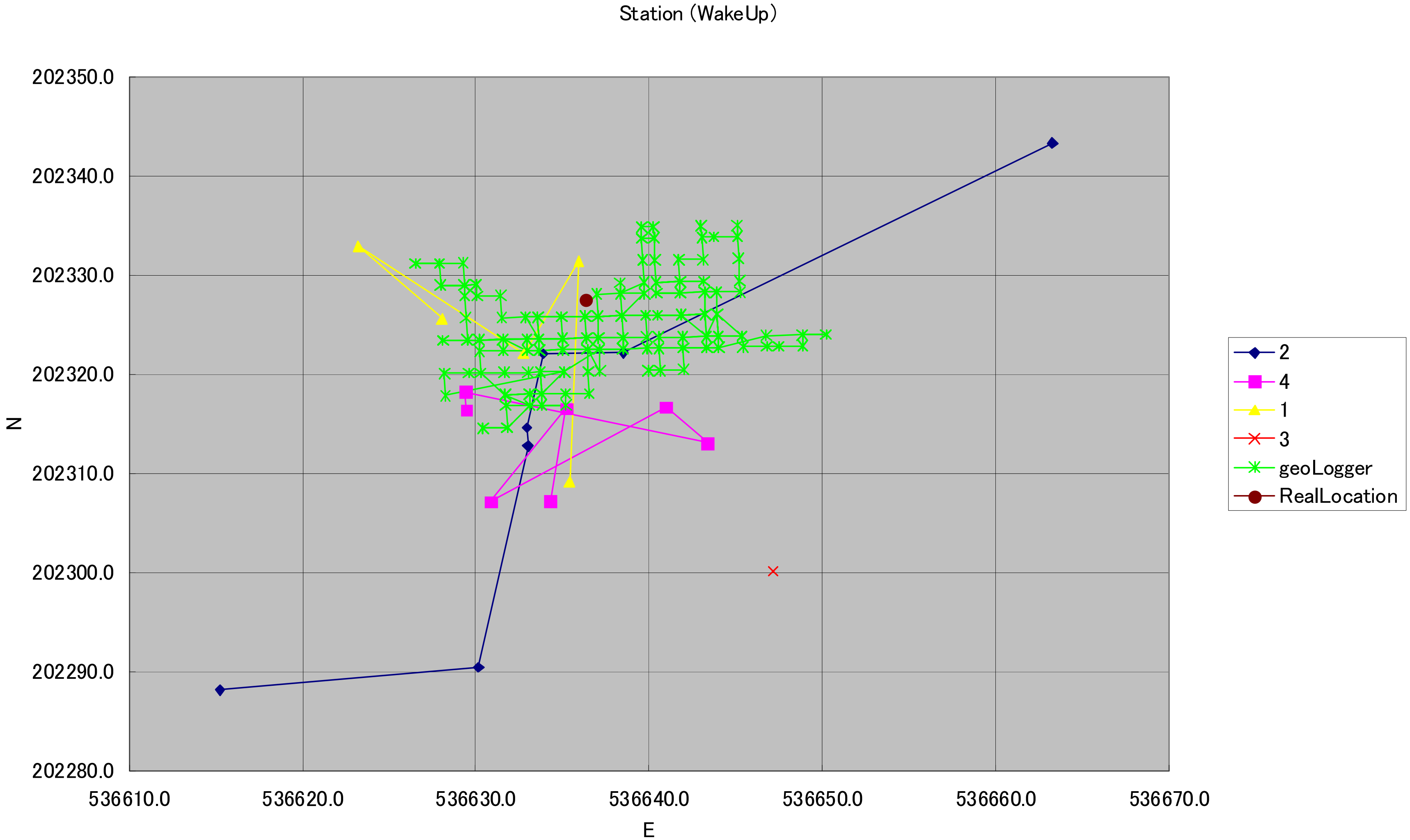


Figure 28　GPS Accuracy test :GPS location information from 5 GPS units under stationary condition.

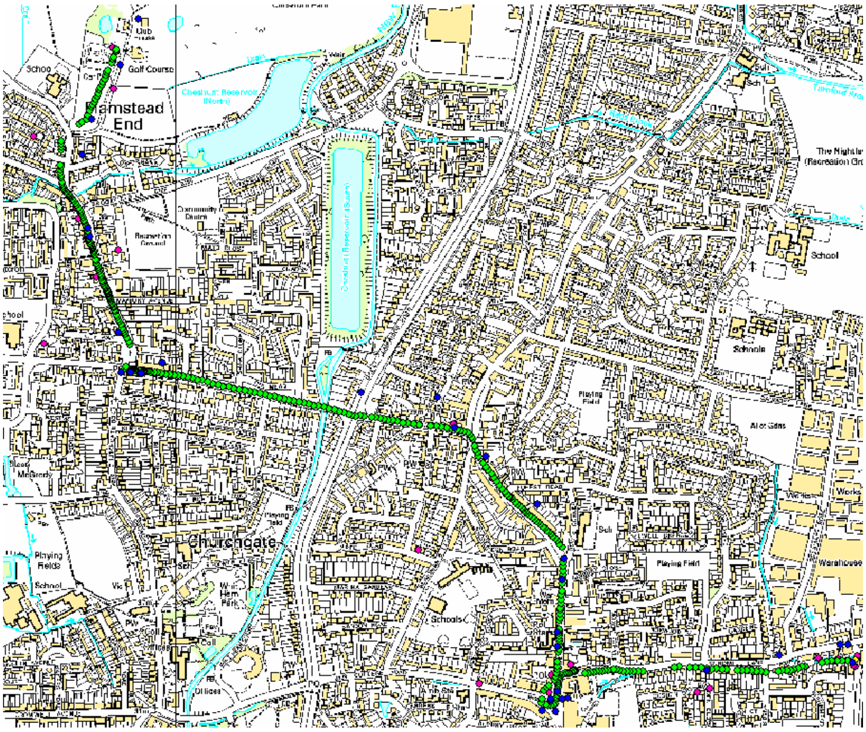


Figure 29 GPS points data from GPS accuracy test (car travel)

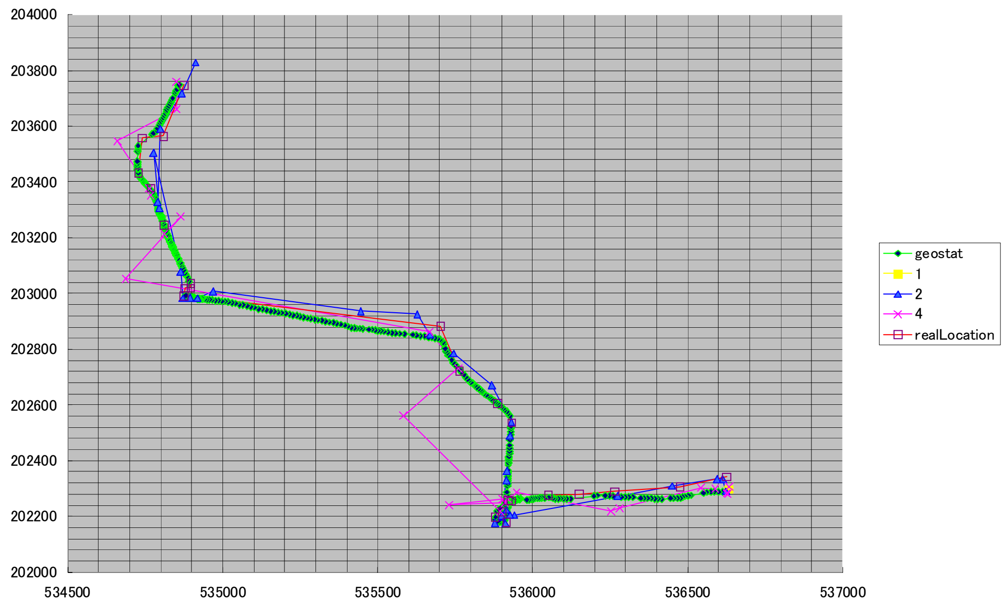


Figure 30 GPS Accuracy test: GPS location information from 5 GPS units under car travel condition

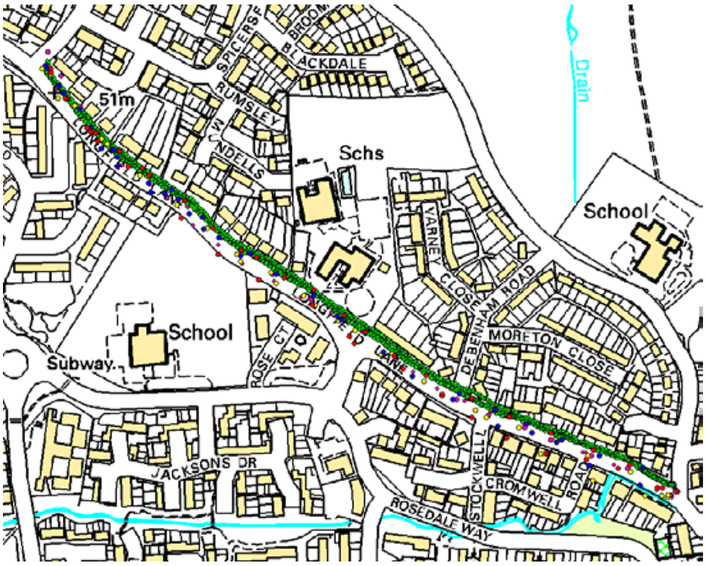


Figure 31 GPS points data from GPS accuracy test (on foot)

Similar tests were carried out for 3 transport mode; car, bicycle and walking (Figure 29,Figure 30,Figure 31). The data from these GPS accuracy tests were used to calculate each GPS unit's precision and accuracy to determine our confidence level of using the GPS data. Although GPS can generally achieve relatively high accuracy (30m ∓ 15m), its data is not precise enough to tell which side of the road the children walk. In fact, it sometimes fail to identify which road was used. In one of the GPS accuracy tests that focused on walking travel, only 77.34807% of Garmin GPS points fall onto correct road. When the data from Garmin units and that of GeoLogger was combined, only 38.15359% of GPS points were usable (Figure 32).

Figure 32 Calculation of the GPS points that fall onto roads and pavement

Data analyses

CAPABLE is still ongoing project and results of data analyses would be presented in another document. Currently ongoing or planned analyses include:

1. Exploratory studies on the size and location of children's area of activity
2. Exploratory studies on where, how long children play
3. To see whether there is any variation in the choice where to play based on the distance from their home to school/playground
4. To see the relationship between children's area of activity land use of local environment
5. To see the relationship between children's choice of transport mode and socio-economic characteristics of neighborhoods

Also CAPABLE GPS Survey animation software was developed to visualize the movement of GPS points in chronological order and produces a QuickTime movie. It was developed as a part of Simulation development project and written in JAVA. The software has user-friendly Graphical User Interface with zoom In/Out function, changing scale function, add/remove layers functions, and other map handling functions (Figure 33). It can handle OS MasterMap data (shape files) and GPS data (csv files). Its executable file will be distributed towards the end of CAPABLE project, but in the meantime, you need to install JAVA Runtime Environment and two library (REPAST and OpenMap) on your computer in order to run this software.

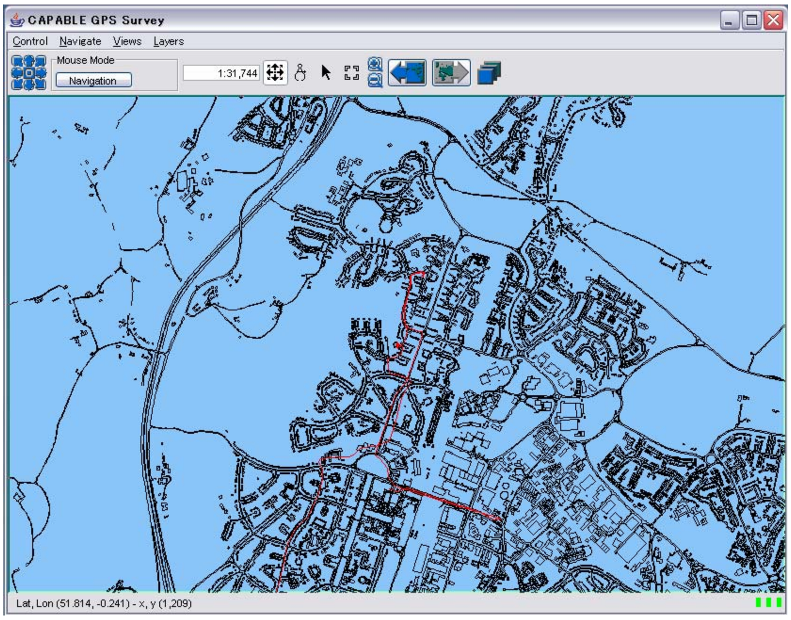


Figure 33 CAPABLE GPS survey animation software

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