Advanced Transport Telematics Positioning Requirements: An Assessment of GPS Performance in Greater London

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This paper presents the results of a study carried out in the Greater London area to assess and characterise the performance of the Global Positioning System (GPS) for vehicle positioning in urban areas. The performance assessment addresses, in varying levels of detail, the issues of service coverage, positioning accuracy, integrity and availability of service. The project was supported by Racal Survey Limited and is part of the wider research at Imperial College in the area of architectural design and testing of Advanced Transport Telematics (ATT) systems. The results highlight the shortcomings of GPS as the sole means for in-car navigation in urban areas and details the temporal and spatial considerations to be taken into account in the process of designing an integrated positioning system capable of meeting navigation requirements placed on ATT systems.

1. INTRODUCTION. The use of *telematics* in the field of transport is one of the greatest innovations this century. It applies and combines a number of underlying 'component' communications, computing, navigation and electronic control technologies to deal with everyday problems created by surface transportation such as congestion, risk of accidents and environmental pollution. Figure 1 shows a high level functional architecture of an ATT system consisting of navigation, data capture, communications including local area networks (LAN) and external networks, interface (I/F) and processing functions.

The different technologies that support these functions can be combined in a wide variety of different ways, leading to a potentially enormous range of different systems for different services. Table 1 shows the different user groups and services defined in a draft American National Plan that will benefit from ATT system technology (Chadwick, 1994).

The navigation function within the ATT systems is responsible for providing spatial (geometric and physical location) and temporal information to support the various services. For example, vehicles equipped with ATT system components can determine and report their positions back to a control centre enabling traffic managers to control the flow of traffic. Vehicles can also receive real-time updates on the state of the road network and can use this information in conjunction with their

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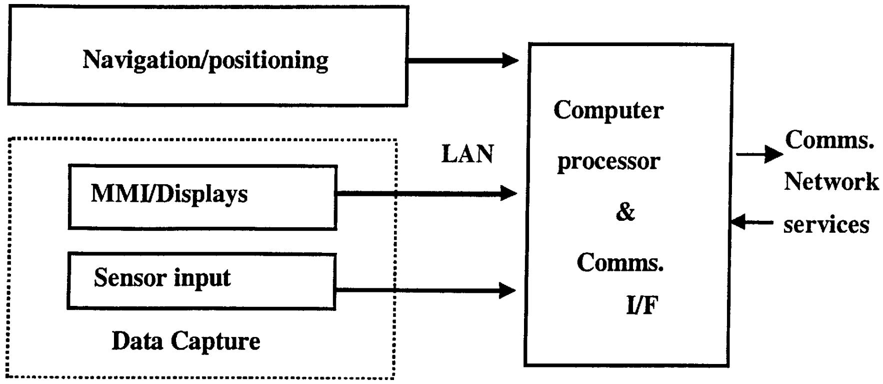

Figure 1. ATT system functional architecture.

Table 1. ATT system user groups and services.

User group	Services
Travel and traffic management	Pre-trip travel information; En-route driver information*; Route guidance*; ride matching and reservation; traveller services information*; traffic control; incident management*; travel demand management.
Public transportation management	En-route transit information*; operations automation*; personalised public transport; public travel security*.
Electronic payment	Electronic payment systems.
Commercial vehicle operations	Electronic clearance*; automated roadside safety inspection; on-board safety monitoring; administrative processes; fleet management*, in-situ vehicle condition monitoring.
Emergency management	Emergency notification/personal security*; emergency vehicle management*.
Advanced vehicle safety/security systems and other value added services	Longitudinal collision avoidance; lateral collision avoidance; intersection collision avoidance; vision enhancement; pre-crash restraint deployment; safety readiness; automated vehicle operation; emissions testing and mitigation, vehicle security.
Research	All of the above, including travel data survey for travel behaviour research.*

* The services marked with an asterisk are those that require a positioning capability.

location data to compute optimal routeing. This will have the effect of re-distributing traffic around the network, thereby reducing congestion and its environmental and social impacts. A pre-requisite to this is that the positioning system adopted must satisfy a wide range of requirements (including performance and cost) as specified for the various services. Due to the huge benefits that can be gained by solving transport problems in urban areas, it is important that the navigation system meets the specified requirements in an urban environment. This is made more difficult given the characteristics of urban areas where physical restrictions are imposed due to buildings, urban canyons, narrow streets, tunnels, bridges etc.

This paper addresses the key issues involved in the selection of a navigation system to support the ATT navigation function, assesses the capability of GPS to meet the performance requirements of the ATT services and characterises its performance in a typical urban environment. The concept of *Required Navigation Performance* (RNP) is described in Section 2. The RNP for ATT services is discussed in Section 3. Section 4 gives a brief overview of the different categories of navigation systems available and makes a case for the experiment carried out in London and presented in Section 5. The paper is concluded in Section 6.

2. NAVIGATION PERFORMANCE MEASURE (NPM). There are four main parameters that can be used to measure the performance of a navigation system, *accuracy*, *integrity*, *continuity of service* and *availability*. These quantities are referred to as the *Required Navigation Performance* (RNP) parameters. The RNP parameters have their origin in aviation and, taken together, define the level of safety required of a navigation system. Because of the realisation that aviation driven navigation systems can also be used to support other modes of transport, this concept has been extended to marine and surface transportation. The RNP parameters are (Ashkenazi *et al*., 1995; Ochieng *et al*., 1996):

(a) *Accuracy* – defined as the degree of conformance of an estimated or measured position at a given time, to the *truth*.
(b) *Integrity* – relates to the trust which can be placed in the correctness of the information supplied by the navigation system. It includes the ability of the navigation system to provide timely warnings to users when the system must not be used for navigation/positioning. Specifically, a navigation system is required to deliver a warning (i.e. *an alarm*) of any malfunction (as a result of a set *alarm limit* being exceeded) to users within a given period of time (i.e. *time-to-alarm*) and with a given probability (*integrity risk*).
(c) *Continuity* – defined as the ability of the total system to perform its function without interruption during an intended period of operation. Continuity risk is the probability that the system will be interrupted and not provide guidance information for the intended period of operation. This risk is a measure of system unreliability.
(d) *Availability* – defined as the percentage of time during which the service is available for use taking into account all the outages whatever their origins. The service is available if accuracy, integrity and continuity requirements are satisfied.

Hence the selection of an existing navigation system to support ATT services must involve an assessment of whether the system satisfies the RNP for ATT services in all respects. The current status of the definition of ATT user services and corresponding requirements is addressed briefly in the next section.

3. ATT NAVIGATION REQUIREMENTS. Having identified the services to be supported by ATT systems (Table 1), the next step is to define the corresponding RNP which must be satisfied to ensure that the corresponding ATT services are delivered safely. Whereas the RNP for civil aviation is well defined (Ochieng *et al*., 1996), the RNP for marine and surface transport is still to be consolidated and agreed. In the United States, preliminary studies have identified the RNP for some potential services. These are given in Table 2 (Chadwick, 1994). Work is continuing in the United States, Europe and Japan to identify the various user groups and services and the corresponding requirements. In Europe, working groups have been set up to consolidate the requirements and architectures for ATT systems (EC, 1997a,

1997b, 1998). The aim of such studies is to develop internationally agreed architectures through open, flexible and expandable system design.

It is important to stress that the requirements in Table 2 are by no means exhaustive. As more user groups and services emerge, one can envisage even higher requirements, especially in urban areas because of special conditions outlined in the introductory part of the paper. As mentioned earlier, there are potentially huge benefits in solving urban transport problems, economically, socially and environmentally. For this reason, higher accuracy will be required in urban areas compared to open space. The availability of integrity information (i.e. the ability of the system to identify and notify any malfunction), whilst not as critical as in aviation, is still important in surface transportation. This will give users confidence in the system and is therefore an important pre-requisite for user acceptance.

4. NAVIGATION SYSTEMS FOR ATT. Positioning systems can be divided into two categories, *self-positioning* and *remote positioning*. These are also referred to as *dependent* and *independent* positioning systems respectively. Remote positioning systems rely on centrally-controlled sensors to locate objects, e.g. the radar system used in locating aircraft in air traffic control (ATC). This information can then be relayed to the objects if required. Self-positioning systems let the objects position themselves and, if the central control requires this information, it is communicated to it. Examples of self-positioning systems include Loran, Omega and Global Navigation Satellite Systems such as the United States' Global Positioning System (GPS) and the Russian equivalent Global Navigation Satellite System (GLONASS).

Until the advent of GPS, dependent systems were not very practical in the surface transport environment. Earlier navigation systems such as Loran and Omega lacked either coverage, accuracy and/or reliability. Satellite navigation systems such as GPS have the potential to provide these essential requirements. It should be noted that, while GPS has many strong points, it suffers from many weaknesses. These include the fact that it is a military system (full accuracy is made selectively available), it suffers from signal blockage (from objects such as buildings, tunnels, trees, canyons, large vehicles) and is susceptible to signal interference and jamming. Signal blockage and interference are major problems in urban areas. Given this scenario, two questions arise.

(1) How does GPS perform in a typical urban environment? This is particularly important as information gathered can be used as input to the design and development of augmentations to GPS, should they be required.
(2) Does GPS meet the RNP for supporting ATT services, for example those identified in Table 1?

4.1. *The Global Positioning System* (*GPS*). GPS is a space-based system of satellites providing 24-hour, all-weather, three-dimensional positioning and timing all over the world. It was developed by the Department of Defense (DoD) in the United States. GPS achieved its full operation capability (FOC) in 1995 with 24 satellites distributed uniformly in six orbital planes and at an altitude of 20 200 km. The orbital configuration ensures that at least four satellites are visible at any time and from any point on the earth's surface. All satellites transmit signals at two distinct frequencies, L1 at 1575·42 MHz and L2 at 1227·60 MHz.

GPS employs two fundamental observables for positioning and navigation, the code-phase (pseudo-ranges from code phase observations) and carrier-phase. The

Table 2. ATT navigation requirements.

Services	Accuracy (metres)	Integrity (sec)	Availability (%)
Vehicle routeing	5	1	99·7
Vehicle location (generic services)	30	5	99·7
Emergency location	5	11	99·7
Hazmat response	5	5	99·7
Transit location	10	5	99·7

Table 3. GPS SPS performance specifications.

Coverage		99·9%
Accuracy	Horizontal	100 m (95%)
	Vertical	156 m (95%)
	Time transfer	340 ns (95%)
Reliability		99·97%
Availability		99·85%

robust and readily accessible, but coarse, pseudo-range is the basic observable for navigation and is a measure of the distance between the satellite at the time of transmission and the receiver at the time of reception of the signal. The term *pseudo* is used to represent the clock bias contaminating the range measurement due to the lack of synchronisation between the satellite time and the receiver time. Measurement to at least four satellites enables the determination of the 3-D position and time at a user location. Used in instantaneous stand-alone mode, accuracy at the 100 m level is possible. Differential techniques can be used to improve the achievable accuracy to the metre level (Section 4.1.1).

The carrier phase observable is derived from the measurement of the difference between the phase of the signal arriving from the satellite, and the phase of the signal generated locally at the receiver. The direct measurement consists of a phase reading of the fractional part of the whole (*integer*) number of cycles in the range between the satellite and the receiver. Unfortunately, the receiver has no knowledge of the number of whole wavelengths when it acquires (locks on to) the satellite (either at the start or after loss of lock) but keeps count of the integer number of wavelengths to be added or subtracted as the receiver to satellite range changes. The whole number of cycles referred to as *integer ambiguity* must be resolved in order to determine the range between the receiver and the satellite. With the correct ambiguity resolved, ranges can be determined with millimetric accuracy.

GPS is affected by a number of error sources including orbital and atmospheric propagation errors, but the dominant error source is the deliberate degradation of the signals referred to as selective availability (SA). SA is applied by the DOD to degrade the positioning accuracy available to civilians. The performance specifications for the civilian service (i.e. the standard positioning service, SPS) are given in Table 3 (Kaminski, 1995).

4.1.1. *Differential GPS*. The differential positioning technique was developed to reduce some of the errors that affect the system. The technique involves accurately

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measuring the errors in the ranges to the satellites observed at a given time and at a known point (reference station). This data (i.e. differential corrections) is then broadcast either using terrestrial radio links or geostationary (GEO) communications satellites to other receivers in the vicinity to determine their positions more accurately, by correcting their received ranges. Since the advent of the concept of differential GPS, techniques that can operate on a local, regional and wide area basis have been developed (Ochieng, 1993). Figure 2 illustrates these developments from stand-alone

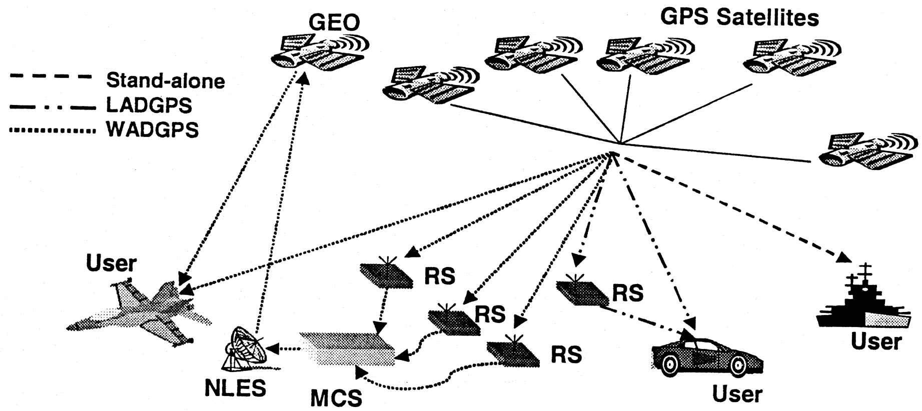

Figure 2. Differential GPS concepts.

positioning through local area differential GPS (LADGPS) to wide area differential GPS (WADGPS). The WADGPS techniques use data from several reference stations to model the different error components (orbit, clock and ionospheric) at a master control station (MCS) for application over a wide area. These errors are uploaded to the communications satellites by a near land earth station (NLES) for dissemination to the users.

A good example of a differential service is GPS LandStar, which is owned and operated by Racal Survey Limited. Landstar provides 24-hour, real-time, precise positioning for many applications on land and in the air over 40 countries. LandStar uses L-band spot beam technology which allows for the use of smaller, lighter receivers and antennas. It uses the AMSC satellite in the USA, the OPTUS satellite in Australia and the EMS satellite in Europe as the data carriers, each giving a wide coverage and proven reliability. A network of reference stations are located strategically within the coverage areas of the satellite footprints. These stations are used to track and record GPS data. DGPS corrections derived from these stations are sent via dedicated landlines to the LandStar hub and control centre. The information is checked, for quality and performance, before being formatted into a continuous stream of correction messages for uplink to the satellites for subsequent dissemination to users. The corrections are derived from a wide area network solution assuring LandStar users of a robust and highly redundant service. This allows real-time positioning accuracies of 1 metre or less. LandStar applications cover a wide range of businesses including survey and mapping, agriculture, natural resources, land management, utilities, engineering, land and air navigation (Racal, 1998).

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4.2. *Other Satellite Positioning Systems.* The Russian system, GLONASS is the other major satellite positioning system to date. GLONASS is similar to GPS in many respects. However, due to political and economic problems in the CIS (Commonwealth of Independent States) and particularly the Russian Federation, GLONASS has neither achieved the maturity nor the level of use of GPS. Other systems under consideration and/or development include the first and second-generation civilian global navigation satellite systems (GNSS-1 and GNSS-2) (Ochieng *et al.*, 1996).

5. GPS PERFORMANCE ASSESSMENT. The aim of the experiment carried out in the Greater London area in 1998 was to characterise and assess the capability of GPS to support the ATT navigation function; key features are presented in this section. Important elements considered in the planning and execution of the experiment included analysis criteria, experimental design, data capture, data processing and analysis, and presentation of results. It should be noted that the LandStar Differential system is not designed for urban environments. It is only used here to expose some important characteristics that will need to be considered in the process of designing an optimum telematics system suitable for urban environments. Other more effective delivery systems in urban areas, such as those based on RDS (Radio Data System) and GSM (Global System Mobile) technologies, are currently under development. Racal has in fact addressed this issue through the GPS/GSM based ORCHID system (Archer, 1998; Lui, 1998).

5.1. *Analysis Criteria.* The definition of analysis criteria represents a very important stage in the planning and execution of any experiment as it drives the other stages. Accuracy, and to a lesser extent integrity, were the two criteria used for the analysis presented. However, it is important to note that before an assessment of the RNP parameters can be undertaken, the required minimum number of satellites must be available. Hence an additional criterion, *satellite availability* was added. Furthermore, a detailed study of satellite availability would provide useful information for the design of any augmentations to the primary system under investigation. The specific details of the analysis, constraints and parameters are given in the section on results and analysis.

5.2. *Experimental Design Drivers and Data Capture.* In order to carry out a credible and realistic assessment and characterisation of the performance of GPS, the experiment was designed to include different operational scenarios. The routes were chosen to have a wide mix of important spatial and temporal urban characteristics. Two routes were chosen in London, one in Central London and the other in the West End. The routes offered a good mix of spatial characteristics such as open spaces, urban canyons, tall buildings, tunnels, bridges, potential sources of electromagnetic interference and the potential for availability of a good mix of small and large vehicles. Temporal considerations included capturing data during peak and off-peak hours. To provide a baseline for relative assessment, data was also captured in a predominantly open road, the M4 motorway between London and Reading.

For each of the three routes, a vehicle was equipped with a Trimble 4000SST receiver and a Racal Survey LandStar Differential System. Figure 3 shows the equipment set up. The two antennae were mounted on the roof of the vehicle 0·5 m apart in an East-West direction each connected to a corresponding receiving unit (with independent power supplies). The receivers were connected to two laptop computers (each with internal power supply) in the vehicle. Data was logged at a

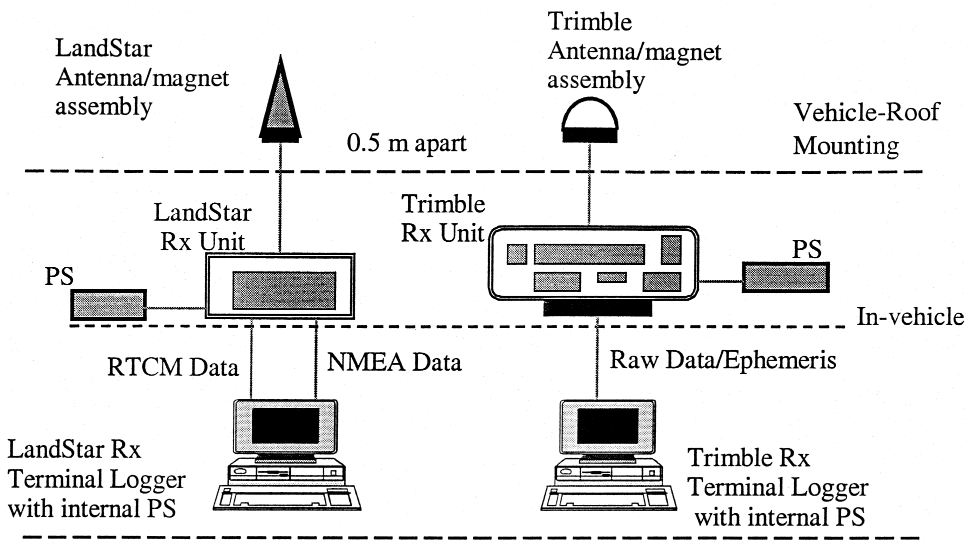

Figure 3. Equipment set up.

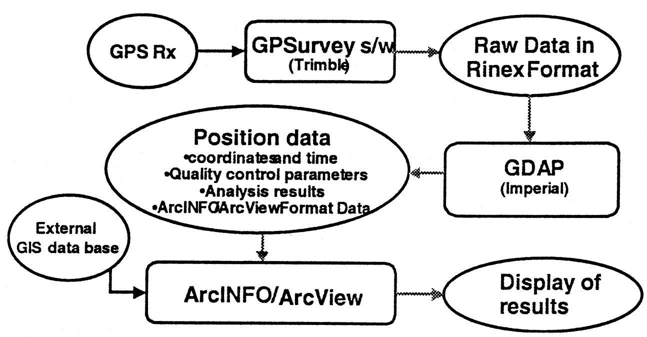

Figure 4. Trimble data processing.

frequency of 1 Hz from the LandStar unit in both the RTCM (Radio Technical Commission for Maritime services) and NMEA (National Marine Electronics Association) standard formats. Raw Trimble Data (pseudo-range and carrier phase) was logged at 0·2 Hz from the Trimble 4000SST receiver.

5.3. *Data processing*. The data was processed using both commercial and in-house software. Trimble software was used to download and convert the raw data into RINEX (Receiver Independent Exchange) format. This data was then processed with GDAP (GNSS Data Analysis Package) developed at Imperial College, to generate positional data and quality control parameters. The output of GDAP was used with the GIS packages (ARCINFO and ARCVIEW) and superimposed onto a digital basemap (1:5000 scale) of the London road network from Bartholomew plc. NMEA data from the LandStar Differential unit was also processed with GDAP and ARCINFO and ARCVIEW GIS packages. Figures 4 and 5 show the schematic diagrams for the processing of Trimble and LandStar data respectively.

5.4. *Results and Analysis.*

5.4.1. *Satellite Coverage.* The variation in the number of satellites visible with time, over the mission duration of about 35 minutes, for the built-up area in West London in shown in Figure 6. The corresponding satellite availability for positioning

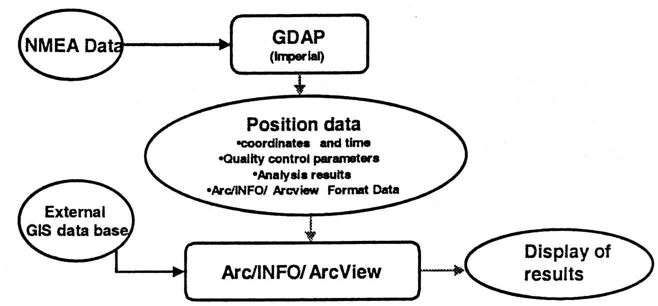

Figure 5. LandStar data processing.

(assuming that all satellites are in good technical working order) expressed as a percentage of mission duration is shown in Figure 7. The results show that, in this case, the availability of at least four satellites (i.e. the minimum number required for 3-D positioning and time determination) is approximately 72%. Considering the basic requirement for integrity (i.e. the availability of at least five satellites), the figure drops to 31%. These levels of satellite availability are too low to support the requirements of ATT identified earlier. However, an important finding here is that availability of at least one satellite is relatively high at 98·5%. This essentially guarantees at least one measurement and is important when one considers augmentations to GPS.

The corresponding figures for Central London (total mission duration of 92 minutes) are 56% for the availability of at least 4 satellites, 23% for the availability of at least five satellites and 99% for the availability of at least one satellite. As with the West End data, the satellite availability for sole positioning and integrity is low. The availability of one satellite is again relatively high at 99% and guarantees at least one measurement for use with other systems in an integrated design.

To provide a baseline for comparative assessment, a similar analysis was carried out for the predominantly open space route (i.e. the M4 motorway between London and Reading). For this operational scenario, the satellite availability figures are 98% for at least four satellites, 95% for at least five satellites and 99% for at least one satellite. These figures are slightly lower that than those expected from the GPS standard positioning service (SPS). This slight difference can be attributed to obstructions at the initial stages of the route on the London side.

5.4.2. *Positioning Accuracy.* The assessment of accuracy was carried out at two levels. The first level considered accuracy as dependent on *satellite geometry* (i.e. the product of the dilution of precision and measurement precision gives an estimate of positioning accuracy). The second level involved comparing the estimated positions with the *truth*.

5.4.2.1. *Assessment Based on Satellite Geometry.* For this test, a horizontal

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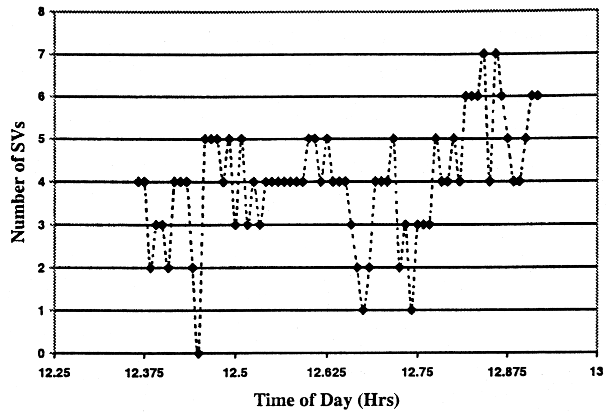


Figure 6. Satellite visibility.

dilution of precision (HDOP) factor of six or better was the requirement to be met. This is the geometric constraint required to deliver acceptable horizontal positioning accuracy in differential mode. In order to study the impact of an additional requirement in the differential mode, i.e. the availability of differential corrections, both stand-alone and differential solutions have been considered. Hence:

(a) Stand-alone position fixes were computed, and those meeting the HDOP requirement identified and noted.
(b) Differential position fixes were also computed, and those meeting the HDOP criterion noted.

From this data, the following parameters were determined for each route:

(a) The *fix density* (i.e. the ratio of the total duration that this condition was met to the total mission duration expressed as a percentage) was then determined for each route.
(b) The *total outage* (i.e. the total period of the mission duration over which the condition set was not met).
(c) The *maximum outage* (i.e. the maximum single continuous period over which the HDOP condition was not met). This is an important parameter as it defines the periods over which any systems to be used in an integrated sense with GPS will have to operate without the full real-time support of GPS. Table 4 shows the results of this analysis for the West End, Central London and the M4 open space.

The fix density in open space is high at 96·8% and 73·8% for stand-alone and differential modes respectively. This implies total outages of 1·4 and 11·9 min respectively. The maximum single outage durations are 9 and 58 sec respectively. As stated earlier, the maximum single outage parameter will drive the design of augmentation to GPS, as this is the period that any additional system will have to operate without the full support of GPS. The fix density results for the built-up areas, starting with the West End are lower at 66·2% for the stand-alone mode and 30·8%

Table 4. GPS accuracy based on geometry.

Route	Total mission duration (min)	Total outage (min)	Fix density (%)	Maximum single outage (min)
West End of London				
Stand-alone positioning	35·3	11·9	66·2	2·5
Differential positioning	35·3	24·4	30·8	6
Central London				
Stand-alone positioning	92·9	42·6	54·1	7·6
Differential positioning	92·9	65·6	29·3	21·5
A4–M4 (London to Reading)				
Stand-alone positioning	45·5	1·4	96·8	0·15 (9 seconds)
Differential positioning	45·5	11·9	73·8	0·97 (58 seconds)

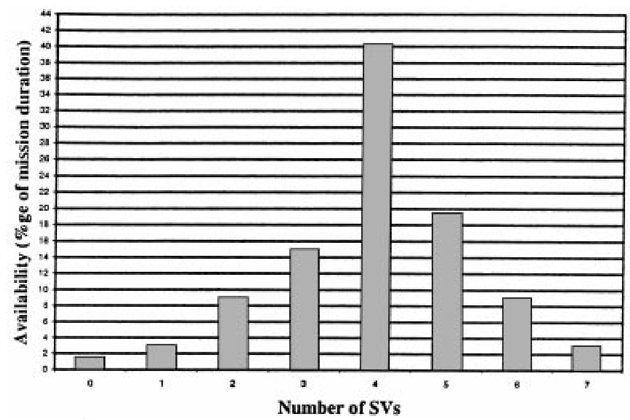
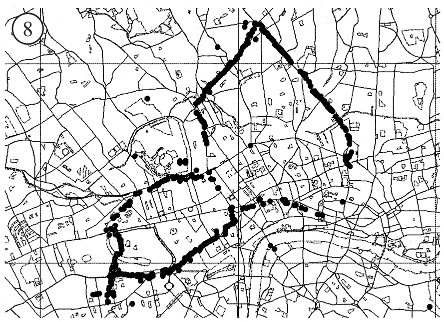


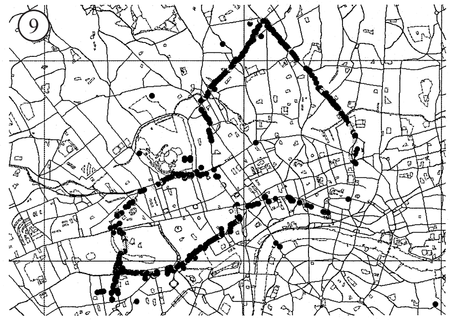
Figure 7. Satellite availability.

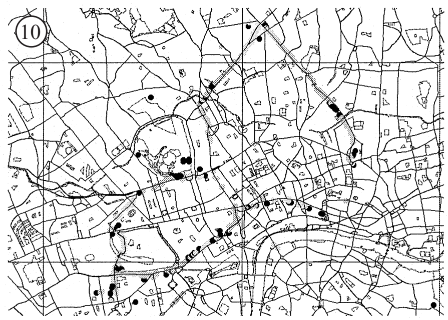
for the differential mode. The corresponding maximum single outage durations are 2·5 and 6 min respectively. For Central London, the fix density figure are 54·1 and 29·3% for stand-alone and differential modes respectively. The corresponding maximum single outage values are 7·5 and 21·5 min respectively.

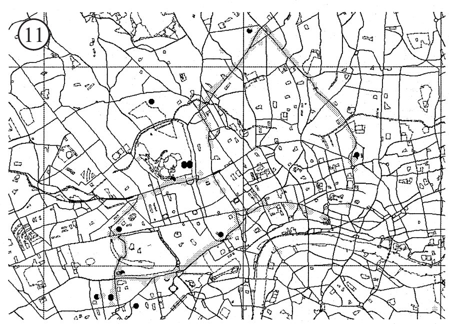
5.4.2.2. *Assessment Based on Truth.* The availability of a digital GIS-compatible base-map of the London road network made it possible to carry out a high level assessment of the performance of GPS in stand-alone and in differential mode against *truth*. In this case, the *truth* was represented by a Bartholomew map at a scale of 1:5000 (equivalent to a minimum plotting error of 5 m). This error should be kept in mind when interpreting the results. The high level data processing aspects have been illustrated in Figures 5 and 6. In summary, both stand-alone and differential co-ordinates from GDAP (in the UK grid) were input into GIS packages ARCINFO and ARCVIEW from where this data was laid onto the digital base-map. The GIS software was then used to perform high level proximity analysis, which consisted of finding out how many points (co-ordinates) were within a given distance from the centreline of the routes travelled.

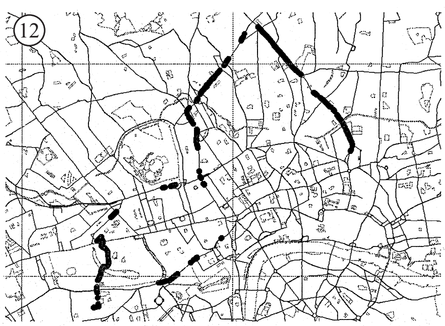
Figure 8 shows the overall stand-alone fixes and the general outline of the Central London route. This general outline forms the basis for comparative analysis with the

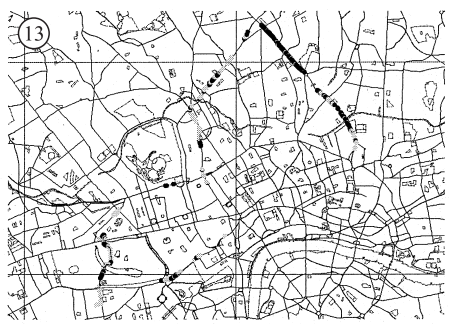


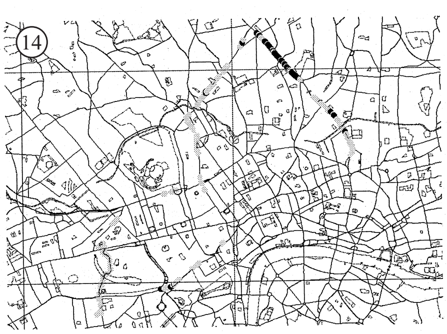












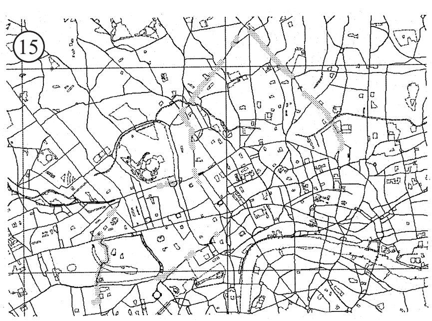


Figure 8. Stand-alone fixes (C-London).
Figure 9. 5 m stand/alone proximity analysis.
Figure 10. 50 m stand/alone proximity analysis.
Figure 11. 100 m stand-alone proximity analysis.
Figure 12. Differential fixes (C. London).
Figure 13. 5 m differential proximity analysis.
Figure 14. 10 m differential proximity analysis.
Figure 15. 20 m differential proximity analysis.

results shown in Figures 9–11. Note that the points that lie within a certain distance from the centreline of the route are removed from the original stand-alone results (Figure 8). Using this approach, a 100% satisfaction of a given proximity analysis should show no dark points on the road network. The 5, 50 and 100 m proximity analyses results are shown in Figures 9–11 respectively. Comparing these figures with Figure 8, and omitting the obvious outliers, the results show that most of the fixes fall within 50 m of the road and that all the fixes are within 100 m of the road. This is consistent with the accuracy specifications of the GPS SPS.

The results for the differential fixes are shown in Figures 12–15. Figure 12 gives all the actual differential fixes and forms the basis for further comparative analysis. The 5, 10 and 20 m proximity analysis results are shown in Figure 13–15 respectively. Comparing these figures with Figure 12, and using a similar approach to that in the stand-alone mode, it is evident that over 50% of the fixes are within 5 m, over 80% are within 10 m and that all fixes are within 20 m of the road. Considering the accuracy of the base-map and the requirements for ATT, it is clear that differential GPS will meet the accuracy specifications.

5.4.3. *Integrity*. Integrity has been defined in Section 2 as the key safety parameter that relates to the trust that can be placed in the correctness of any information supplied by a navigation system. In order to determine the trust parameters, redundant measurements are required. Hence at least five satellites must be available for integrity purposes. Satellite availability analyses have shown that in the heavily built-up area of London, this basic requirement is not met. The satellite availability is low at 31% in West London and 23% in Central London. This in contrast to a high of 95% in open space.

6. SUMMARY AND CONCLUSIONS.

This paper has addressed the positioning requirements of Advanced Transport Telematics systems (ATT). Particular attention has been paid to the capability of ATT systems (and in particular, the navigation function) to operate in built-up areas such as large cities. This is important because of the problems (social, environmental and economic) generated by urban traffic. The results of the experiment to assess and characterise the performance of GPS in a typical urban environment show that differential GPS (DGPS) will be capable of providing the accuracy required for the various ATT services but with a relatively low level of availability. The availability of at least five satellites for integrity, is very low at about 30%. This can only get worse with the inclusion of more stringent integrity criteria.

The above results point to the fact that GPS will have to be augmented if it is to meet the requirements of ATT. An important characteristic in this respect is the very high availability of at least one satellite (above 98%), essentially guaranteeing at least one measurement that could be used in an augmentation process. Obviously more work is required over longer durations and for different scenarios to consolidate these findings. The potential augmentation scenarios include:

(a) GPS augmented with GLONASS and GEOs,
(b) GPS augmented with terrestrial systems such as INS (Inertial Navigation System),
(c) A combination of the above.

These scenarios will be investigated at Imperial College, as follow-on to the work presented here. In addition, the use of innovative delivery systems such as those based on RDS and GSM technology will be explored.

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KEY WORDS

1. GPS. 2. GNSS. 3. Telematics. 4. Trials.