The Use of GPS and GIS in Environmental Impact Assessment

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abstract: Recently the Global Positioning System (GPS) has become fully operational, this has meant that all-weather 24 hour continuous positional data is available globally. This data can and is being used in the transportation industry for various applications, including vehicle fleet monitoring, computer aided dispatch, public transport and many other applications. This paper shows how the integration of positional data obtained from GPS together with vehicle and traffic data obtained from other systems will help in the environmental assessment of various projects, and in other applications such as automatic vehicle location and congestion monitoring.

1. INTRODUCTION

The Global Positioning System (GPS) has recently become fully operational, giving 24 hour all weather coverage globally. The position, time and speed data generated by GPS are being used in various transportation examples. Some of these examples will be highlighted in this paper; these include the use of raw GPS data to determine congestion parameters. These data can be used to give an indication of the dynamic nature of congestion as it varies on a daily, weekly and even monthly basis. Actions can then be taken to relieve the congestion and therefore provide shorter travel times, better fuel consumption, and hence provide a benefit to the environment.

The paper demonstrates how the combination of GPS and other systems such as the Australian Road Research Board's (ARRB) Fuel Consumption and Travel Time Data Acquisition System (FCTTDAS), which has been fitted to a 1993 Ford Falcon station wagon for the Transport Systems Centre, and the Vehicle and Engine Performance Monitoring and Analysis System (VEPMAS) designed and built at the University of South Australia, can lead to the quantifying of the environmental benefits obtained by congestion relieving measures. An example is given of the integration of GPS and noise measurements on a real time second by second basis as the vehicle is travelling through the street network. The paper also demonstrates how Geographical Information Systems (GIS) are a useful tool for both the display and analysis of this type of spatial and environmental data.

2. CONGESTION MONITORING

Monitoring of traffic congestion levels is seen as an important component of network performance measurement. Knowledge of congestion, delays and travel time is an important part of Intelligent Transport Systems (ITS). The use of probe vehicles **provides** one means to gain much of the required information. GPS technology offers one medium by which information can be obtained by probe vehicles.

As a case study the first author has recorded his journey to work and home over an extended period of time using GPS. This repetition, together with the use of some congestion indices (see below), should give some indication on the nature of congestion along the particular route. A number of congestion parameters have been proposed over the years (Taylor, 1992). Some of these have required complex data observations, which may have limited their previous usage, for the ability to log such data has been limited. GPS provides one inexpensive means to collect detailed data. This is the advantage of a simple and versatile system such as GPS that can easily collect the large amounts of data required for some of these parameters.

2.1 The Congestion Factors

Using the data collected by GPS seven of the congestion factors given by Taylor (1992) were derived:

1. Travel Time; the time from the beginning to the end of the journey;

2. Average Speed of the journey (V); calculated by dividing the total distance travelled by the time taken to travel that distance;

3. Congestion Index; which is defined as :

$$\text{Congestion Index} = \frac{C - C_0}{C_0} \tag{1}$$

where C = Travel Time, and C_0 = Free Flow Travel Time

This is a useful parameter since it is non-parametric and independent of route length, road geometry or intersection control and capacity factors that could mask the differences between two sites;

4. Time Moving; calculated by assuming that the car is moving for all observed GPS speeds that are >5 km/h. The reason for selecting this criterion is due to the inherent errors in GPS speed observations when stationary. The use of this criteria has shown to give results that are consistently within one percent of the value given by FCTTDAS, which is known to be accurate.

5. The Acceleration Noise parameter derived by Underwood(1968). This parameter has not been popular due to the difficulty in obtaining appropriate data for it, although it has considerable power in revealing the extent of congestion and the effects of congestion or network performance. Acceleration noise (σ) is given by :

$$\sigma^2 = \frac{1}{C_r}\sum_{i=1}^{n}\frac{\Delta V_i^2}{\Delta t_i} \tag{2}$$

where Δt_i is the time interval taken for a change in speed ΔV_i , and C_r is the time spent moving. Underwood found that acceleration noise proved a useful parametric measure of the level of congestion when the average speed for the journey was greater than 30 km/h;

6. Mean Velocity Gradient; Underwood (1968) suggested that this parameter, derived from acceleration noise, could be used under a wider range of travel times. It is given as:

$$\rho = \frac{\sigma}{V} \tag{3}$$

where V = overall travel speed;

7. Proportion of time stopped, which is defined as :

$$F_s = \frac{C_s}{C} \tag{4}$$

where C_S = stopped time, the component of travel time that the vehicle is stationary, and

C = travel time

The amount of data required to calculate acceleration noise and velocity gradient has limited their usage, but these factors have been revived for this study for evaluation and comparison purposes. Systems such as GPS and FCTTDAS have made the collection of this type of data much easier. They both allow second by second logging of time and speed data: in addition FCTTDAS gives a running distance from tne beginning of the journey as well as fuel consumption; GPS also gives second by second position data.

Congestion is a slippery variable to define but it is with the help of the above factors that a better understanding can be obtained. Once these factors were calculated for the data collected, they indicated that the AM journey to work experienced more congestion than the PM journey from work to home. It was also discovered that there were only small amounts of variation in the values of the congestion parameters, implying that they are reliable and repeatable indicators of congestion. The next section will go on to show how these congestion factors when applied in a fleet situation can be used to obtain an area wide dynamic picture of congestion.

2.2 Realtime Congestion Monitoring

Realtime congestion monitoring is a vital part of ITS. This might be either as a general input to a traffic information system, or for specified fleet scheduling and fleet management tasks. An example of this would be a fleet of vehicles fitted with GPS, from which parameters such as average speed of journey, percentage stop time and others such as the ones quoted above were calculated in realtime and sent to a central base. A realtime picture of congestion levels and their change over time could be determined. Figure 1 shows the potential application of this technology, where the contours represent the congestion levels at an instant in time. These contours have the potential to change as more data is relayed back to the base and processed, so a dynamic picture of congestion can be obtained. This data if stored could then be aggregated and used to model daily, weekly, and even monthly variations in congestion. It would then be a matter of getting this information to the public to allow them to make a more informed decision on their route choice, or even whether to travel at all. An example of this is in Houston, Texas, where volunteers' vehicles are fitted with transponders, as they pass various points in the freeway system data such as travel times and average speed is recorded. This information is then relayed to te public in various ways including variable message signs and media reports. The main aim of this system is to detect any incidents that have occurred on the freeway and clear them as quickly as possible. By the very nature of the system data can only be obtained when an instrumented car passes a transponder, therefore the data is limited and site specific. Whereas data obtained from GPS applies to where ever the vehicle moves in the street network.

The fleet or fleets of vehicles involved in obtaining this data could be from many sources, including public transport, government vehicles, couriers, taxis and any other willing organisation could be fitted with this type of equipment. In Sydney, Australia, the Road Transport Agency has a number of taxis and state government vehicles fitted with transponders used to detect travel times at the major intersection that are fitted with inductor loops, called the Automatic Network Travel Time Measurement System (ANTTS) (Longfoot and Quail, 1990). As in the Houston example data can only be obtained from a vehicle when it travels through a particular intersection. Whereas GPS could supply the data no matter where the vehicle, it would then be a matter of getting the raw data to a base station through some sort of communication system. Then the base station being able to process the huge amounts of data into useful information. This is where GIS packages could be used not only in the displaying of the data but also in the manipulation and analysis of the data so it can be turned into information.

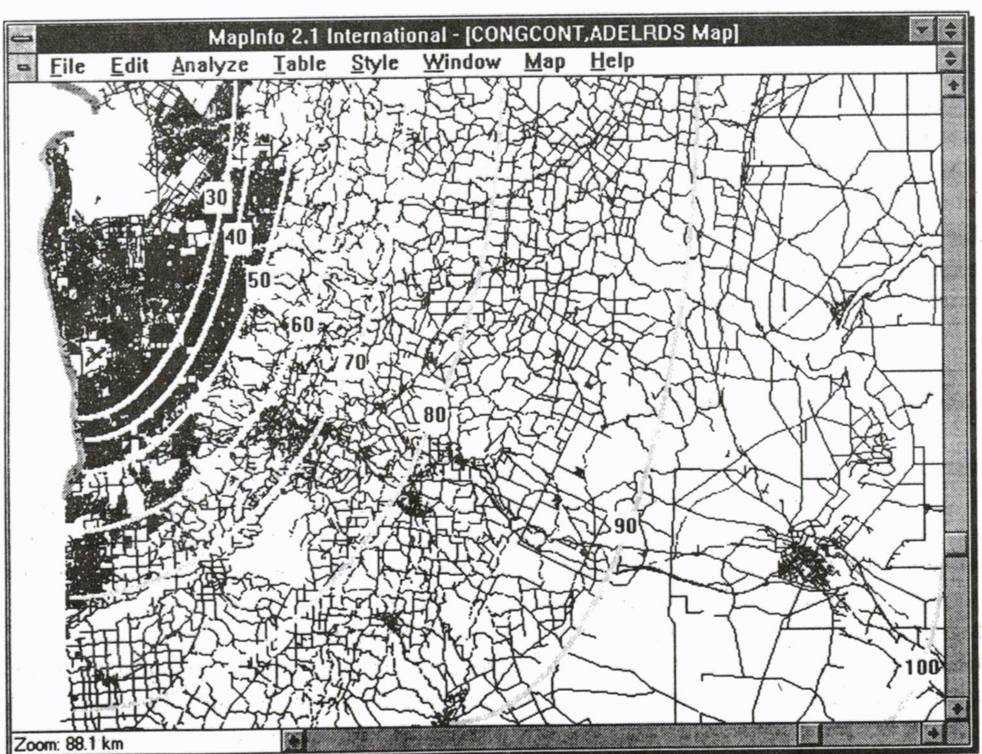

Figure 1-Congestion Contouring with GPS

It is these stored parameters that can be used to quantify the benefits of any congestion relieving strategies employed, as the congestion levels can be stored before and after the measures were taken, and a picture obtained of the effectiveness of the measures.

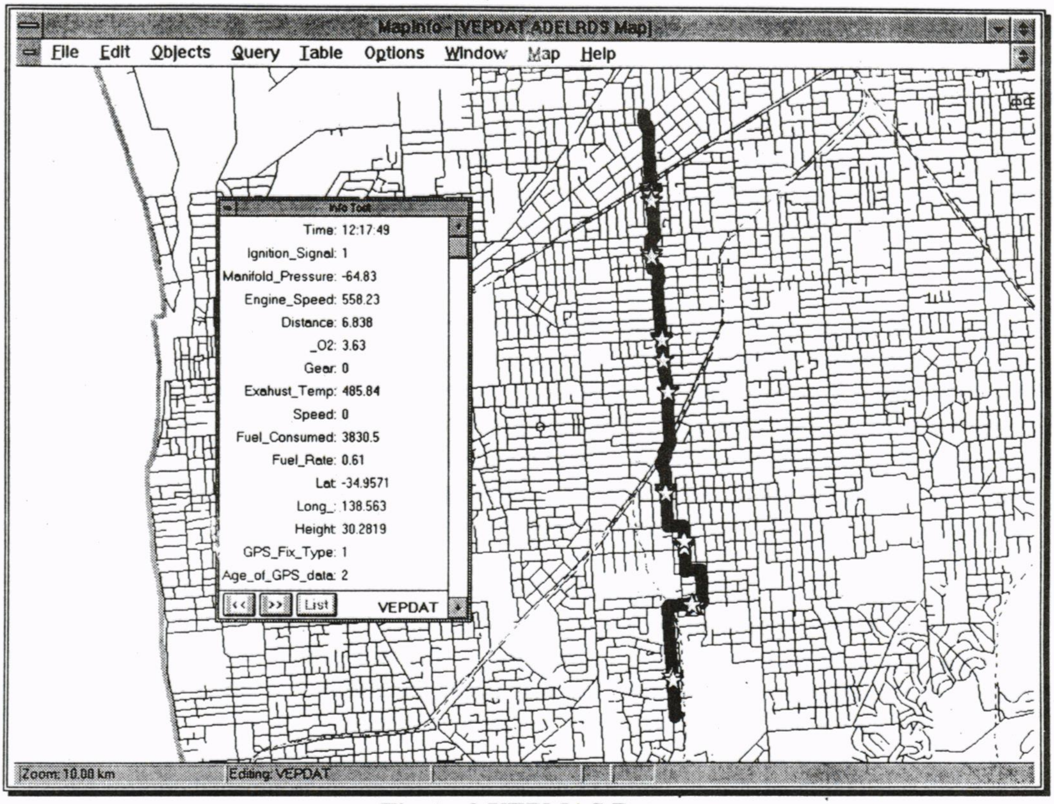

Figure 2 VEPMAS Data

3. VEPMAS, GPS AND GIS INTEGRATION

The Energy and Engines Research Group are affiliated with the Transport Systems Centre at the University of South Australia. They have developed a system that predicts vehicle performance and emission parameters in realtime, called VEPMAS. This engine performance data is then combined with the spatial information given by an onboard GPS receiver, thereby giving a spatial dimension to the engine data. It is this combination that allows the data to be displayed and analysed in a GIS, in this way producing useful information.

The engine data captured by the VEPMAS system includes, the manifold pressure, engine speed (rpm), the total distance travelled so far, the percentage of oxygen in the exhaust, the gear the vehicle is travelling in, the temperature of the exhaust, the speed the vehicle is travelling at in km/h, the amount of fuel being used in g and the fuel rate in g/sec.. These are combined with GPS data such as the latitude, longitude and height of the point, the GPS fix type and the age of the GPS data. All of these GPS and VEPMAS variables give a comprehensive picture of where the vehicle has travelled and how its engine is performing in realtime. The info tool dialog box in figure 2 shows some typical values that have been associated with each point in the journey.

The VEPMAS system has been developed to such a level that other emission parameters that are not logged in real time can be later derived with the use of engine maps. Some of the derived parameters include nitrous oxide, carbon dioxide and carbon monoxide emissions. These are all green house gases that must be controlled and monitored if benefits to the environment are to be achieved. All this data as well as the GPS data is being collected at rates of once per second. Therefore even over short periods of time huge amounts of data can be collected, the voluminous amount of data must be managed so that it can be turned into useful information, hence the need for a data management system such as GIS.

Figure 2 can be used to show where the higher concentrations of green house gases are found, and thus remedial actions can be selected to suit the specific locations. For example if another layer was to be added to figure 2 showing land use boundaries, then policies could be formed that would put strict environmental controls around residential areas, schools and public gathering places. These controls could then be lifted or relaxed in areas that were not as environmentally sensitive. This type of process is a good example of the advantages available with the spatial analysis capabilities of a GIS.

Another example of the spatial analysis capabilities of a GIS is also shown in figure 2, where the stars represent all points in the journey where the speed is greater than 50 km/h and the gear the vehicle is in is equal to 4 ie top gear. This is a simple example showing how queries can be displayed graphically. The map displaying this query shows the points along the route where the vehicle is travelling at the greatest speeds.

If this type of spatial analysis is repeated before and after an environmental control measure is adopted, then the benefits and or dis-benefits of the measure can then be quantified and an assessment made as to their effectiveness. This allows the policy maker to make more informed decisions as to which environmental control methods are likely to be successful in different situations.

The type of data being collected by VEPMAS and GPS can also help in assessing individual driver techniques. Since different driving strategies will produce different engine performance, and hence different emission characteristics. Drivers could be educated and trained to drive in a more 'green' fashion. Since 'green' driving usually leads to a reduction in fuel consumption, and hence a reduction in greenhouse gas emissions, these could be quantified using GIS analysis.

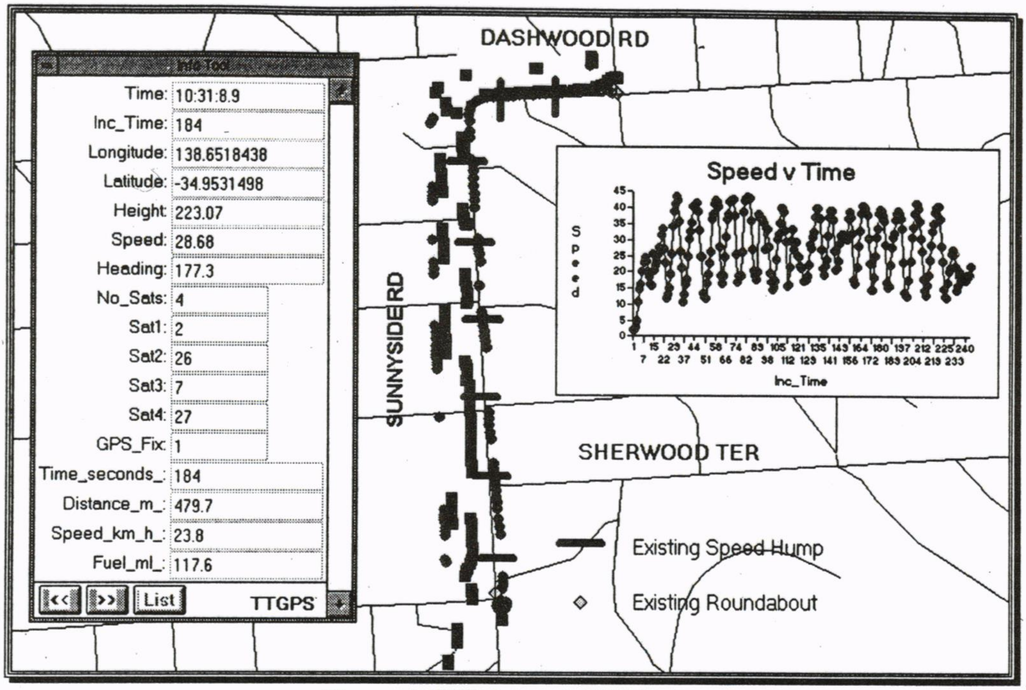

Figure 3 TTDAS and GPS Data

4. TTDAS, GPS AND GIS INTEGRATION

The integration of GPS and FCTTDAS system provides a means of environmental assessment of various Traffic Demand Management (TDM) schemes. Figure 3 shows an example of this where a series of speed humps and roundabouts have been used as traffic calming measures in some local streets in Burnside, an eastern suburb of Adelaide, South Australia. The figure shows a series of squares representing travel in the northern direction and circles the returning southern direction. The scatter of the squares and circles is due to GPS only being accurate to within ±50m in absolute positioning, therefore the locational points do not line up precisely with the centerline of the road. The info tool dialog box shows the attributes that have been associated with each point in the journey. These include the actual time the point was logged, the incremental time from the beginning of the journey, the latitude, longitude and height of the point, the speed of the vehicle given by GPS, the direction of travel, the number of satellites used to obtain the position, the satellite numbers of each one of the satellites, and the GPS fix type eg 2D or 3D fix. The next four parameters in the dialog box have all been obtained from FCTTDAS the time from the beginning of the journey, the distance travelled so far in the journey, the speed the vehicle is travelling at and the amount of fuel used so far in the journey in ml.

An interesting observation from the dialog box is that the speed value given by FCTTDAS, which is known to be correct, and the values given by GPS differ by almost 5km/h. This discrepancy is not the norm, for when the whole data set was analysed it was shown that most of the GPS speed values were within ±2 km/h of the FCTTDAS values. This result is consistent with many other GPS speed tests that have been performed at the Transport Systems Centre. It has been found that the reliability of the GPS speed value is not a function of the actual speed the vehicle is travelling at, but is a function of the GPS conditions. Although suburban conditions are not ideal GPS conditions they have proven to give quite adequate results in both positioning and speed (Zito and Taylor, 1995).

The insert in figure 3 shows the speed profile of the streets Sunnyside Road and Dashwood Road. The speed profile shows a fluctuating nature, this is due to the effect of the traffic calming measures used. The graph shows that the maximum speed of the run was in the order of 45 km/h, so the scheme does seem to be successful in reducing speed. To further extend the analysis the total fuel consumption of the journey can also be analysed. In addition, we can also select the points adjacent the speed humps and roundabouts to analyse the fuel consumption in the vicinity each device.

The local council in this area have decided to remove the speed humps in Sunnyside and Dashwood Roads. This is partly due to pressure from local residents who claim that the speed humps are too aggressive as a speed controlling device. However the removal of the speed humps can also be justified on environmental grounds, since it can be shown that cruising at a constant lower speed is more fuel efficient than the accelerating and decelerating speed profile of the street at present (Taylor, 1993), reflected in the variations in speed shown in the graph. Hence if fuel consumption is reduced so will emissions. This can be quantified if the route is driven again after the removal of the speed humps (this study is currently in progress). Alternatively, some sort of modelling procedure could be undertaken if streets that are similar in nature have already been tested by the instrumented vehicle.

This is another example showing how a GIS analysis can help transportation professionals make more informed decisions, concerning TDM measures, basing them on past analysis and so quantifying the benefits before the scheme is undertaken to justify it.

5. NOISE MEASUREMENTS, GPS AND GIS INTEGRATION

Traditionally noise measurements have been taken at a single location with a noise meter that will log data for various time intervals. The Transport Systems Centre has a ARL EL215 noise meter that has the capability to log L_{eq}s at one second intervals. L_{eq} can be defined as the energy mean of the noise sample, (Nelson, 1987). For the test that was undertaken the meter's noise sample was one second with 16 readings being taken in that sample period to determine the L_{eq}. The test involved putting the noise meter in a vehicle fitted with a GPS receiver. The GPS receiver was logging data at one second intervals and in this way the GPS data can be associated with the appropriate L_{eq} by matching their respective time values.

Figure 4 shows a plot of the run that was undertaken during the test, it starts in the northern suburbs of Adelaide, passes through the central business district to the southern suburb area Mitcham. The attributes that have been associated with each point in the journey are the usual GPS variables of; position, time, speed, distance and satellite variables, as well as an L_{eq} value. The L_{eq} noise level in this test is representative of the internal noise of the car, which incorporates road noise, engine noise, aerodynamic noise, and to a certain degree the noise due to the surrounding environment, namely the road traffic. While this method does not give a true indication of traffic noise it does have the ability to identify areas in which the noise levels were high. For example the data set as a whole, which represents some 1932 readings, has an average L_{eq} value of 61.6 dB(A) with a standard deviation of 7.0 dB(A), the data ranges from a minimum of 42.5 dB(A) to a maximum of 81.0 dB(A). Therefore instantaneous L_{eq} values that are greater than 70 dB(A) can be see as being high for this run. The stars in figure 4 represent the points in the journey where the L_{eq} was greater than 70 dB(A), hence locating spots where more traditional type noise measurements might need to be undertaken to assess their effect on the surrounding environment. This is another application where the spatial analysis capabilities of a GIS can be utilised.

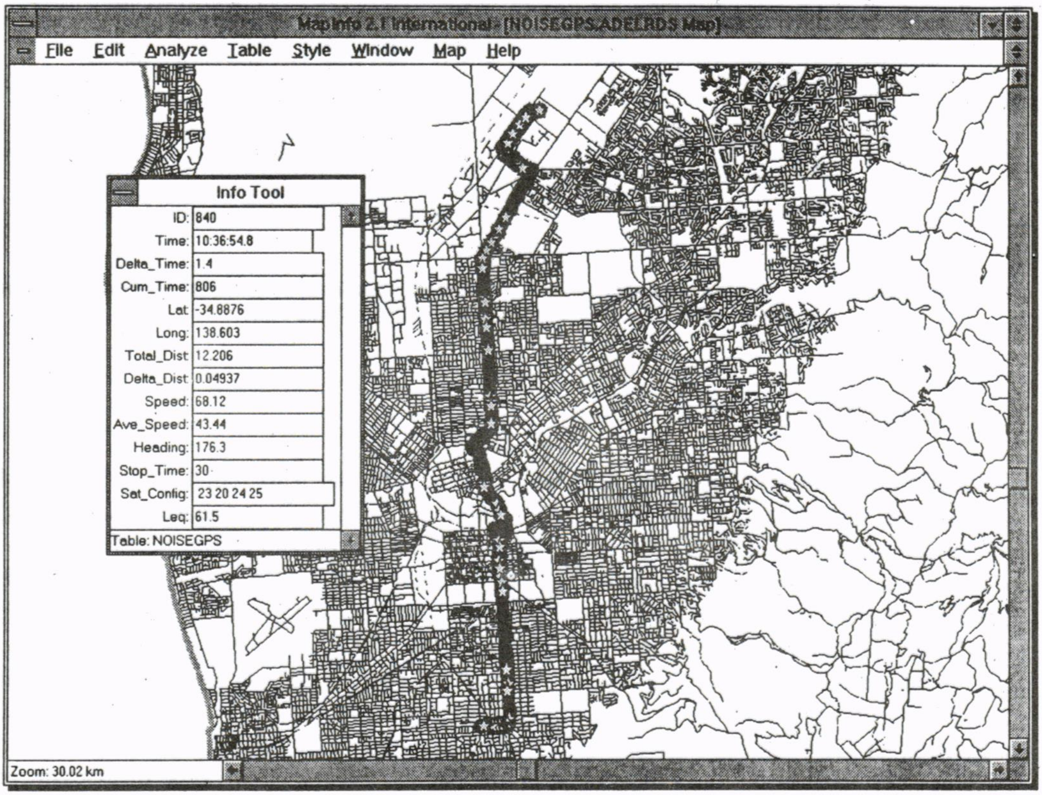

Figure 4 GPS and Noise

Another interesting observation that can be made from the data collected by the noise meter, is the correlation between the speed of the vehicle and the L_{eq} shown in Figure 5. A statistical analysis shows a correlation coefficient between speed and L_{eq} of 0.56. Although this does not indicate a strong correlation, the shape of both the speed and L_{eq} curves do seem to have similar characteristics. This is probably due to the road noise and aerodynamic noise having a greater effect on the overall noise level at higher speeds. However there are points along the L_{eq} graph where there are distinct rises in L_{eq}, but the speed values remain quite low. These would tend to indicate that the traffic noise is dominating in that particular area. This phenomenon usually occurs at intersections, which can be verified with some simple GIS queries. Thereby identifying the intersections that are likely to have noise problems, and so require further noise testing, using more traditional techniques.

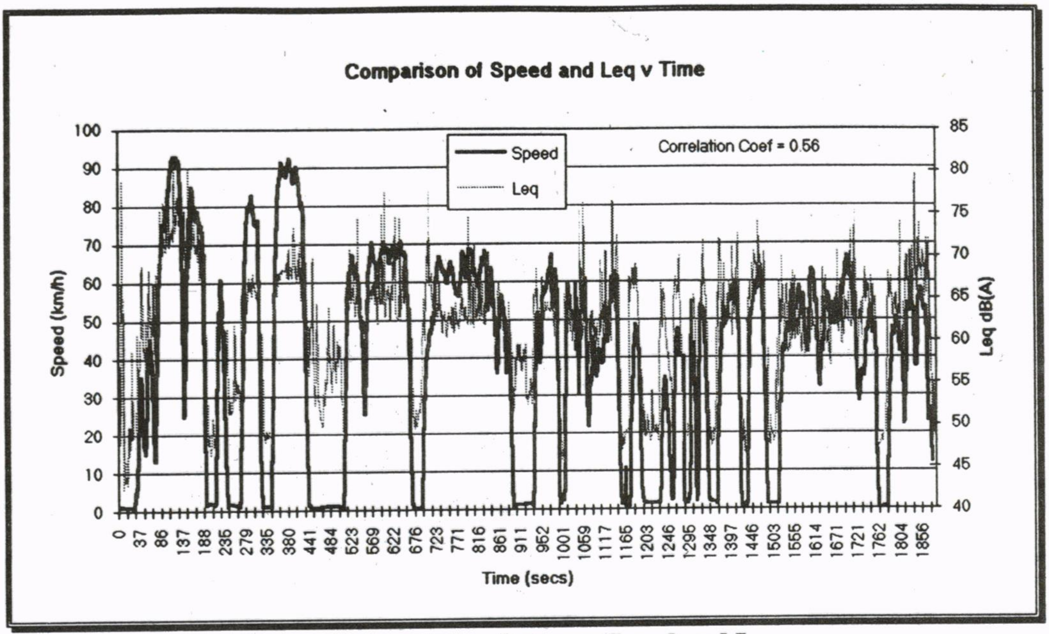

Figure 5 Correlation Between Speed and L_{eq}

6. CONCLUSIONS

To obtain environmental sustainability, measures must be taken to reduce the amount of green house gas emissions and other local pollutants. Once these measures have been implemented there must be a process in place to be able to quantify the benefits or dis-benefits of the scheme. This is where the analysis abilities of a GIS are an invaluable tool. However there must be some means by which spatial data can be added to the environmental factors. This is an ideal application for GPS, which can provide a reliable and flexible method for recording vehicle position and speed data over time to complement the time based observations of environmental and energy variables. Therefore it is the integration of GPS spatial data and GIS's spatial analysis capabilities with various third party devices, such as the ones mentioned in this paper, that allows this type of assessment to be performed.

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