Abstract

Australia's road transport agencies are under increasing pressure to allow transport operators to use large special-combination vehicles (often referred to as freight-efficient vehicles or FEV's) on a larger proportion of the road network. This is at a time when funds to upgrade road infrastructure to cope with these increased demands are extremely tight.

This research looks at capability of satellite-based global positioning systems (GPS) in allowing the movement of these FEV's to be monitored with a view to know when they have departed from permitted parts of the road network.

This paper demonstrates:

- The accuracy of GPS now that it is no longer intentionally degraded by the US Military;
- That an indicator for the quality of GPS data is readily available; and
- Even quite coarse road network definitions allow acceptably wide road corridors to be monitored.

Introduction

The challenges of being a custodian

Like all road agencies in Australia, the Queensland Department of Main Roads faces a significant challenge in managing the use of the road network by large commercial (or freight) vehicles.

The 34,000 km of road for which Main Roads is responsible has a replacement value of around some $23 Billion (Queensland Department of Main Roads 1999) – which makes it one of Queensland's largest single infrastructure investments. Even with an annual Roads Implementation Program in the order of $1 Billion, Main Roads is increasingly under pressure to maintain this road network to a level that meets the demands of both the community and industry.

A large part of industry's demand of and on the road network is seen in the operation of heavy commercial vehicles (HCV's) – even though HCV's represent only some 3.5% of the total Australian vehicle fleet (Australian Bureau of Statistics 1999), they can be attributed with 55% of Australia's road wear costs (Martin 1999). And this demand is growing – the amount of road freight movement (measured in tonne-kilometres) is forecast to double by 2015 (Cox 1999), with over 95% of this being currently clocked up by HCV's (Australian Bureau of Statistics 1996).

This growth in freight movement, and the continuing demands for greater efficiency, is motivating transport operators to make more frequent use of large special-combination vehicles – from the ‘routine’ B-Doubles and Road Trains (see Figure 1) through to the ‘innovative’ AAB Quads and ICON’s (see Figure 2).

These more freight-efficient vehicles (FEV’s) not only inflict a greater toll on roads and bridges, but also represent a potentially greater accident risk to other road users. Thus, road agencies such as Main Roads have to manage these impacts in a sustainable way whilst facing increasingly constrained budgets.

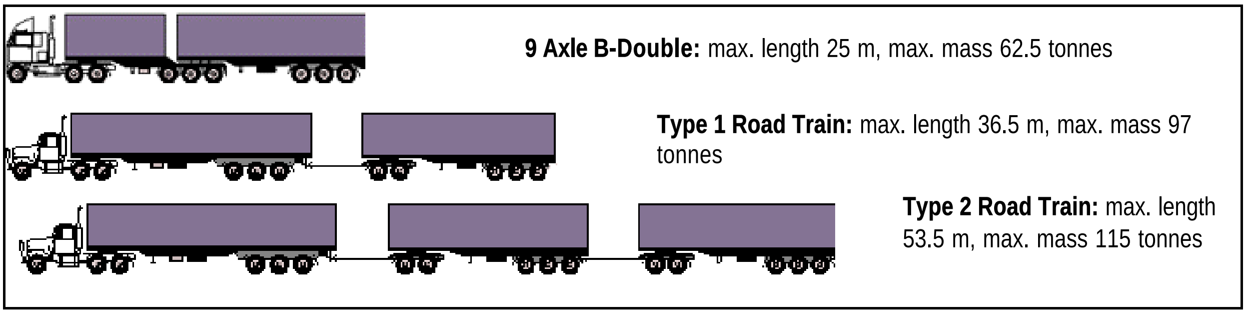

Figure 1. Commonly found freight-efficient vehicles

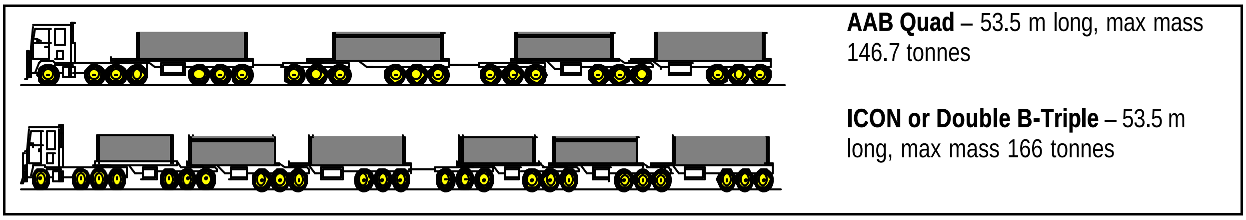

Figure 2. More innovative freight-efficient vehicles

Getting smart about compliance

Of course these kinds of FEV don’t have free access Australia’s road network. Road and transport agencies across Australia restrict where and when these FEV’s can travel, and how much they can carry – typically through the standard set of legislative, regulatory (ie. approval forms) and enforcement (ie. road-side inspectors) tools. However the growth in the use of these FEV’s is out-stripping the ability of these relatively ‘blunt’ management tools. A ‘sharper’ (more precise, smarter) tool is needed to ensure these FEV’s comply with their operating restrictions.

A scan of the activities of overseas road and transport agencies shows that there is a definite move towards implementing systems that automatically monitor the movement of individual vehicles (typically articulated trucks). In the USA, this implementation is focusing on linking that nation’s extensive network of weigh-stations with HCV’s via dedicated short-range communication (DSRC) systems (Faciane 1998). In Europe, work is progressing on both DSRC-based systems (Scientific American Newsletters 2000) and GPS-based systems (Hamet 2000).

It is this work on GPS-based systems that has fuelled a lot of interest in Australia – given our large physical area and relatively low population density. In 1998, the then Tasmanian

Department of Transport undertook an assessment of the suitability of GPS for vehicle tracking and the GSM mobile phone network for extracting data from the vehicle (Highways Technologies Ltd 1999). The trial was successful enough for a number of state road and transport agencies to commence work on a national project – called the "Intelligent Access Project"[1].

The unanswered question

Though the early Tasmanian work proved that the basic premise was feasible, and work overseas was progressing, the fundamental question of "How well can a GPS-based system monitor the operation of a FEV (ie. a high-impact vehicle)?" remained unanswered.

With an understanding of the compliance tasks facing road agencies, this question can be dissected further:

> "How well can a GPS-based system monitor the compliance of a FEV with respect to its permitted operating …
> - Routes and areas,
> - Speeds, and
> - Times and seasons,
>
> … in manner that is not burdensome to either the transport operator or the road agency?"

A trial in two parts

To explore the above question in a manner that demonstrated a degree of rigor but still managed to explain the issues associated with monitoring a FEV in a pragmatic fashion, two interrelated trials where undertaken. The 'first' trial clinically described the level of accuracy with which it is possible to monitor a moving vehicle. Incorporating these learnings, the 'second' trial implemented a basic, but functionally complete, vehicle monitoring system in real-life and identified the practical limits to monitoring the operation of a FEV.

The clinical trial

The focus of the clinical trials was to demonstrate the accuracy and predictability of GPS-derived information, especially now that the intentional degradation of the signals (known as "Selective Availability" or SA[2]) from US Military's Global Positioning System (known as Navstar) has been permanently turned off. The question posed above places the spotlight on three pieces of information: position, speed and time. The Navstar satellites used throughout the trial each have an on-board atomic clock, which means the time/date information transmitted is extremely accurate – easily to within a millisecond (Fried 1994). This fact allowed the clinical trial to focus on position and speed.

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[1] More information on this project can be found on the Internet at http://www.transport.tas.gov.au/iap/.

[2] This degradation was designed to reduce the tactical accuracy (and hence value) of GPS information to all but the US military and its allies. It was permanently turned off on 1 May 2000.

The preliminary phase of the clinical trial involved a number of static (or stationary) tests of the GPS and differential GPS equipment[3]. These tests enabled the accuracy of the differential GPS system to be quantified and provided a large set of 'plain' GPS data to test the analytical procedures later applied to data collected 'out on the road'.

The main phase of the clinical trial involved running an instrumented vehicle[4] repeatedly over a section of the Bruce Highway just north of Brisbane – see Figure 3.

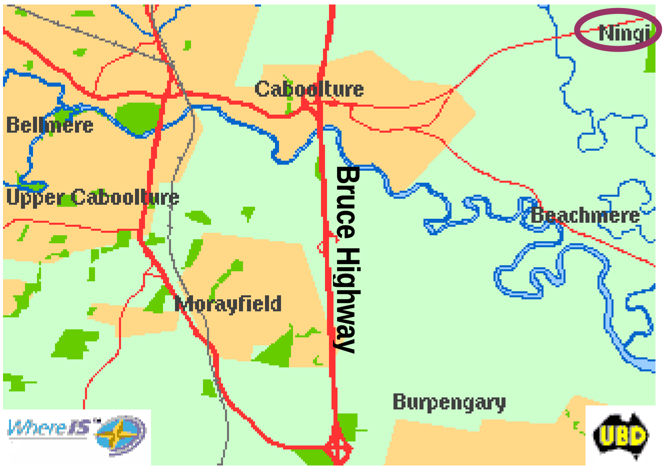

Figure 3. Clinical Trial test site[5]

This site was chosen because:

- It is a relatively flat and straight 5 km section of road with a generally excellent 'view-to-sky' (the only obstruction being an overpass approximately half way along the route);
- It allowed data to be collected at 60, 80 and 100 kph; and
- It is only some 10 km from the Australian Maritime Safety Authority's (AMSA) radio beacon transmitter at Ningi, allowing differentially corrected GPS (DGPS) data to be gathered to a horizontal positional accuracy of 2.4m (at the 95th percentile).

The differentially corrected GPS data were used to identify the location of lane driven on the test section of the highway. Additional runs were then recorded using a normal, or conventional, GPS receiver. Data were collected at one-second intervals and compared with the DGPS reference data. The same lane was used for all runs.

Speed data recorded from the GPS receiver were compared with the speed measurements from the instrumented vehicle, which was calibrated to within 1% of the actual ground speed.

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[3] GPS receiver used was a NovaTel 3151R. Differential corrections supplied by a CSI MBX-2 radio beacon receiver.

[4] QUT's Department of Civil Engineering Commodore equipped with an ARRB Transport Research Fuel & Travel Time Logger and a DataTaker DT50 data logger.

[5] Image courtesy of Pacific Access and Whereis.com.au.

Both speed and location data were the basis of Figures 4, 6 and 7 presented later in this paper.

The real-life trial

The Real-life Trial is intended to demonstrate the practical limitations to using a GPS-based system to monitor FEV's. To avoid 're-inventing the wheel', a Brisbane-based R&D company (Geonautics International Pty Ltd) that specialises in GPS-based vehicle tracking systems was retained to assist with the development, installation and monitoring of the system used in this trial. To provide a 'test-bed' for the in-vehicle part of the system, the cooperation of a Queensland-based road transport company (Rocky's Own Transport) was secured.

This trial was broken into three main phases:

- The first phase involved the installation of a standard Geonautics in-vehicle unit (IVU) in a truck of the participating road transport company. This vehicle typically covered a standard route between Brisbane and Rockhampton twice weekly. This allowed a sizable data-set to be built up, for the proofing of algorithms in later phases.
- The second phase involves the development of a custom vehicle tracking system, based on existing Geonautics products. The customised IVU will be re-installed in the 'test-bed' truck to allow the routines and algorithms to be refined.
- The third phase will involve the use the customised Geonautics system to monitor the movement of 3 FEV's across southern Queensland.

In keeping with the practical nature of the Real-life Trial, a set of broad system design constraints were developed in consultation with Government agency staff – see Table 1.

These basic constraints involved trade-offs in the areas of implementation and running costs, and final system accuracy.

Highlights thus far

Clinical accuracy

The Clinical Trial has demonstrated that a high degree of accuracy is now possible with the use of GPS to determine a vehicle's location and speed.

Figure 4, below, depicts the spread of locational error obtained when the instrumented vehicle was run over the Clinical Trial test track. It is immediately obvious that the accuracy associated with locating the vehicle in the horizontal plane (to within 3.6 m 99% of the time) is much better than the accuracy associated with locating the vehicle in both the horizontal and vertical planes (to within 18.6 m 99% of the time). This result can be attributed to the overall geometry of Navstar system, which lends itself to greater errors in the vertical plane.

Table 1. Basic system design constraints

1. To ensure data, and later alarms, can be extracted from the IVU on a timely basis; a wireless communication system was the communication mode of choice. This meant the obvious first choice was the GSM digital mobile phone network. However, given that the GSM network covers some 6% of Queensland's physical area, mobile satellite systems (MSS) would also be considered in the next major stage of the Real-life Trial (in 2000/2001).
2. To minimise the communications between the IVU's and the tracking system's base-station (and hence the system's running costs), as much intelligence as possible would be built into the IVU – allowing the IVU to determine whether the FEV is where it should be or not.
3. To compare currently known methodologies for monitoring vehicle position would be implemented in the IVU – namely route/zone and virtual gantry[6].
4. To minimise the task of defining routes and zones, only readily available sources of geographical data would be used.

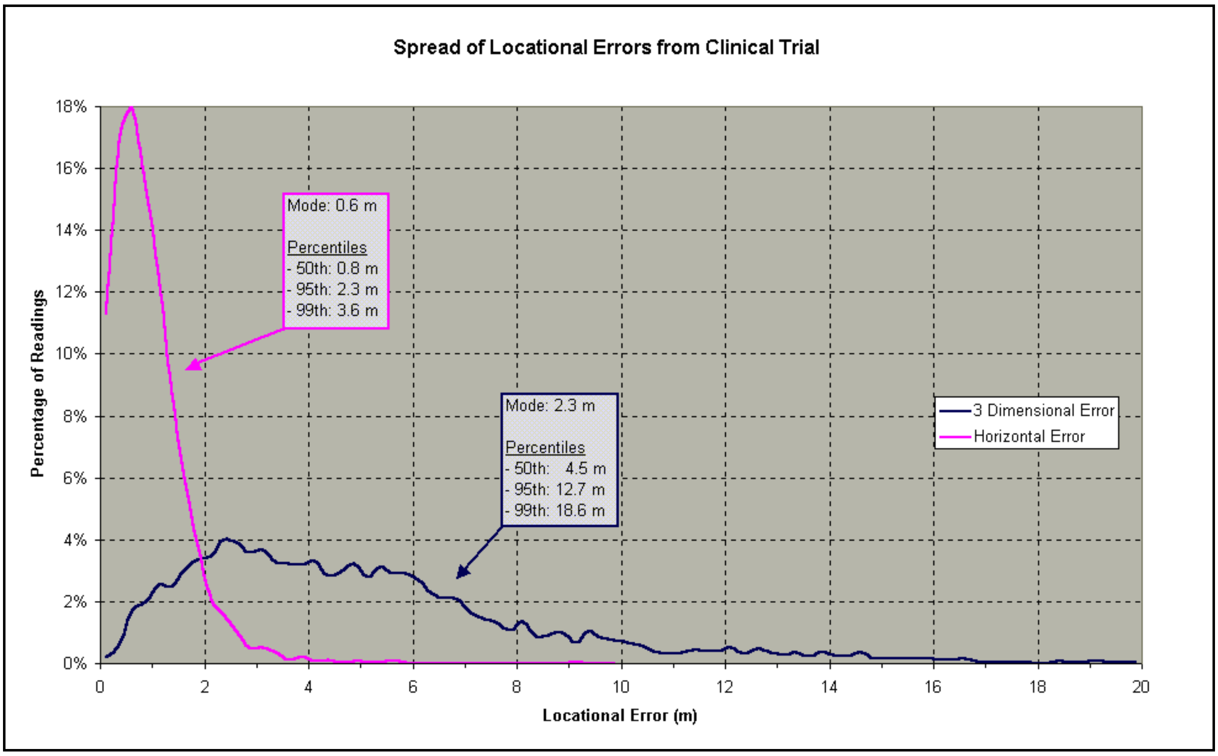

Figure 4. Typical Locational Error from GPS without SA

[6] The 'virtual gantry' refers to the simulation of a physical gantry (ie. the over-road infrastructure and vehicle tagging technology) via a combination of GPS data and computer software. In this case, it meant storing the spatial location of the virtual gantry in the IVU and recording an event when the vehicle went 'under' that gantry.

This excellent horizontal accuracy will be capitalised on in the real-life trial, as the monitoring and reporting tools will predominantly be based on "flat" (horizontal plane only) map products – allowing the matter of vertical accuracy to be largely ignored.

The Clinical Trial also successfully identified an indicator (or predictor) of the potential range of error associated with a GPS positional 'fix'.

The mathematics associated with computing a position solution from Navstar satellite signals allows for the derivation of a set of "Dilution of Precision" (DOP) values. These values provide a measure of the error contributed by the geometric relationship of the satellites whose signals are used in computing the position solution (NAVSTAR GPS Joint Program Office 1996) – the lower the value, the lower the contributed error. Figure 5 illustrates this geometric relationship by reducing it to a two dimensions[7].

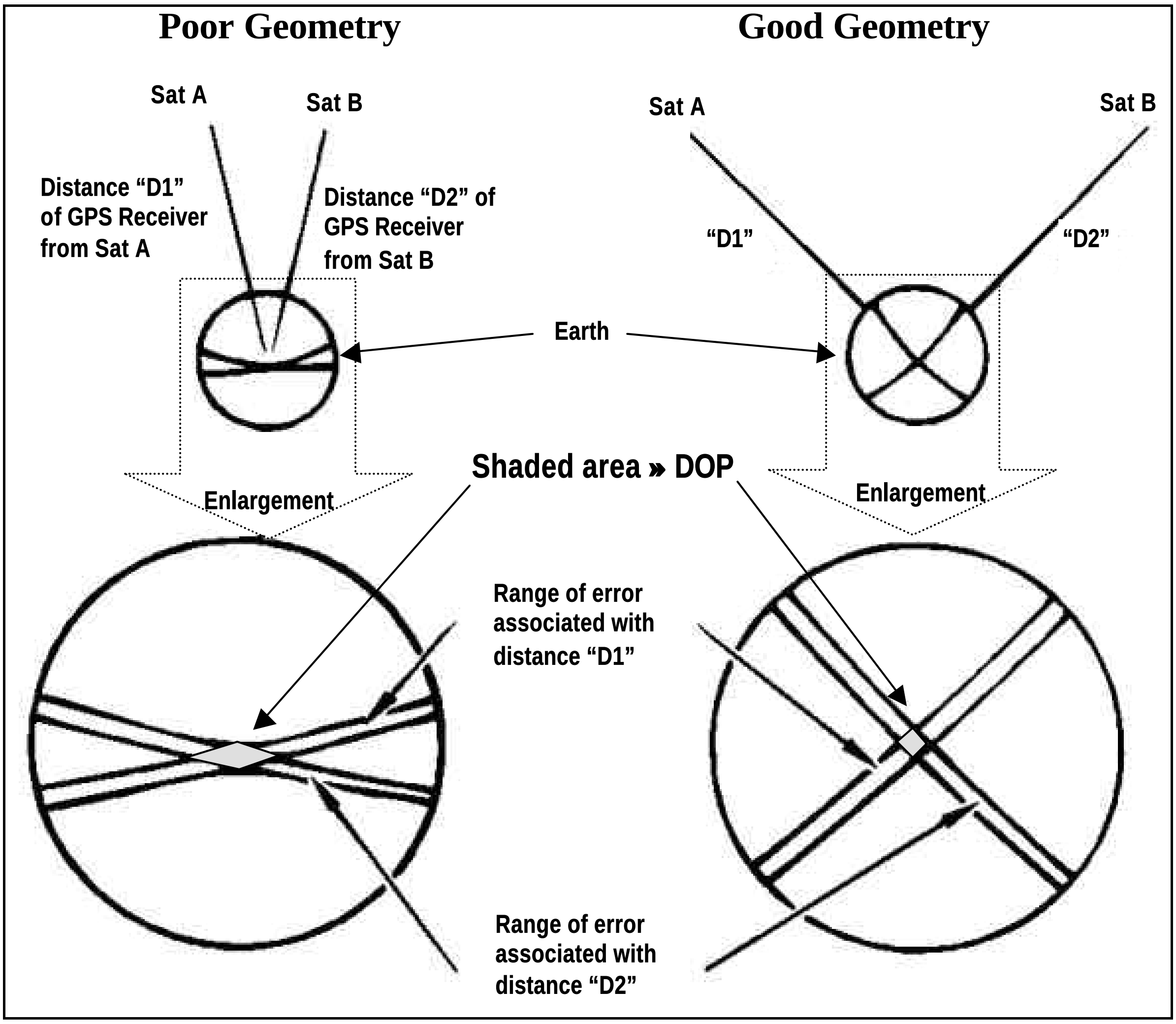

Figure 5. Depiction of good & poor DOP

[7] For GPS this geometric relationship exists in 4 dimensions – three dimensional space and time.

Assuming that only two lines of position are necessary to establish a user location, the least amount of error is present when the lines cross at right angles. The greatest error is present as the lines approach parallel. Similarly, for GPS, the greatest amount of error is present when the lines-of-sight between the user (ie. the GPS receiver) and two or more satellites approach parallel, or when all four satellites approach the same plane.

Of the set of DOP values that can be derived, Position DOP (PDOP) represents this error in three dimensions whilst Horizontal DOP (HDOP) represents this error in the horizontal plan.

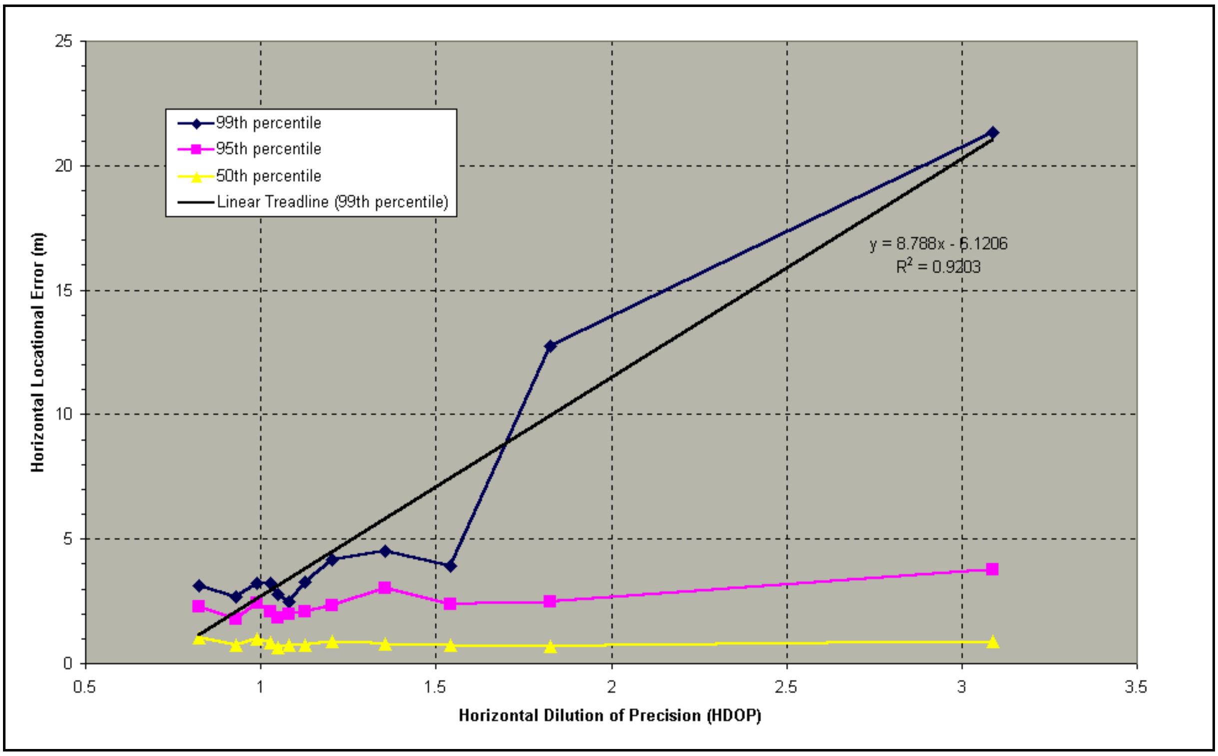

Figure 6. Horizontal Locational Error Percentiles by HDOP

Analysis of the data collected during the Clinical Trial indicates that HDOP is a statistically valid indicator of the amount of error associated with a positional fix at the 99th percentile – see Figure 6. The 50th, 95th and 99th percentiles where used in this analysis because of their prominence in GPS literature.

This predictor of GPS-related error will be put to good use in the real-life trial to ensure the potential error of a locational fix is taken into account before non-conformance events are logged and alarms raised.

GPS receivers have two means available to them for determining speed:

- The first is simply to divide the distance covered between two positional fixes by the time taken. Historically, SA has made this method notoriously unreliable – with vehicles having instantaneous negative velocities as SA “wandered” around.

- The second, which many GPS receivers on the market use, is to compute the phase shift in the carrier signals received – ie. Doppler effect. SA, along with atmospheric interference, has much less impact this technique.

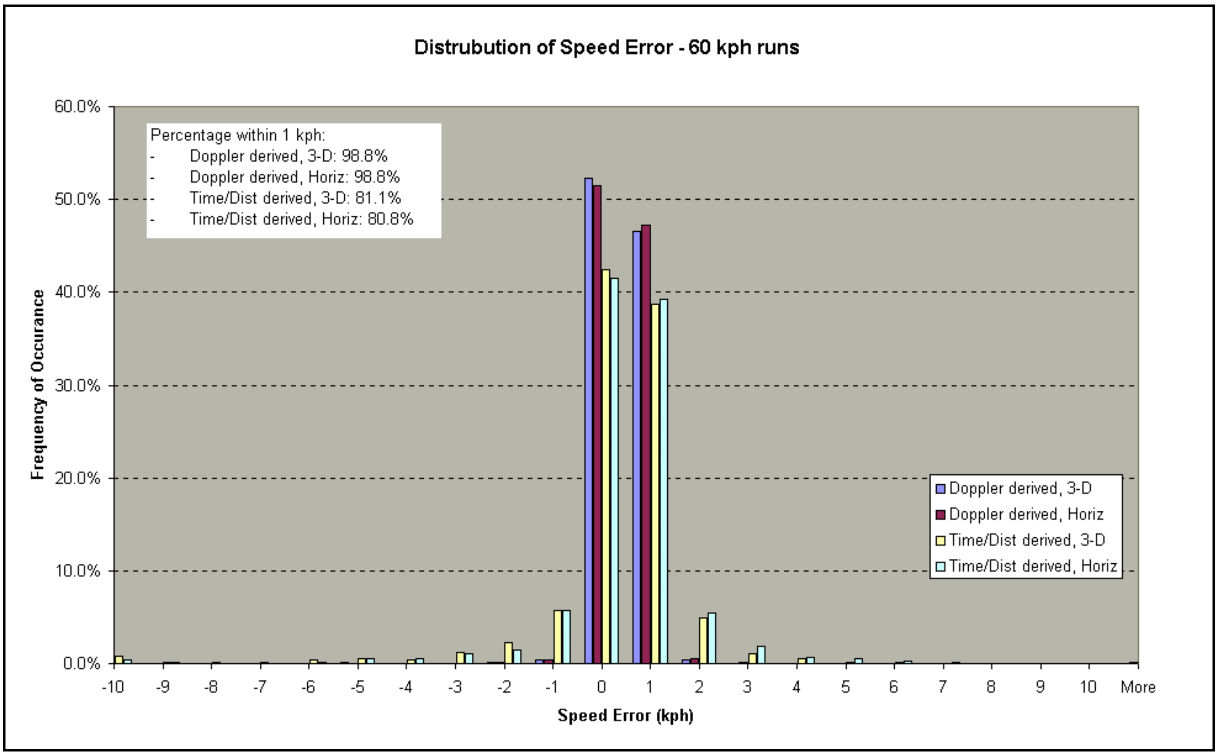

Figure 7. Spread of error associated with GPS-derived speed

The analysis of the speed data from the Clinical Trial indicates that with SA off both methods are very accurate (Figure 7). 98.8% of all Doppler-derived speeds were within 1 kph of the measured ground speed of the instrumented vehicle. This level of accuracy is more than adequate for monitoring FEV speeds.

Anecdotal evidence during the Clinical Trial points to Doppler-derived GPS speed being typically more accurate that a vehicle's speedometer.

Building a tracking system

The process of specifying and implementing a demonstration vehicle-tracking system (see Figure 8 for a screen shot of the base-station component of the system) has provided numerous opportunities for the trade-offs and limitations of such a system to be explored. By way of demonstration, the most interesting of these issues to-date will be discussed here: the impact of trading off accuracy in route and zone definition to meet storage and processing limitations of the IVU.

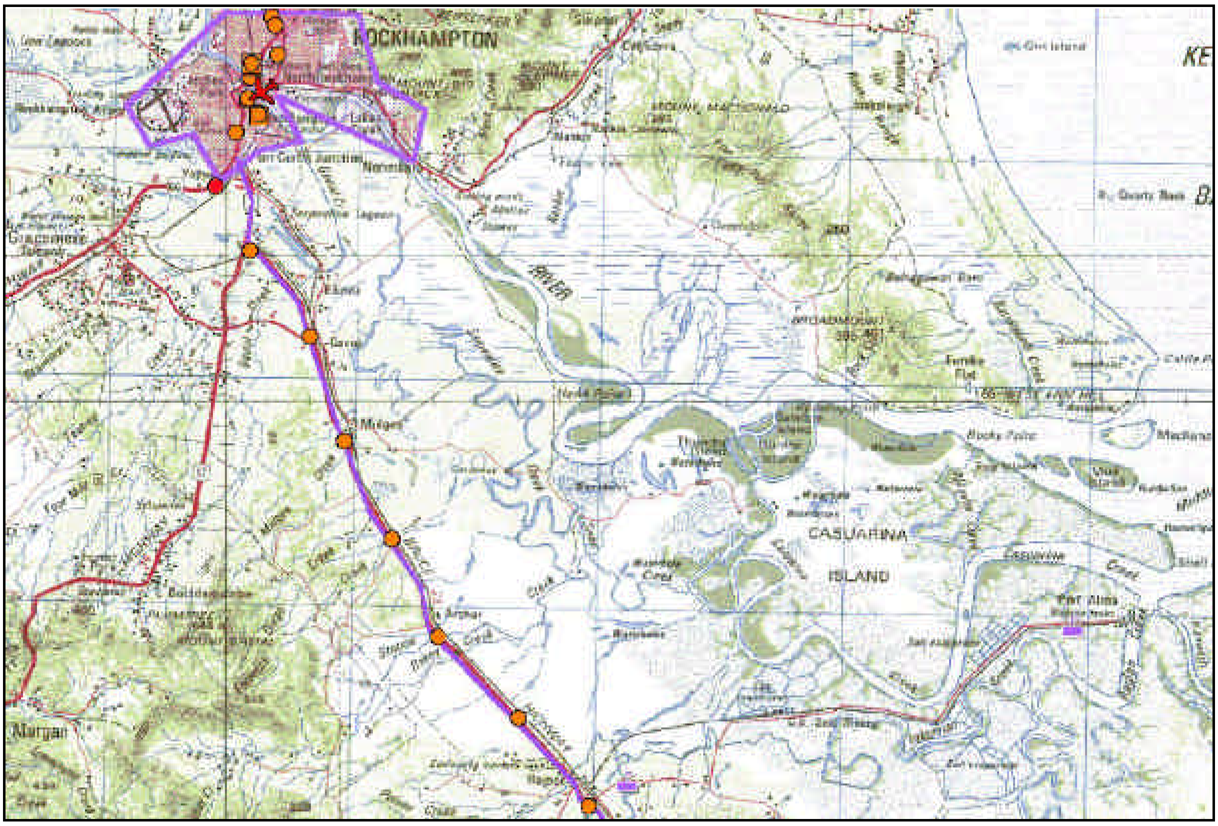

Figure 8. Tracking a FEV in real-life

To meet the second of the basic system design constraints (see Table 1 in this paper), all the data necessary to describe a route or zone had to be stored in the IVU. This means that allowable speeds, times-of-day and seasons had to be stored in the IVU along with a geographic representation of the routes and zones the FEV in question is permitted to use. As the 'test-bed' truck was operating along the Bruce Highway between Brisbane and Rockhampton, a geographical description of this route was extracted from a commercially available data-set of Queensland roads[8] (basic system design constraint #4). On removing the urban areas from this sub-set[9], it was found that the Brisbane-Rockhampton route could be described with a total 2,430 points. At this point density, it would only take several routes to 'fill up' an IVU.

To reduce this point density, a filter algorithm was developed that selectively dropped points from this data-set based on a pre-defined allowable offset error or tolerance – this is presented diagrammatically in Figure 9. The top section of Table 2 (Cock 2000) presents the number of points to describe the Brisbane-Rockhampton route for a range of tolerances. For example, with a tolerance of 50 m this route can be described in only 480 points – a five-fold reduction.

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8 The data-set was provided by Queensland Department of Main Roads. It is a commercially available product supplied by ERSIS Pty Ltd, based on the Queensland digital cadastral database (DCDB) – which describes all the parcels of land in Queensland.

9 This does simplify the analysis and is an acceptable reduction of the problem as the Government agencies involved are mainly interested in the inter-urban transport task.

Table 2. Comparing Compressed Route and GPS Data

Tolerance	0m	50m	100m	200m	300m	400m	500m	1000m
No. of Points	2430	480	318	201	146	146	95	55
Distance (kms)	580	578	573	568	565	565	556	547
GPS Positions	1087	1087	1087	1087	1087	1087	1087	1087
0m	1087	1087	1087	1087	1087	1087	1087	1087
50m	84	106	368	686	898	876	941	978
100m	7	9	30	315	583	711	768	897
200m	2	2	3	17	218	406	523	775
300m	0	0	1	2	12	177	306	634
400m	0	0	0	0	0	4	158	528
500m	0	0	0	0	0	0	12	413
1000m	0	0	0	0	0	0	5	4

The data actually collected by the IVU for this Brisbane-Rockhampton route were then compared to each of these less accurate route definitions to see how well they aligned – see the bottom section of Table 2. So for the route definition with 50 m tolerance, of the 1087 points recorded by the IVU 106 of them were more than 50 m away, with none more than 300 m away.

Thus with a described route that is accurate to within 50 m of the original and takes one fifth the space to store in an IVU, a corridor 300 m either side of the actual route can be monitored with confidence[10] – all with an imperfect definition of the original route[11].

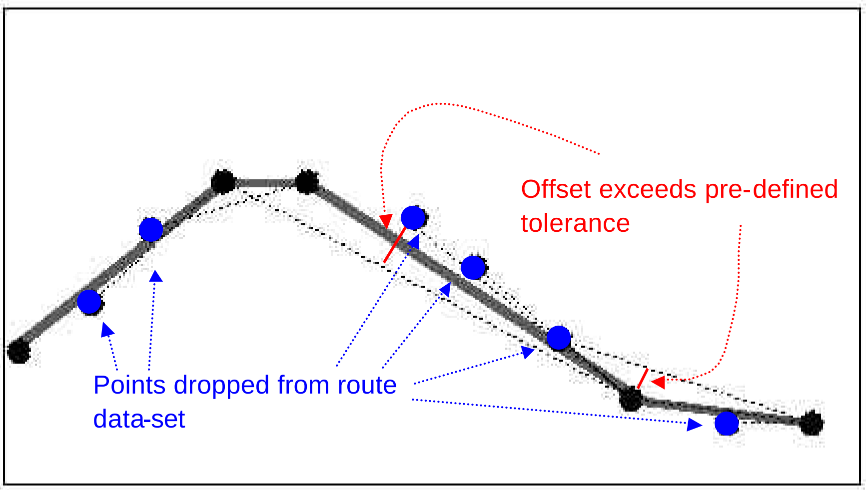

Figure 9. Diagrammatic representation of the route-filtering algorithm

10 In fact, 600 m (2 x 300) is the maximum width of the corridor being monitored – it can be less depending on the geometry of the road.

11 The DCDB from which the route description was drawn is publicly acknowledged to contain error – up to some 10's of meters.

Some observations on the work-to-date

The Clinical Trial has demonstrated that the accuracy of GPS-derived information, since the deactivation of SA, is more than adequate for the task of monitoring the operation of FEV's. The ability to use HDOP to predict the amount of error associated with a locational fix will be used to full effect the later phases of the Real-life Trial.

The Real-life Trial is already bringing to light some surprising issues, such as that of 'route compression', discussed earlier. It is interesting to note that the 600 m wide corridor example sits well with current operational constraints on heavier-mass HCV's[12] that are currently limited to within 500 m of national highways.

Where to from here

The next phase of the Real-life Trial is progressing well. Several 'smart' IVU's have been developed that can monitor a FEV's compliance with a set route and/or area – reporting only cases of non-compliance – and it is hoped a mobile satellite communications device[13] will be integrated into one or more of these IVU's to facilitate the use of the demonstration vehicle-tracking system in remoter parts of Queensland.

The final phase of the Real-Life Trial will involve the development and execution of a comprehensive test plan that will fully exercise the demonstration vehicle-tracking system. This will provide data that will allow the sustainability aspect of "the unanswered question" to be explored – covering such issues as:

- Communication frequency and cost; and
- Effort in maintaining route data.

It is expected this final phase of the Real-life Trial will commence in February 2001 and is targeted to finish in the second quarter of 2001.

An area that might warrant further research is the impact more geographically accurate route descriptions would have on the width of corridor that can be monitored. This would be of value to Government agencies sponsoring this research.

Acknowledgements

The assistance of several organisations should be acknowledged, without whose support the bulk of this research would not have been possible:

- The Commonwealth Department of Transport and Regional Services, for its financial contribution to these trials;

[12] The recent national Mass Limits Review has lead to the legal mass of semi-trailers increasing from 42.5 to 45.5 tonnes provided 'road-friendly' suspension is used. In Queensland, this class of HCV is currently limited to within 500 m of national highways.

[13] Such as a GlobalStar handset from Vodafone Australia.

- The Queensland Departments of Main Roads and Transport, whose assistance guiding, underwriting and securing industry involvement in the trials was greatly valued; and
- Finally, the academic staff of the Queensland University of Technology, whose underlying guidance helped shape and focus this research.

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