IMPROVED LOCATIONAL ACCURACY OF SCRIM DATA USING GPS

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ABSTRACT

It is the usual practice to define locations along a road in terms of displacement from a reference station. With modern odometers accuracies on straight sections of better than1m\km are achievable. However, the factor that limits the accuracy of linear referencing is not the measurement systems but the drive line of the survey vehicle. As the survey route becomes more torturous with frequent curves and steep gradients, the accuracy can easily reduce to 4 or 5m per kilometre giving accumulated errors of around 50m on long sections. Linear referencing has tried to overcome this problem by stretching or shrinking the surveyed length of a section to equal the actual length. Unfortunately, this procedure can only assume the distance error is uniformly distributed along the section length when in practice it will be concentrated only along the winding and hilly part of the section. In short, the achievable accuracy of linear referencing on long sections could easily result in errors of up to 50m in the placement of survey data and when surveys from different directions are compared side by side the transverse pairing of measurements could be up 100m in error.

The development of Geographical Information Systems (GIS) has offered the opportunity for more accurate spatial referencing and this approach has been used together with GPS to present the measurements. However, software used to analyse the measurements and manage the data to produce maintenance treatment options associated with asset management plans, relies on linear referencing. Changes to this software would require a major investment. This paper shows how the accuracy of GPS referencing can be transferred to linear referencing thus gaining the benefits of GPS while maintaining the use of existing software systems. The paper describes the application of the approach in New Zealand and reports from 3 years of survey data:

- the accuracy that can be expected,
- the benefits that result,
- and the lessons learned to date.

BACKGROUND

Skid resistance is routinely measured from regular surveys of whole networks. It is normally recorded at 10m intervals during these surveys. The measured results are then compared with skid standards, which vary along the network and reflect the risk of occurrence of a skid accident. The highest risk sites are often as short as 50m. There is, therefore, a need for accurate referencing of the measurements to ensure they are compared with the appropriate skid standard, often referred to as investigatory level.

Historically, network referencing has been based on splitting the network into sections defined by their start and end positions and the length of the section. The survey data is ‘fitted’ to the section length by making the surveyed length equal the reference length. This approach on long sections can result in significant errors, not due to the measuring equipment recording elapse distance but due to the drive line taken on sections containing curves and steep gradients. This can lead to significant errors in the location of 10m averages along a section and even larger errors when surveys from the two directions of a two lane single carriageway are compared. Software used to analyse and manage skid resistance and other measurements of highway condition are based on this linear referencing concept. The associated database tables are constrained to the linear length of each section with a prescribed number of data cells required to 'fill' the table, or section.

The development of GPS and GIS has provided the opportunity to overcome the limitations of linear referencing to locate position by referencing the location of every condition measurement and then to present the measurements against map backgrounds. However, the software for analysis and management of the data has not developed to accommodate these new techniques and since the software is comprehensive, significant changes to its architecture will be expensive and would represent a significant investment by either a highway authority or a software supplier.

This paper describes how the benefits now available with accurate referencing using differential global position systems, DGPS, can be used to produce an improved method of location along a linear-based referencing system. The traditional view has been that the choice for highway information has been either the use of linear referencing, or the use of spatial referencing. The approach described provides the benefits of BOTH by forcing the linear referencing system to inherit the greater accuracy of GPS while maintaining the link linear referencing systems have with existing analysis and management software systems.

LINEAR REFERENCING

Conventional linear referencing divides the highway network into a series of sections. Each section is allocated a unique name and a section normally describes a uniform length of the network such as between two junctions. The length of each section can vary, from 20 – 50m at their shortest in urban areas, up to 15 – 20km at their longest in rural areas. The start and end of each section is often defined by start and end nodes, although this is not an essential requirement. Machines measure the conditions along a series of these sections where they are continuous. The survey machines are fitted with accurate distance measuring devices, which typically produce accuracies of ±0.03% or better (±3m per km). Furthermore, survey data is normally reported as 10m long averages. Thus, section start and ends each have at least a ±10m error. The section start and end locations are 'inserted' into the stream of condition data by a survey operator manually from a survey vehicle travelling at normal road speeds; the actual accuracy is therefore likely to be greater than ±10m.

When collected data is 'fitted' to a network, the section length recorded by the survey vehicle is compared to the length held by the highway authority in its network database. If the length measured by the survey is typically within 10m ± 0.03% of the section length, the survey data is accepted and is stretched or contracted to fit the database length. Errors at the start and end of each section will be equal to the accuracy with which the survey operator has inserted the start/end event into the data stream, because with any stretching or shrinking process the start and ends are fitted exactly at the point where the event occurs. Throughout the section other variable errors will then be incorporated. Inaccuracy in the distance measuring system will occur and these should be reasonably uniform throughout the section length. Other errors resulting from differences in the actual drive line taken will also occur but these are unlikely to be uniform along the section and will be concentrated into areas where different drive lines are most likely to be selected. The stretching or shrinking process will be effective in reducing the errors that are reasonable uniform along a section but less effective in addressing the non-uniform errors because the correction will be spread across the whole section length rather than only along the lengths where they occur.

In practice therefore, with linear referencing, differences in the measurement of the distance travelled along a section recorded by separate survey vehicles will occur throughout the section. Where a section contains curves, errors will be concentrated as a driver cuts corners or takes a wide drive line. Thus the overall accuracy of the length of a section may satisfy a tolerance of say 10m ± 0.03% of the section length, but that tolerance could be exceeded along particular parts of the section where the variable errors are concentrated.

Limitations of Linear Referencing

Despite considerable efforts by clients and survey operators to improve the accuracy of linear referencing systems they have reached the limits of accuracy that can realistically be achieved. The accuracy of linear referencing systems relies on three fundamental assumptions:

- That the physical marking of section start and end points will remain constant on the road;
- That distance measuring systems fitted to survey vehicles contain small and highly controlled inherent errors;
- That it is possible to follow a consistent driveline across multiple surveys.

In practice the start and end locations of the start and end of sections can vary after every surface maintenance treatment, depending on where the highway superintendent, or similar person, decides to re-mark the road. If minor engineering work is carried out on, for example, a junction this can also result in changes in the position of the start/end of a section if the side road centreline is moved.

The measuring devices fitted to survey vehicles are calibrated against known distances. The calibration will include some fixed inaccuracy but generally this will be small and generally less than ± 1m per kilometre. However, after calibration during normal survey work other errors will be introduced from changes in the rolling radius of the vehicle wheels including:

- Tyre wear;
- Change in vehicle weight from that used in calibration;
- Change in tyre pressure;
- Changing weight distribution as survey vehicles traverse through curves.

Linear referencing is not therefore an absolute referencing system, which it has often been thought to represent. It is simply a relative referencing system defining the location of points along the survey that are unique to a given survey pass.

The accuracy of linear referencing will always be a balance between the cost of maintaining high levels of accuracy and the consequences of accepting lower levels of accuracy.

The accuracy of the referencing can be increased by keeping section lengths short and making network referencing a high focus performance issue for highway authorities, but this would be prohibitively expensive and a balance is required on length of sections and ensuring the associated start/end points are accurately maintained.

The accuracy of the survey process can be improved by frequent re-calibration of the on-board distance measuring systems For network wide surveys this again would be very expensive, either requiring the highway authority to establish and maintain a large number of accurately measured distance calibration sites throughout their network, or, survey costs increasing significantly as survey vehicles incur non-productive time travelling back and forth to widely spaced calibration sites.

The implications for referencing measurements of skid resistance

Skid resistance measurements can change rapidly as areas of high stress such as curves are approached and negotiated. Providing the site category is defined by the operator during the survey, or other measurements from the same survey such as horizontal curvature, the measurements of skid resistance and the appropriate site category remain aligned in the data set. This means that sites where there is a deficiency in skid resistance will be identified correctly. However, it also means that the deficiency will appear at different linear distances along the section with each survey. The consequence of this need to define site category and measure skid resistance at the same time are that:

- site categories cannot be 'fixed' or defined and maintained separately from a survey, and thus start and end points of, for example a curve can vary for each survey;

- that trends in skid resistance cannot be established accurately by plotting survey results year on year against each other.

In summary, despite the limitations of linear referencing, providing the site category is recorded at the same time as measurement of skid resistance, the limitations do NOT result in errors in identifying locations deficient in skid resistance. However, the limitations do result in the location being defined at different positions along the section with each survey and more importantly do mean that different points along a section can be allocated a different site category with each survey making maintenance management much more difficult.

THE USE OF GPS REFERENCING

The introduction of differential GPS, DGPS, through commercial satellites has significantly improved the accuracy with which survey vehicles travelling at up to 100km/hr can record their location. Differential GPS is an enhancement to GPS that uses a network of fixed, ground based reference stations to broadcast the difference between the positions indicated by the satellite systems and the known fixed positions. Using the latest systems and recording satellite output at 100Htz, the accuracy of 10m boundaries of elapsed distance can be defined to coordinate accuracies of about ±1m. The significant benefit of DGPS based referencing of highway data is that it provides an absolute referencing system; changes to the exact start/end marks of a section marked on a road are no longer relevant and errors in distance measurement on the survey vehicle, and even more importantly the exact drive line around curves is no longer relevant to the special positioning of measurements from survey to survey.

The levels of accuracy offered by DGPS have allowed new methods to be considered for referencing measurements of skid resistance as well as other measurements of the condition of the network. NZTA carries out annual surveys of skid resistance and other assessments of surface condition on the whole of their state highway network. The total annual survey length is about 22,000 lane km. The network is broken down into unique road sections that are up to 15km length.

Definition of the GPS Network

In order to introduce the use of GPS for referencing, the 2007/08 network survey was used to define the reference networks for future GPS based referenced networks. 85% of locations for section start and end points were available from previous static GPS surveys. Another 10% could be defined from aerial photographs and the remainder were physically surveyed or estimated from averaging successive track logs. As a final audit, a check was done to ensure that the track log from previous skid surveys passed over the start and end points. The start/end location was defined as the carriageway centre-line for single carriageway roads and in the central median for dual carriageways.

When an accepted accuracy for all the section start and end points had been established, it was necessary to ensure connectivity between the sections. Even small differences recorded between the end of one section and the start of another needed to be resolved. This process was essential so that network survey routes which typically cover 3 – 8 sections could be set-up automatically by selecting only the first and last sections manually.

Definition of the Baseline GPS Network

During surveys, the DGPS is received at 100Htz or, at 80km/hr, every 0.22m of elapsed distance. These co-ordinates are recorded and compared with the reference measure until the closest co-ordinates were obtained. This defined the lane centre section start. Section starts were defined for every lane surveyed. These section start co-ordinates for every lane will be used in future surveys.

Once the section starts and ends for every surveyed lane were established, the recorded elapsed distance was compared with the reference length held in New Zealand Transport Agency, NZTA's, Road Asset Maintenance Management (RAMM) system. Providing the recorded elapsed distance from the survey was within 0.2% ± 10m, the reference length section data was accepted. (Note the networks reference lengths have been progressively improved over the past 8 years from SCRIM and high-speed surveys and few, if any, survey lengths fail this check unless there has been a real network change resulting, for example, from a re-alignment of part of a section). The recorded section length was then stretched or shrunk to equal the length in RAMM and then split into the exact number of 10m lengths expected from the database length, together with the short final length which had a length of between 1 and 9m. The co-ordinates for every 10m boundary were then extracted from the DGPS and stored as the 10m co-ordinates for subsequent years' survey data.

The majority of the State Highway network in New Zealand is two lane single carriageway that is surveyed in both directions each year. The above procedure was applied to the increasing direction. For the decreasing direction, the shorter last section from the increasing direction was applied at the start when co-ordinate boundaries were being fixed so that 'paired' datasets would be recorded across the road when the decreasing direction data was reversed.

In future surveys, the start and end lane centreline co-ordinates will be used to split the data into sections. The section length test will be applied and if within tolerance, the data within the section will be sub-divided into the '10m' length by the 2007/08 reference co-ordinates. In this way, the data from the same '10m' lengths will always be from the same location each year. The DGPS co-ordinates used to define the '10m' boundaries is currently expected to be within ±1m; thus each year a '10m' data set can contain between 8m and 12m of data. Despite this variation, it is considered this represents a significant improvement to comparing measurements based on linear referencing that might be from locations 40m or 50m apart year-on-year and, within year 40m or 50m apart across a two lane single carriageway, resulting from separate surveys on each lane.

This form of referencing using co-ordinates to define the limits of '10m' condition data has been defined as Data Set Boundaries, or, DSB referencing.

Alignment across the Carriageway

After the 2007/08 survey it was discovered that the above DSB referencing method did not align the 10m GPS co-ordinates across the road for single carriageway roads. It will produce consistent results year on year for the increasing and decreasing directions, but the data will not necessarily be aligned across the carriageway. Because the errors in the linear referencing measurement used to define the baseline are not always consistent for both directions, it was found there could be a 50m difference between the co-ordinates. It was therefore agreed to use the same baseline for both directions of a single carriageway road so that the data would align across the carriageway. For both survey directions, the GPS co-ordinates were taken at the end of each 10m segment. The decreasing direction data is reversed during processing to align with the increasing direction, so this would have caused a 10m difference between the directions. In order to align the 2 directions for every 10m segment, the increasing direction GPS co-ordinates are taken at the start of each 10m section. The data for decreasing direction are taken at the end of the 10m section, so that when the data is reversed it lines up with the increasing direction.

Before the 2008/09 survey, new baselines were created for all single carriageway sections using the same data for both directions. The increasing direction was used as the baseline, except where there were issues with the increasing direction GPS coverage from the 2007/08 survey and the decreasing direction appeared to be more accurate.

RESULTS OBTAINED

Year on Year Comparison

The co-ordinates for individual 10m segments have been compared for the last 3 years of surveys processed using the DSB referencing. The current 2010/11 survey is still being undertaken and so has not been used in the analysis. In order to have 3 sets of data to compare, only the increasing direction has been used, because the baselines aligned across the carriageway were mostly created from the 2007/08 increasing surveys.

The 10m co-ordinates from the 2008/09 and 2009/10 surveys were compared to those from the 2007/08 baseline survey for several of NZTA's Network Management Areas (NMA). Any sections where new baselines were created during the analysis period due to reconstruction or realignments were removed from the analysis. Because the co-ordinates for both directions of the 2007/08 survey were taken at the end of each 10m segment, not at the start of the segment for the increasing and end of the segment for decreasing direction, the 2007/08 data has been shifted by 10m to match up with the co-ordinates from the 2008/09 and 2009/10 surveys.

The percentage of 10m segment co-ordinates from 2008/09 and 2009/10 with differences compared to the 2007/08 baseline survey greater than 2.5m is shown in Table 1. About 97-99% of all 10m segments have co-ordinates within 2.5 m of the baseline survey. The results in the Table are based on the combined error of eastings and northings.

Table 1: Percentage of 10m segments where difference between co-ordinates is greater than 2.5m

NZTA NMA	Year 2 2008/09 > 2.5m	Year 3 2009/10 > 2.5m	Survey Length/km
Napier	4.5%	1.8%	370.15
Gisborne	3.9%	2.2%	153.64
Central Waikato	3.7%	4.1%	451.44
West Wanganui	2.6%	2.0%	546.58
Rotorua	3.1%	2.7%	164.56
South Canterbury	1.6%	0.9%	542.92
Central Otago	2.4%	0.5%	503.31
Overall	**2.9%**	**1.9%**	**2732.60**

Figure 1 shows a sample plot of the GPS for one Reference Station section in Rotorua for the 3 years used in the analysis processed using DSB referencing. Figure 2 shows the same RS, between RP 5.0 and 5.3, so that the individual GPS co-ordinates for each 10m segment can be seen.

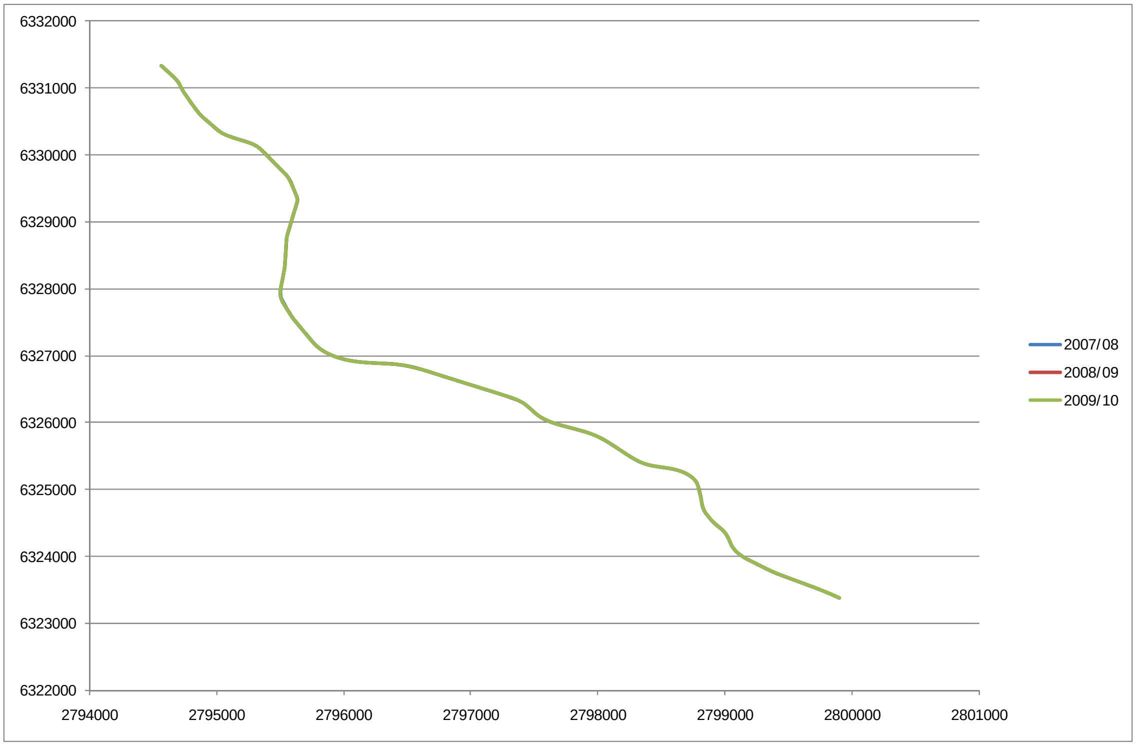

Figure 1: Sample GPS plot SH5 RS56 Rotorua

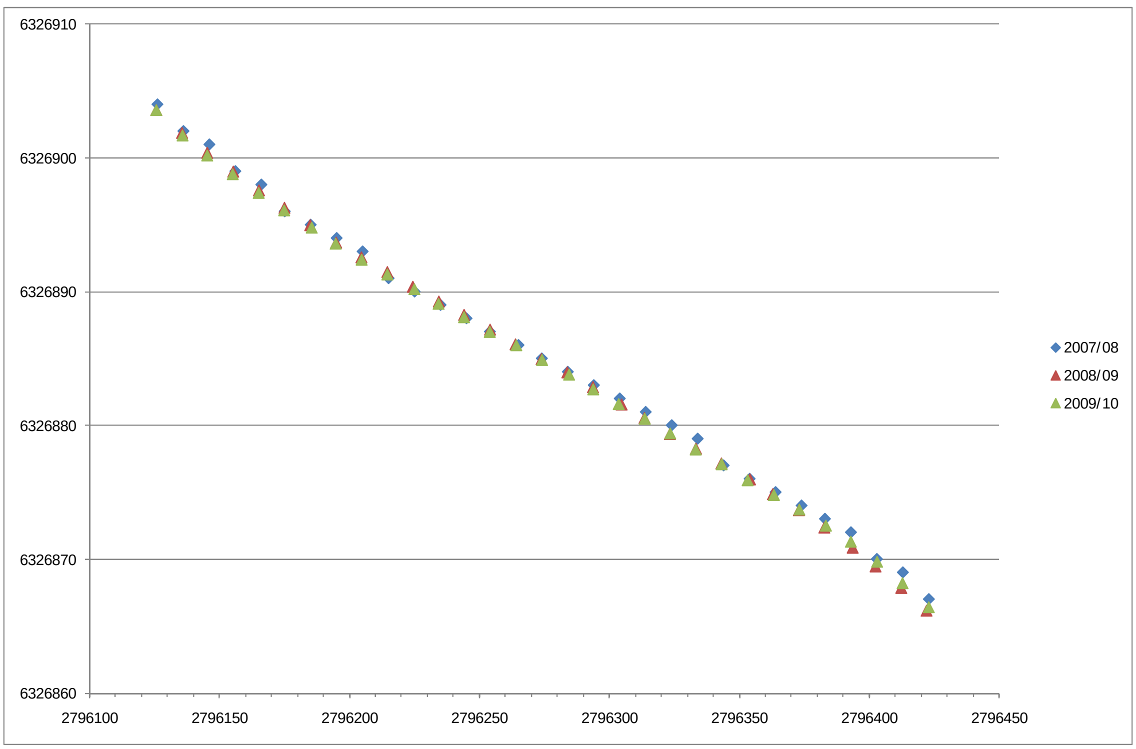

Figure 2: Sample GPS plot SH5 RS56, RP 5.0 to 5.3, DSB Referencing

Figure 3 shows an image from Google Earth providing a birds eye view of the GPS coordinates positioned exactly on the SH 2 in the Wairarapa.

Figure 3: Google Earth View of GPS, Positioned on SH 2

To further demonstrate the improvement the DSB processing has over linear referencing, surveys from 2 years on one RS section have been processed using linear referencing and DSB referencing. Data from the 100km trial validation surveys have been used for SH53 RS 0, in Wellington. Figure 4 shows the gradient data for this section, for 2.5 km between RP 10.0 and 12.5, processed using linear referencing. It can be seen there is a 30m offset between the 2008/09 survey and the subsequent survey. The gradient data has been plotted because the geometry data is unlikely to change between surveys, so the offset between surveys is easier to see. However the same offset would be present in the other road condition measures. Figure 5 shows the same 3 surveys processed using DSB referencing, over the same 2.5 km. The 30m offset between the surveys has been removed using the DSB referencing based on 10m condition measurement segments.

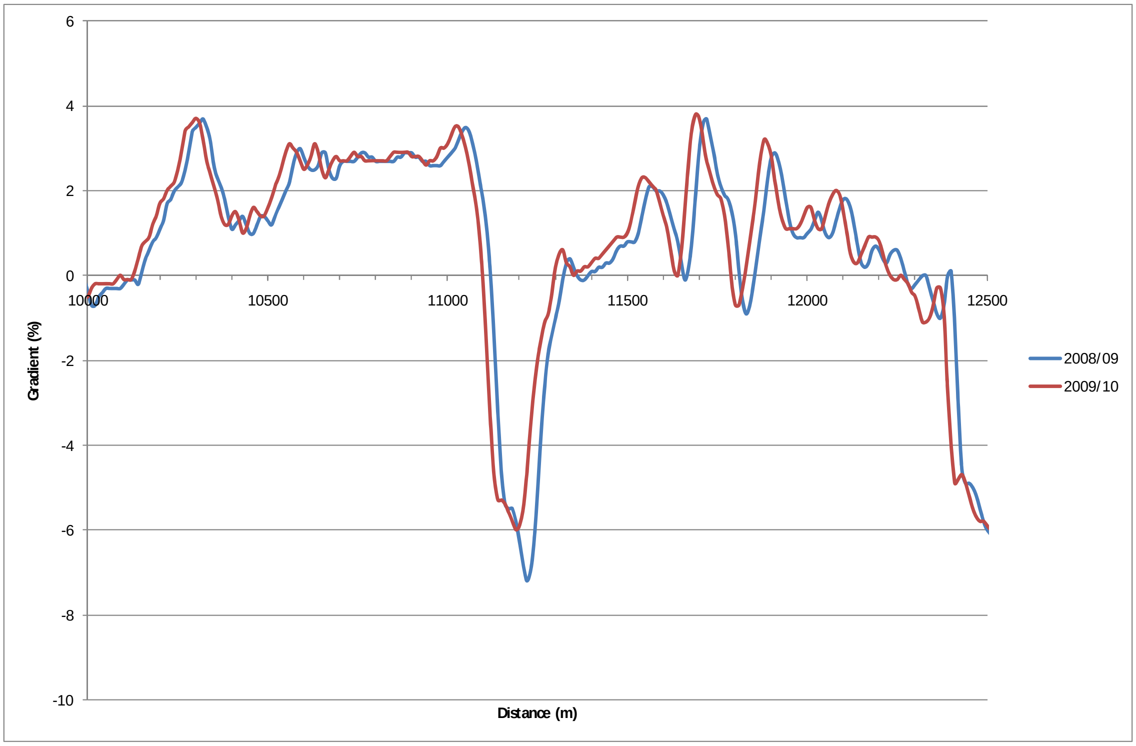

Figure 4: SH53 RS0, RP 10.0 to 12.5, Linear Referencing

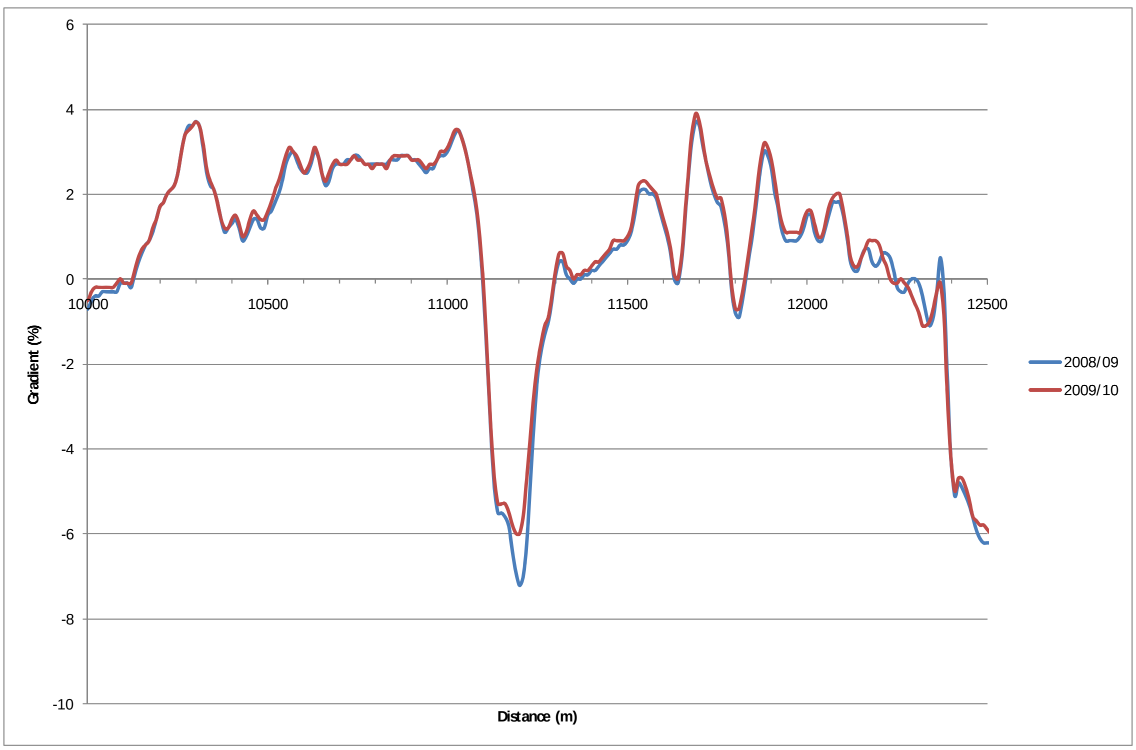

Figure 5: SH53 RS0, RP 10.0 to 12.5, DSB GPS Referencing

The SCRIM left wheel path data for the same RS section, SH 53 RS0, has also been processed using liner and DSB referencing and plotted in Figures 6 and 7 for 2 surveys. The 30m offset between the 2 surveys can be seen in the linear processing plot, but again it has been removed using the DSB referencing.

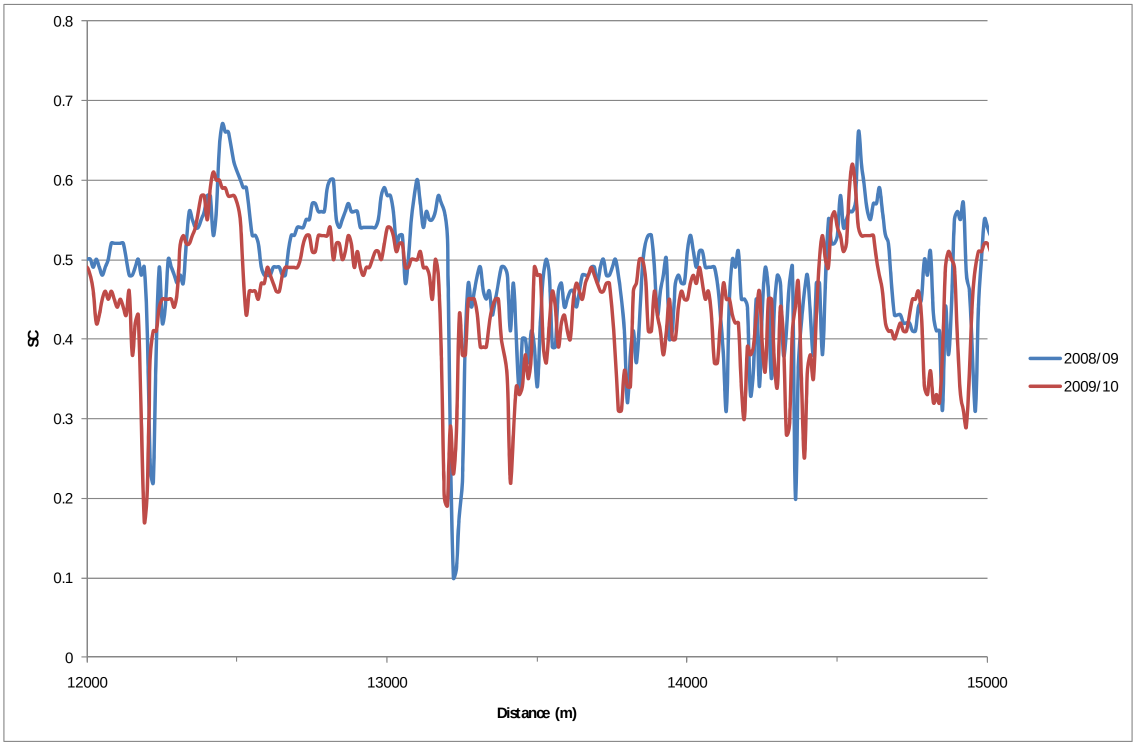

Figure 6: SH53 RS0, RP 12.0 to 15.0, Linear Referencing LWP SCRIM

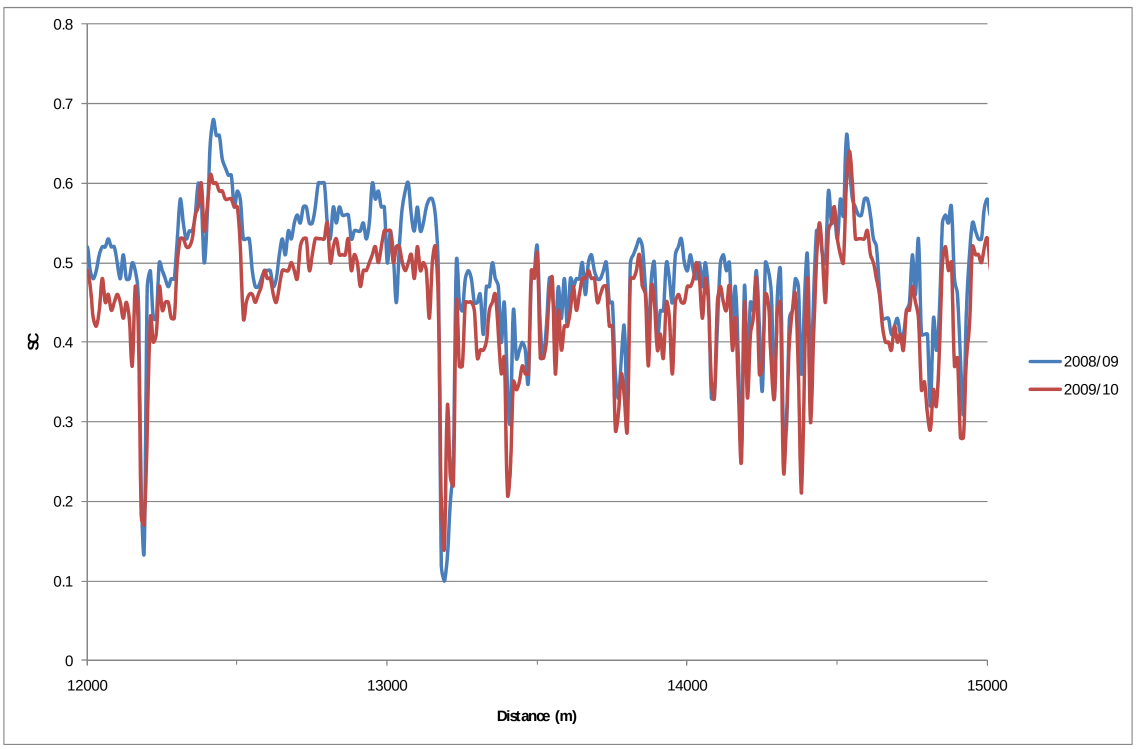

Figure 7: SH53 RS0, RP 12.0 to 15.0, DSB Referencing LWP SCRIM

Alignment across the Carriageway

As well as producing consistent locational data year on year, the other benefit of DSB referencing is that it also aligns the data across the carriageway for single carriageway sections.

Figure 8 shows a sample GPS plot from increasing and decreasing directions for SH35 RS 327 in Gisborne, from RP 7.0 to 7.3. It can be seen that the co-ordinates line up across the carriageway for both directions.

Figures 9 and 10 show the 2 direction data from SH53 RS 0 in Wellington, processed using linear referencing and using DSB referencing. Over this 3.5 km length between RP 13.5 and 16.0 there is a 50m offset between the 2 directions with the linear referencing. Again this offset is removed using the DSB method.

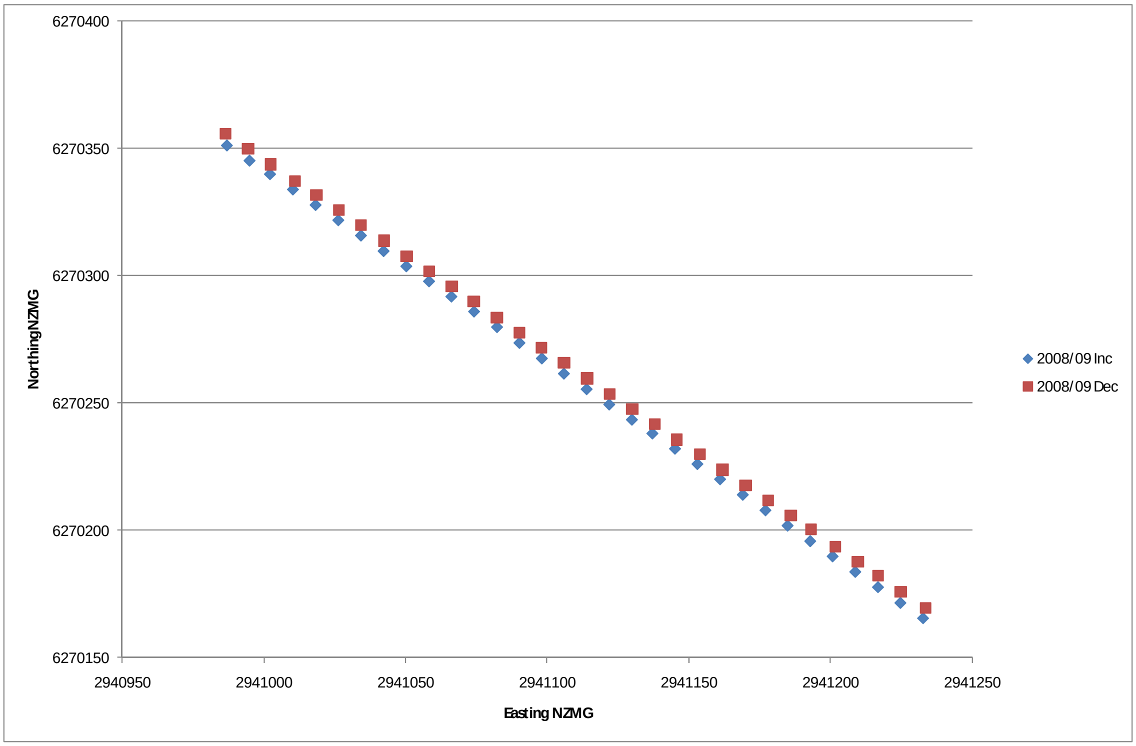

Figure 8: GPS plot SH35 RS327, RP 7.0 to 7.3, DSB Referencing

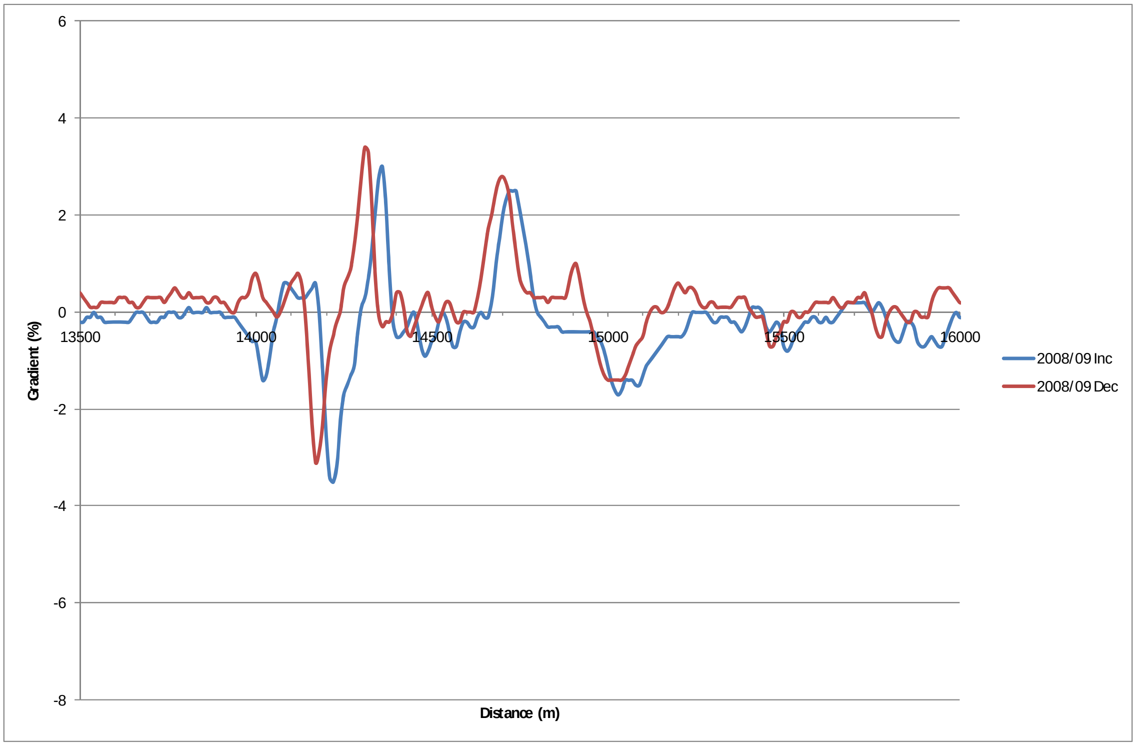

Figure 9: SH53 RS0, RP13.5 to 16.0, Linear Referencing

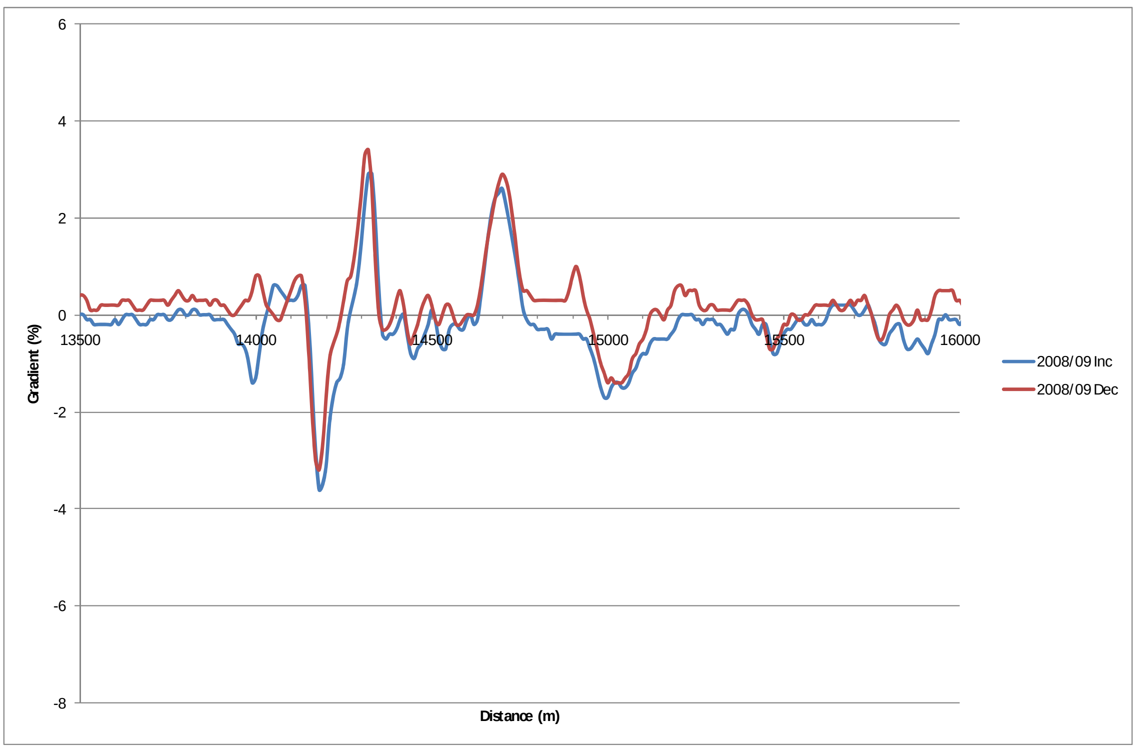

Figure 10: SH53 RS0, RP13.5 to 16.0, DSB Referencing

LIMITATIONS

The fundamental problem with linear referencing is that condition measurements can have an offset of 30-40m between surveys. With the new DSB processing this no longer occurs. Network engineers can now have confidence that they are comparing the same 10 or 20m lengths between years when it comes to deciding on treatments. By implementing a link between spatial location and linear address over short lengths, down to 10m, there is now a verifiable comparison across years. There is also the major benefit in being able to compare left and right lanes across the carriageway. In the past measures across the road could apparently refer to different locations measured by linear distance from the start, and now they do not.

The system has been implemented on the vast majority of the network but issues remain over areas where GPS is not available for long periods. Much of New Zealand's topography is tortuous and as a result sections of the state highway network are not covered by GPS, because the GPS satellites cannot be seen. Examples include narrow ravines and parts of the network where the vegetation obscures the amount of clear sky visible. Where this is the case it is necessary to continue to use linear referencing. Currently only around 300km of the NZTA network is processed using linear referencing because the GPS and an onboard inertial platform allows coordinates to be estimated when satellite cover is lost over short lengths.

The DSB system has been used for all of the mainline carriageway sections, including multi lane sections on the Auckland and Wellington motorways, but has not yet been implemented on the Ramp sections. The Ramps tend to be short lengths of typically 200 to 300m and so will not have the problems using linear referencing. The Ramps also tend to be tested with lots of ramps in a single survey and there were concerns that when the survey vehicle passes the same point more than once during a survey it could cause problems with the GPS processing. A trial is being undertaken in Wellington during the 2010/11 survey, using the year 1 processing method, where the start and end GPS co-ordinates are used to accurately define the start and end location of the ramp, but the 10m baseline GPS co-ordinates are not stored away for future years.

The main issues encountered so far with the DSB processing are where single carriageway sections do not have same vehicle track for increasing and decreasing directions due to roundabouts and other deviations and road alignment changes between survey years. Where there are sections with roundabouts within the section length, some of the processing tolerances between the baseline track and survey track have had to be increased to allow for these differences. Currently where there have been changes to a section due to reconstruction or realignment, a new baseline is applied for the whole section. This loses the historical baseline for the whole section, but is the simplest solution to implement for the relatively few network changes each year.

AUTHOR BIOGRAPHIES

Philip Blagdon

Philip Blagdon has worked for the New Zealand Transport Agency for 12 years, having had roles in both information systems and asset management.

His key interest area is in the application of information systems tools and technology to highway operations, safety and asset management.

James Mitchell

James Mitchell has 13 years experience in highway engineering with W.D.M. Limited, most recently 3 years as a Consultancy Project Manager after 5 years as Survey Project Manager and before that 5 years working as equipment operator developing first hand knowledge of operational processes on highway maintenance management projects.

Since joining W.D.M. Limited, he has been responsible for developing software and procedural documents. He has also been Project Manager for a number of different engineering projects involving high speed data collection. These projects have included surveys on networks operated by NZTA in New Zealand, Department of Energy, Infrastructure and Resources in Tasmania, Highways Agency in England, Transport Scotland and Welsh Assembly, as well as many Local Authorities in the UK.

Chris Kennedy

Chris Kennedy is a Chartered Civil Engineer and a Director of W.D.M. Limited a post he has held since 1985. He is responsible for Survey and Consultancy surveys. This has involved the introduction and development of highway condition surveys which are now operated on a world-wide basis, together with the development of computerised management systems to achieve cost-effective maintenance programmes. His current areas of interest include surface characteristics of roads, particularly skid resistance, and the development of Safety Policies and tools to enhance Asset Management of highway networks as well as developing budget prediction models to define service levels outcomes.

After gaining his Doctorate at Birmingham University he worked for four years at the Transport Research Laboratory where he took a leading role in development the UK Structural Maintenance Evaluation and Overlay Design Method. He then moved to the University of Plymouth, England as Head of Department of Civil Engineering before joining W.D.M. Limited.