A New Method for Referencing Skid Resistance Measurements

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ABSTRACT

The effective use of measurements of skid resistance requires that the measurements are accurately located. Traditionally linear referencing has been used to locate the measurements. The development of accurate GPS systems has offered the opportunity for more accurate referencing and this approach has been used together with GIS systems 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 pilot trials, the improvements in accuracy that can be expected. The paper concludes by describing the benefits that will accrue by implementing the approach and describing briefly the lessons learned from the trials to date.

1.0 INTRODUCTION

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. 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 reference 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 GPS 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.

2.0 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 larger 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 and these are unlikely to be uniform along the section but 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.

2.1 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 rely 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 care 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.

2.1.1 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 accurate 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 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.

3.0 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. 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. An approach is being developed and trialled in New Zealand. Transit New Zealand 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.

3.1 Definition of the GPS Network

In order to introduce the use of dGPS for referencing, it was decided that the 2007/08 network survey would 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% were able to 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 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 reserve 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.

3.2 Definition of the Reference 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 Transit’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, the 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.

4.0 APPLICATION OF THE PROCESS

The major benefit of moving to dGPS referencing is to improve the repeatability with which highway condition data is located onto the highway network. To test that this would be achieved on the network surveys when the full system is operational in 2008/09, two pilot trials have been undertaken around Wellington. These trials replicate the collection of future annual survey results along the trial lengths. The condition data collected have been loaded to databases which are used for the delivery of condition data for loading to Transit's RAMM system. The repeatability of the location of the DSB and conventional linear referencing 10m boundaries have been compared. One trial represented a rural network and one an urban network.

4.1 Trial 1: Rural network

During the 2007/08 survey in New Zealand repeat surveys were undertaken on a section of State Highway 53 near Wellington to evaluate repeatability of the Data Set Boundaries method. Four repeat surveys were collected on a 10km section of State Highway 53 increasing direction, Figure 1.

The GPS co-ordinates for each 10m sub-section were compared from each survey using the linear distance based processing method and then using the new dGPS based DSB processing method.

For the DSB method, the first survey was used as the reference network GPS co-ordinates and for the subsequent surveys the computed 10m coordinates were compared with the reference set.

The distance along the survey route for each 10m coordinate was used as the reference for linear referencing. For each of the repeat surveys the coordinates associated with the same measured distance were compared with the reference co-ordinates to determine the differences.

The results from the four surveys are shown in Tables 1 and 2. Table 1 shows the proportion of the 10m boundaries that are within 2m if the DSB or linear referencing is used. Table 2 shows the average difference between the coordinate positions for each referencing approach; the figures in Table 2 are a measure of the spread of data recorded.

The DSB GPS referencing method greatly improves the accuracy of the co-ordinates for each 10m sub-section. Nearly all of the 10m sub-sections have co-ordinates within ±2m for each repeat survey and all of the differences are within 4m. This is compared to percentages in the order of 6 to 14% of the sub-sections within ±2m for each repeat survey for the linear based referencing where the distance differences between surveys tend to accumulate over the survey length of the section.

For a particular 10m sub-section that is 9.88KM from the start position of the section differences in the co-ordinates between surveys from the linear based referencing can be up to 20 to 30m, Figure 2. For the DSB referencing the differences are around 1m throughout the section length.

4.2 Trial 2: Urban network

As part of the 2007/08 survey, repeat surveys were undertaken on a 9.3km long loop in Upper Hutt, near Wellington, Figure 3. Ten benchmark positions located on the loop were independently surveyed by a registered surveyor and compared to the co-ordinates from the survey vehicle from static and dynamic surveys. Again the GPS co-ordinates for each 10m sub-section were compared from each survey for the linear distance based processing method and the new GPS based DSB processing method.

The results from the four surveys are shown in Tables 3 and 4. Table3 shows the proportion of the 10m boundaries that are within 2m if the DSB or linear referencing is used. Table 4 shows the average difference between the coordinate positions for each referencing approach; the figures in Table 4 are a measure of the spread of data recorded.

The DSB GPS referencing method again greatly improves the accuracy of the co-ordinates for each 10m sub-section. Nearly all of the 10m sub-sections have co-ordinates within ±2m for each repeat survey and all of the differences are within 4m. This is compared to percentages in the order of 10 to 22% of the sub-sections within ±2m for each repeat survey for the linear based referencing.

Table 1: Percentage of Co-ordinates within 2m for each 10m Length for SH 53 Survey

	North	East
DSB Referencing	98.6 %	96.2 %
Linear Referencing	14.8 %	6.4 %

Table 2: Average Difference between Co-ordinate Values for SH53 Survey

	North	East
DSB Referencing	0.86 m	1.12 m
Linear Referencing	4.06 m	7.15 m

Table 3: Percentage of Co-ordinates within 2m for each 10m Length on GPS Loop

	North	East
DSB Referencing	99.6 %	100 %
Linear Referencing	22.1 %	10.8 %

Table 4: Average Difference between Co-ordinate Values on GPS Loop

	North	East
DSB Referencing	0.80 m	0.77 m
Linear Referencing	2.77 m	3.82 m

Figure 1: SH53 DSB Repeat Surveys

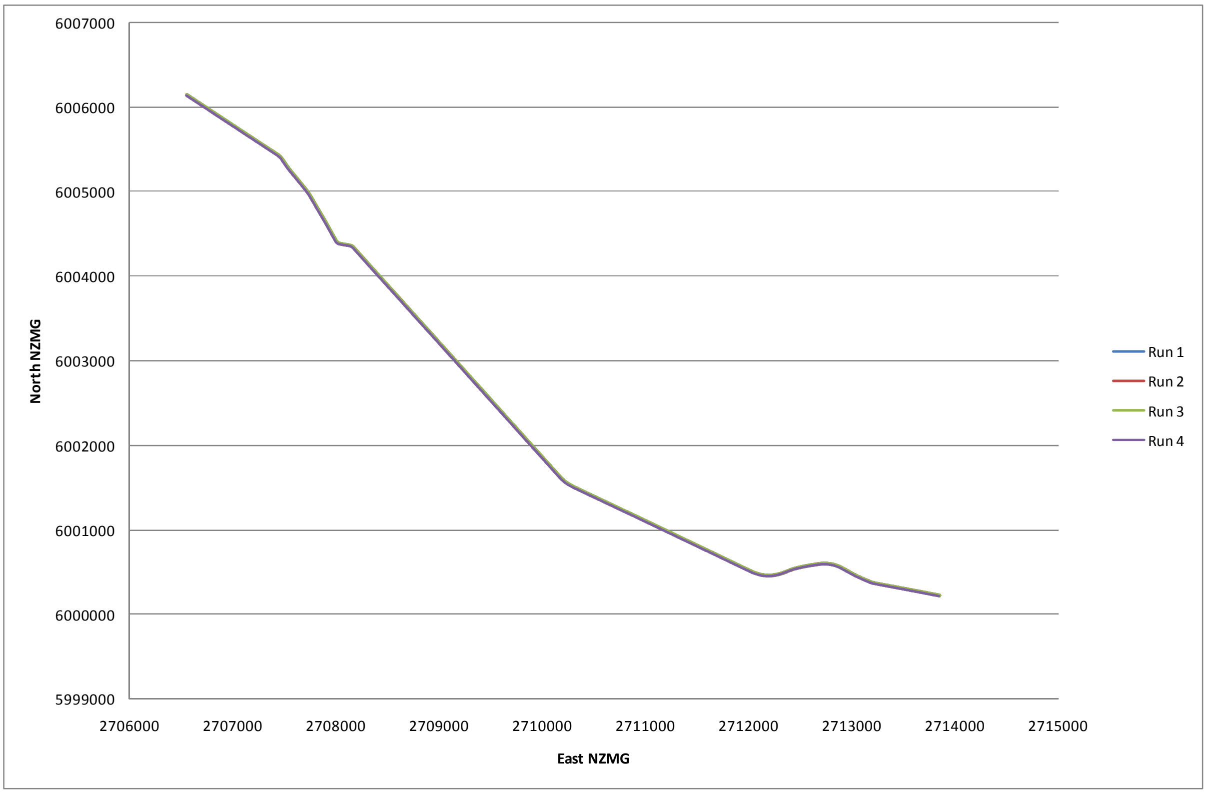


Figure 2: SH 53. Range of DSB and Linear Co-ordinates at 9,880m

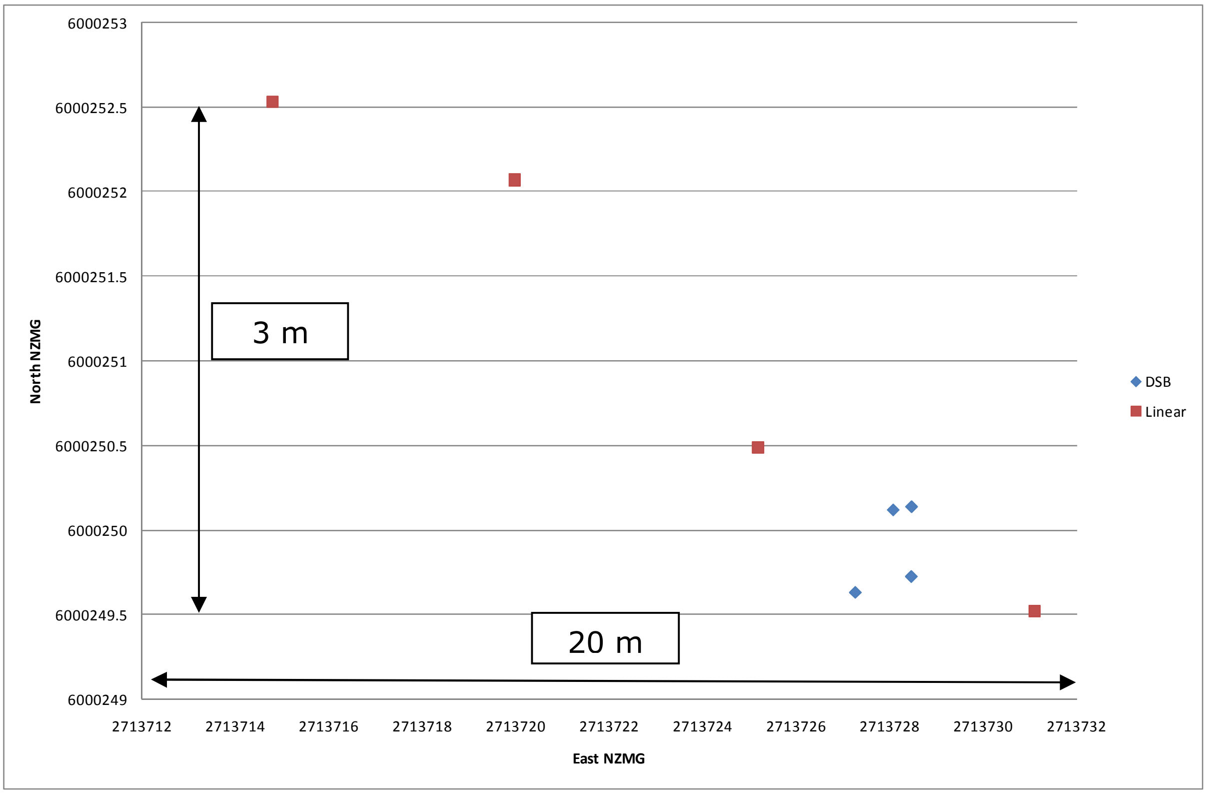
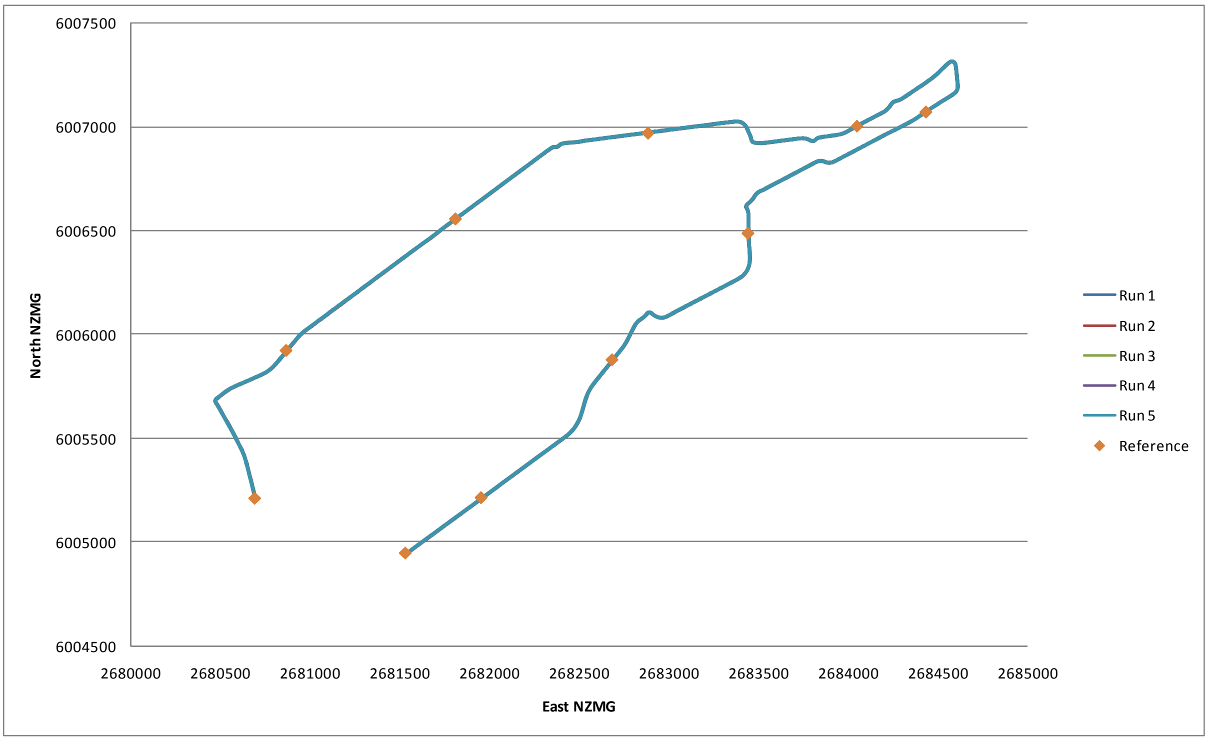


Figure 3: Upper Hutt GPS Loop DSB Repeat Surveys



5.0 ACHIEVEMENTS, EXPECTED BENEFITS AND WHAT HAS LEARNED

5.1 Achievements

These trials have demonstrated that the proposed method both to establish the base GPS referencing and to then collect and compare data sets to a high degree of accuracy is feasible and can be achieved in practice as part of a substantial network survey.

The major achievement from the two pilot trails has been to demonstrate that the locational accuracy of linear referencing can be inherited from the much more accurate GPS referencing. It has shown that the proportion of 10m boundaries from annual surveys can be located to within 2m well in excess of 95% of the time and on the basis of the results from the second trial almost all of the time when dGPS is available.

5.2 Expected benefits

The ability to use absolute referencing will allow results from different surveys to be compared with the confidence that the information being compared relates to the same length of road. It will also mean that results from separate surveys in different directions on a single two lane carriageway will be aligned accurately.

In terms of asset management these represent significant improvements compared with the current accuracy of linear referencing; condition data from different surveys can now be used to establish maintenance treatment programmes without the need for as many careful and labour intensive checks that the correct lengths of road are being targeted for work

With the improved accuracy from the GPS DSB referencing between each year's surveys the skid resistance site category could be frozen into the network removing the small changes that will occur in the start and end of bends and gradients and location of point events from year to year. Also events will be paired accurately from one side of the road to the other with GPS referencing. This will significantly improve the stability of skid deficient lengths on the network and make it more practical to develop effective targeted maintenance treatment programmes. The frozen network will also make it much easier to set up programmes to monitor the effectiveness of skid policies because the basic distribution of site categories will remain static.

5.3 What has been learned?

As with new developments it is in the detail of the unusual rather than of the majority that difficulties are encountered. The system has been implemented on the vast majority of the network but issues remain over areas where GPS is not available and the location of section start/ends where survey vehicles do not pass.

Much of New Zealand's topography is rugged 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 lush vegetation obscures the amount of clear sky visible. Where this has been recorded the sections have been listed and it will be necessary to continue to use linear referencing for these sections. With most of the survey work completed and processed it is not expected that the proportion of the network not referenced by GPS will exceed 5-10% of the network length.

A major Year 1 problem has been dealing with slip roads at T junctions and other similar situations. In these situations the tolerance between the coordinates of the section start/end and the closest approach of the survey vehicle has to be relaxed to allow for the actual drive line that a survey vehicle must travel to satisfy traffic regulations and also to operate safely. Examples of this situation are shown in Figures 4, in which a small increase in the tolerance is required and in Figure 5 where a much larger increase was required. It is important to note that is only a first year problem. Having defined the lane position for the start/end of section this will now be used in future years, with a close lane based tolerance applied between the new reference GPS and the GPS data collected during surveys.

The outstanding issue will be the way the new system can deal with network changes. It is considered that GPS referencing will help with this process because the data collected will automatically show that changes have taken place. This will flag the need for the database network to be updated; when the database network has been corrected the collected data will automatically fit without the need for re-survey.

Figure 4. Small relaxation in snapping tolerance required between survey and node.

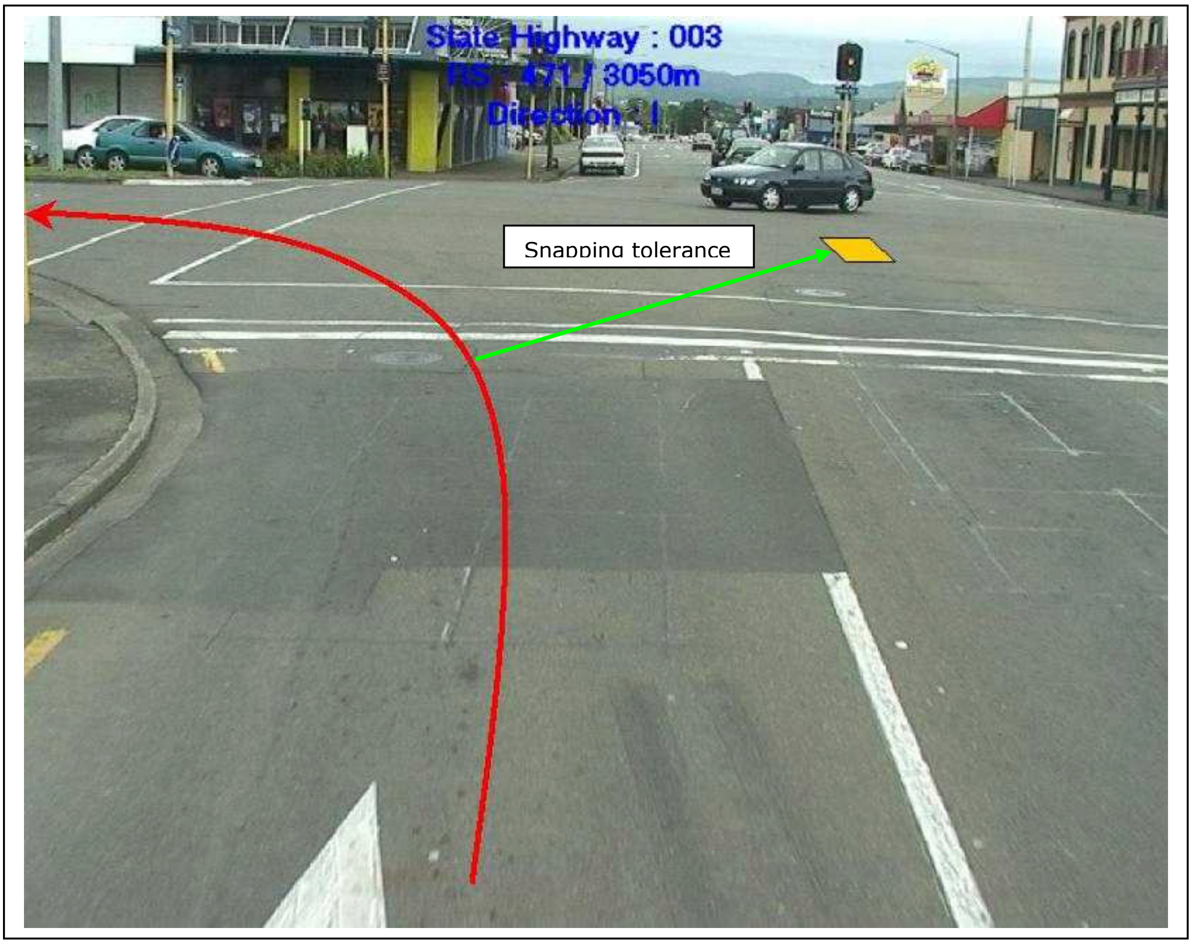


Figure 5. Large relaxation in snapping tolerance required between survey and node.