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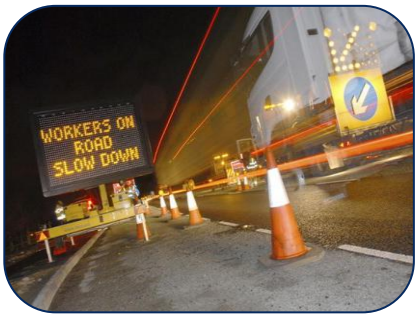


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Performance Assessment of E-Spott Ground Penetrating Radar System

Adam Cook

Prepared for: TRL

Quality approved:

Adam Cook	Alex Wright
(Project Manager)	(Technical Referee)

Performance Assessment of E-Spott Ground Penetrating Radar System

1 Introduction

In May 2011 TRL acquired an E-Spott device, which has been designed to provide spot depth measurements of total bound material thickness in pavements. A testing programme has been undertaken to assess the performance of this equipment and also to determine possible applications. The results of this programme are presented in this report.

2 The E-spott

2.1 Description

The E-Spott is a Ground Penetrating Radar (GPR) system that has been designed to provide in the field spot depth measurements of total bound material thickness. It has been developed by Utsi Electronics Ltd and is marketed by Pipehawk.

GPR is an echo sounding technique whereby electromagnetic pulses are transmitted into the subsurface and the portion of the signal that is reflected is analysed. Traditional GPR (utilising a single transmitter and receiver at a fixed separation) requires calibration to obtain depth measurements from the travel times of reflected signals. This is normally accomplished by direct measurements of depths from coring. E-spott provides depth measurements to the most significant interface within its measurement range, which is typically the total thickness of bound material. Although no information was given as to how the depth measurements from E-Spott are calibrated, it is expected it uses a form of Common Mid Point (CMP) sounding. CMP utilises measurements of the same interface taken with varying transmitter and receiver separations where a relationship between separation and travel time can be used to calculate depth.

Figure 1 - The E-Spott

The E-spott unit is constructed from ABS plastic, with a white base and yellow upper half (Figure 1, left). It is powered by AA batteries, which can be rechargeable. Its user interface consists of a single momentary push button, which activates the unit and triggers a reading. A two-line alphanumeric LCD display provides readings as well as information relating to the status of the device.

The system records its measurements to an SD card in a CSV format file. The batteries and SD card slot (along with a RS232 port which is assumed to be for system maintenance and upgrade) are located under a cover which is retained by a latch. The E-spott can be provided with a built in GPS device for recording time and date of readings as well as the GPS position.

2.2 Operating the E-spott

Operation of the unit is performed by placing it on the surface of the pavement and pushing the momentary button. This firstly displays the unit's current firmware on the LCD screen. It will also activate the GPS unit and commences signal acquisition - "waiting for GPS" is shown on the display for a short period. However, it does not wait indefinitely for the GPS to acquire a fix, an error message is displayed after a few seconds if it has been unable to acquire a fix and it will then take a reading without GPS. Such readings are stored without GPS and time information, which can make data reconciliation difficult but readings are stored in order of collection so that they can still be related to positional information, provided that the user has used other means to record this information.

2.3 E-spott data

The system returns two readings with each measurement, displayed as 'upper' and 'full'. Figure 2 shows an example reading shown on the LCD display. The readings are obtained from the same GPR data although it is understood that slightly different algorithms are used to interrogate the data to obtain the two readings.

Figure 2 - E-spott data display

The 'full' reading refers to the depth of the strongest (in terms of amplitude) reflection received from within the whole of the time/depth window, which is approximately 600mm in asphalt. The 'upper' reading refers to the depth of the strongest reflection from an interface within the upper 25% of the time/depth window, approximately 150mm in asphalt. Usually the system will return two different interfaces for the upper and full measurements. For example, if there is a particularly strong internal interface within the bound material or the bound material is less than 150mm total but there is a particularly strong interface in the pavement foundations. For this reason it is necessary for the operator (or the data user) to have some knowledge of the likely construction of the pavement under test.

The system is set to ignore interfaces detected within the upper 70mm, due to possible conflict with the direct wave path. If the system cannot find a discernable interface within the upper 150mm, the 'upper' reading will simply display "***" to indicate a null value. Should the strongest interface within the total time/depth window also be within the upper 150mm time/depth window the readings will indicate the same interface. However, when this is the case the two readings are not always identical. In this case the manufacturer recommends that the upper reading should be used as this is a more sensitive algorithm for shallow depths.

The latest versions of the E-spott provide measurements to a resolution of 5mm (an earlier system that provided 1mm measurements was also made available for parts of this assessment) which suggests this is the expected maximum accuracy of the system.

The minimum thickness E-spott can measure is 70mm and the maximum is 600mm. This suggests an accuracy of 7% to 1%. It is, perhaps, more likely is that the percentage accuracy remains constant with depth. A 7% maximum accuracy would give a potential error of 42mm for a depth of 600mm.

3 Performance Testing

3.1 Test Equipment

Three E-spott devices were made available for the performance testing. Table 1 describes these systems. It can be seen that all devices were not identical due to the E-spott being relatively new to the market and not produced in large quantities. However, all three systems had been correctly calibrated for use on asphalt.

Table 1 - E-Spott Systems used during Assessment

Serial Number	Software Version	Comments
504	V8.2	• Hand built antenna screens • 1mm resolution
506	V8.6	• Machine built antenna screens • 5mm resolution
508	V8.8	• Machine built antenna screens • 5mm resolution

The above systems were used to assess the following:

- repeatability of an individual device,
- reproducibility of multiple E-Spott devices,
- coverage assessment
- accuracy compared with coring and core calibrated GPR.

The assessments were carried out on test sites located at TRL and on the local and trunk road networks, as discussed in the following sections.

3.2 Repeatability of an individual device

This test aimed to quantify the E-Spott's ability to produce consistent measurements under controlled conditions. The controls in place were:

- Only readings taken in the same position and orientation were compared
- The operator was retained for all readings
- A single system was selected for this assessment (serial number 508, which used the most recent version of the E-Spott operating system (version 8.8)).

Data was collected on the local road network near TRL - Jiggs Lane and Kennel Lane - covering a total of 26 groups of three identical measurements on reinstatements that were expected to be around 100mm thick.

The surveys of Jiggs Lane were taken prior to drilling cores on this site (for use in the accuracy assessments – see Section 4.3). At each of these locations five groups of three measurements were taken. Table 2 lists the groups of three measurements taken at locations prior to core drilling.To collect the three measurements that make up the group, the E-spott was placed in the correct position and orientation and the first reading was taken. Without disturbing the position and orientation of the system, the second and third readings were taken. If the operator was required to remove the system from the pavement during a group of measurements, the whole group was repeated.

Table 2 - E-spott measurements taken on core locations prior to drilling

Position Reference	Device Position	Orientation
1	Centred on proposed core location	Parallel to road direction
2	Centred on proposed core location	90° clockwise to position 1
3	Centred on proposed core location	180° to position 1
4	Centre of E-spott 0.25m forward of proposed core location	Parallel to road direction
5	Centre of E-spott 0.25m behind proposed core location	Parallel to road direction

The surveys of Kennel Lane were taken at sites of core already drilled (for use in the accuracy assessments – see Section 4.4). In each case E-spott was positioned on the nearside and offside of the core and orientated parallel with the road direction.

The repeatability for each reading (upper and full) was obtained by calculating the range of the reported thicknesses in each set of three measurements (e.g. reported thicknesses of 150mm, 153mm, 155mm would have a range of 5mm). The percentage of groups of three measurements that had a range of reported thicknesses equal to or less than a given range (0mm ,5mm and 10mm) was then calculated, and is reported in Table 3. The maximum range over all the reported groups of thickness measurements is also given in Table 3

Table 3 - Individual Machine Repeatability

	Percentage of Groups of three Measurements where the range was ≤ Given Range			
Reading	0mm	5mm	10mm	Maximum Range
Upper	69%	96%	96%	30mm
Full	26%	69%	92%	125mm

Assuming that this is a typical level of performance, Table 3 suggests that, for the upper reading, if multiple measurements are taken at any given spot using the same device, over two thirds of the repeat readings should agree, and over 95% of the repeat readings should fall within a 5mm range. For the full reading, it suggests that over 25% of the repeat readings will agree, and over two thirds will fall within a 5mm range (over 90% will fall within a 10mm range).

The 125mm maximum range represents data from one location only and can be categorised as an outlier, as of the three readings two were 120mm and one was 215mm.

It may be concluded that, for very thin pavements or reinstatements (less than 150mm) where the upper reading is used, 2 measurements should be sufficient. However, for thicker asphalt pavements (between 150mm and 600mm) there is benefit in obtaining at least three measurements and taking an average (excluding any obvious outliers). The time required to take a measurement is such, at around 20 seconds for the GPS equipped model, that this should not significantly affect productivity.

3.3 Reproducibility of E-Spott devices

This test aimed to assess the consistency of measurements, regardless of the E-Spott system used. Reproducibility was assessed by comparing readings taken in the same position and orientation using at least two of the three available systems. This provided 51 opportunities for comparison across the whole of the data set. Each location was positioned on a reinstatement that was expected to be approximately 100m thick. The E-Spott is very sensitive regarding its placement position therefore every effort was made to ensure that the units were positioned consistently. This was accomplished by marking each location with road crayon.

Where the 504 unit was included in a comparison, its data were rounded to the nearest 5mm to match that of the 506 and 508 units (to make the data directly comparable). Where more than one reading was taken with a particular unit (i.e. in a group of three measurements as was used for the repeatability assessment) the modal value of that group of readings was used.

The maximum difference between the thickness values reported at each location was then obtained. The reproducibility was then expressed as the percentage of maximum differences between devices that fell within given ranges (0mm, 5mm,10mm, 20mm, 50mm, 100mm), as shown in Table 4. The maximum difference over all the reported measurements is also given in Table 4.

Table 4 - Reading Reproducibility

	Percentage of Groups of Identical Measurements using different systems where the range was ≤ Given Range						
Reading	0mm	5mm	10mm	20mm	50mm	100mm	Maximum Range
Upper	37%	49%	69%	75%	92%	94%	140mm
Full	20%	27%	55%	78%	86%	90%	345mm

Assuming that this is a typical level of performance, the data of Table 4 suggests that, regardless of the system used and providing it has been correctly calibrated by the manufacturer, it is highly likely that a thickness measurement obtained with an E-spott at a particular location will lie within 20mm of a thickness measurement obtained with a different E-spott at the same location.

It is assumed that a reproducibility of better than 10% is a reasonable expectation of such a system like the E-Spott. Since the vast majority of readings were taken over typically 100mm bound reinstatements, the 10mm range is considered the key reproducibility indicator. Greater than 50% of the measurements delivered this level of reproducibility (almost 70% for the upper reading).

3.4 Coverage Assessment

The aim of this test was to investigate the application of E-spott to obtain higher levels of information over a large measurement area, in comparison with that practically achievable with traditional coring. Measurements were obtained on an area of reinstatement approximately 1.5m by 1.5m square. This area was surveyed in an orthogonal grid pattern with readings taken at approximately 0.3m centres (half the length of the unit). The unit with serial number 504 was chosen for this part of the assessment as although it contains older software, it has the ability to provide readings to the nearest 1mm as opposed to 5mm. It should be noted that the manufacturers do not claim that this model is more accurate that those that round to the nearest 5mm. All readings were taken in the same orientation (parallel to the road orientation) and three readings were taken in each position, the modal value of each group of measurements was used for the assessment.

The time taken to collect this many readings (48 in total including repeat readings) was less than 17 minutes. This approximately equates to the time taken to extract a single core, photograph it, log the details, and reinstate the hole. This demonstrates that the E-spott system is a much more productive method of collecting depth data.

Figure 3 and Figure 4 show the readings taken with the E-Spott system, upper and lower reading respectively. The grid patterns are conditionally formatted to show a colour gradient from red (minimum), though yellow (50th percentile), to green (maximum). This colour scale is not meant to show areas that are particularly bad or good, rather to highlight variations. For Figure 3, where the E-Spott was unable to return an 'upper' reading (above 150mm) this has been given a null (*) value. Although the actual values vary between the two readings by an offset, the actual variation across the site is apparent with the upper portion of the site being thinnest. This pattern is clearer in Figure 5 which is the upper and full data combined by using the following rule:

- Upper reading is used if the lower reading is less than 150mm and an upper reading is available
- Lower reading is used in all other cases

This rule leaves only one outlying high value which is the lower right corner value. If this were to be considered a real investigation, that value would be discarded as an outlier and investigated further.

Four cores were also taken from this reinstatement at locations of E-Spott readings, as shown in Figure 6. Four cores is more than would normally be taken from a reinstatement this size, and even with this high number it is not enough to quantify the variation in thickness throughout the whole reinstatement such as it was with the E-Spott readings.

116mm	119mm	100mm	114mm
113mm	*	*	*
126mm	140mm	144mm	143mm
*	126mm	142mm	*

Figure 3 - Coverage Assessment Upper Readings

109mm	337mm	315mm	109mm
108mm	153mm	163mm	161mm
123mm	137mm	137mm	142mm
157mm	122mm	294mm	312mm

Figure 4 - Coverage Assessment Full Values

116mm	119mm	100mm	109mm
113mm	153mm	163mm	161mm
126mm	140mm	144mm	143mm
157mm	126mm	142mm	312mm

Figure 5 - Coverage Assessment Combined Readings

150mm	*	*	120mm
*	155mm	*	*
*	*	*	*
*	*	260mm	*

Figure 6 - Coverage Assessment Corresponding Core Data

4 Accuracy

The accuracy assessment was carried out in four phases, to test the E-Spott in as many situations as possible.

4.1 Phase 1: As built road coring

The 506 E-Spott system was taken on site for a shift by a TRL coring crew on the A3 near Chalk Hill. The crew were given instructions to take a reading with E-Spott prior to taking a core. Unfortunately only 3 compatible cores were extracted, the remainder being too deep to obtain a valid reading from the E-Spott (>600mm measurement range as stated in the manufacturer's specification). Table 5 summarises the core data and the corresponding E-Spott readings. At each location, three repeat E-Spott measurements were taken. The table shows the modal value of each measurement. Appendix A shows the actual core logs which also contain all three E-Spott readings.

Table 5 - Trunk Road Coring Comparison

Core Number (Marker Post)	Asphalt Interface in E-Spott window (mm)	Total Bound from Core (mm)	Modal E-Spott Readings (mm)	
			Upper	Full
17/7	101	274	135	245
18/2	120	280	135	290
18/6	119	280	135	245

In all cases the E-Spott appeared to be detecting a significant interface at 135mm. However, this is not consistent with the core logs that show the only significant internal asphalt interface (within the E-Spott's measurement capabilities) to be at around 120mm for the latter two cores and 100mm for the first core.

Core 18/2 shows good agreement with the corresponding E-Spott readings for measurement of the total bound material depth with only a 10mm difference over a approximately 300mm. The remaining 2 cores are less consistent with the E-Spott differing by 30-35mm from the core measurement.

4.2 Phase 2: Core calibrated GPR

Measurements were collected on test pavements (10m by 3m strips) constructed in the Pavement Test Facility at TRL that had already been surveyed using traditional GPR (using a GV5c system from Utsi Electronics) and interpreted for material thickness as part of a separate TRL project. The data was in the form of cross sections over the long axis of the strips at the centreline, and then at 0.5m and 1m offsets either side of the centreline. The final thickness measurements were calibrated with 3 cores, one in each strip, these core holes where then used to install sensors in the pavement for the separate TRL project.

E-Spott readings (using 506) were taken approximately 3 weeks after the collection of the GPR data. Due to the sensors installed in the pavement it was not possible to take measurements in or around the cores. However, it was expected that the core calibrated GPR should be of an appropriate accuracy for this comparison. The GPR reported that the thickness of the materials varied significantly along the long axis of the sections but was very consistent transversely. Therefore when taking measurements the E-Spott was positioned so its long axis was perpendicular to the long axis of the pavement strip. Appendix B shows images of the calibrated GPR interpretation (one for each pavement section) accompanied by the E-Spott readings represented by bars of blue for the upper reading and yellow for the full reading.

Table 6 shows the numerical comparison of the E-Spott measurements with the calibrated GPR measurements. The cells of the table have been colour coded to show which measurements from the E-Spott have been interpreted to correspond with a material interface from the GPR. In all cases the full measurement from the E-Spott agreed well with the interpretation of the subbase layer from the GPR. The greatest difference between the two methods was 41mm (section 3, centreline, 4m chainage) which was a little over 10% of the measurement from the GPR data.

Table 6 - Comparison with Calibrated GPR

E-Spott Readings					GV5c Measurement			
Section	Offset	Chainage	Upper	Full	Internal Asphalt 1	Internal Asphalt 2	Asphalt	Subbase
1	-1	2	115	340	36		135	368
1	-1	4	135	390	36		141	398
1	-1	6	135	390	41		150	389
1	-1	8	115	335	36		134	345
2	-0.5	2	***	395	53	89	138	409
2	-0.5	4	***	425	48	83	137	431
2	-0.5	6	115	395	28	70	126	402
2	-0.5	8	110	420	25	66	117	388
3	cl	2	***	465	30	98	186	445
3	cl	4	***	420	27	95	167	461
3	cl	6	85	450	22	78	174	453
3	cl	8	***	405	24	93	167	426

However, in some cases the E-Spott was unable to detect the total bound material depth. This was particularly evident in strip 3 where the total bound depth was not measured by the E-Spott. Instead the base of the subbase material was interpreted to be the full measurement. For one instance on strip 3 an internal asphalt boundary was measured as the upper result and the total bound depth was missed completely.

This shows that the actual depth measurements obtained from the E-Spott can be accurate when compared to calibrated GPR. However, where the pavement is not a simple reinstatement, the operator (or data end user) is required to have some knowledge of the likely construction of the pavement in order to correctly relate upper and full E-Spott readings to the correct material interfaces. Should the E-spott reading not correspond to the operator's expectations of material depths or contrasting measurements are obtained within an area which is expected to be uniform, a core would need to be extracted to confirm the assessment.

4.3 Phase 3: Reinstatement cores, pre-drilling

This component of the test was completed in conjunction with Strata Coring and the Gas Alliance. A number of sites of recent trench reinstatement were scheduled for coring by Strata on behalf of Bracknell Forest Council to check compliance with regulations. TRL were allowed access to the reinstatements prior to coring to take E-Spott measurements directly over the core positions prior to drilling operations.

The same E-Spott system was not used in all cases, therefore the results represent the general accuracy of the available models. In some cases more than one reading was taken with a particular system at a particular position and orientation, in this case the modal value was obtained. Appendix C contains the data from this part of the testing in tabular form, and also contains the details for each of the sites.

For site 1 the core extracted showed the full depth of the bound material to be only 50mm, outside the E-spott's stated measurement window of 70mm to 600mm. Therefore this data was ignored.

For site 2 the reinstatement was also unusually shallow according to the measurement from the core, at only 74mm. However, this is within the stated measurement window of the E-Spott. Unfortunately the readings obtained by the system did not agree well with the core measurement. The normal measurement positions read a minimum of 115mm and a maximum of 130mm when using both the upper and full readings (which were consistent with each other). In terms of a percentage difference from the core depth, this comes to between 55% and 76%. However, these reinstatements were on concrete roads with a thin overlay. The E-Spott is not specified for pavements of this nature as it has been calibrated to identify a boundary between a bound asphalt material and an unbound subbase; therefore this data has not been included in the overall assessment of accuracy.

No cores were taken at site 3 due to this being a concrete road with a thin overlay. E-Spott data was taken, but omitted from Appendix C for the reasons given above.

Site 4 consisted of three separate reinstatements. All of the reinstatements were cored multiple times giving a total of eight cores for comparison. It was the intention to consistently use E-Spott unit 508 on this site but a fault developed and unit 504 was also used. The measurements were rounded to the nearest 5mm to be consistent with the measurements from 508. The fault was later attributed to the SD card rather than the 508 system itself. Both systems showed good agreement with the cores throughout this site, as can be seen in Appendix C. The core taken at site 4h contained a large void between 100 and 150mm. The E-Spott did clearly see a difference in this location as opposed to adjacent locations therefore this may have been a suitable location for a targeted core were this a real survey.

The average percentage difference between the E-Spott reading that was interpreted to be the correct reading (generally if the core was less than 150mm the upper reading was used, otherwise the full reading was used) and the core measurement was 9%.

In some cases, without the cores, it would have been difficult interpreting the E-Spott readings. For some measurements the upper reading was correct and for others the full reading was correct. This was also the case for the comparison with calibrated GPR, which confirms the observation that additional information is required regarding the pavement under test to make best use of the E-spott system.

4.4 Phase 4: Reinstatement Cores, Post-drilling

This component of the testing was also completed in conjunction with Strata Coring. Strata provided logs for cores they had taken in Bracknell approximately a year previously. E-spott readings were taken immediately adjacent to these cores, to prevent the reinstated core itself affecting the results. The cores were all located in various patches, and measurements were only taken where the original core reinstatement was still visible. Throughout this test unit 508 was used and in all cases three repeat measurements were taken. The modal value of each group of measurements was used in most cases except in cases where all three measurements were different, when the median measurement was used.

Appendix D shows the results of the post drilling core comparison. The results show good agreement with the cores, the average percentage difference between the core value and the E-Spott reading (upper or full) that was interpreted to be the best to use was 28%. Essentially if the core showed the total bound thickness to be greater than 150mm, the full reading was used; otherwise the upper reading was used. Two cores showed a total bound thickness of less than 70mm which is outside the stated measurement window for the system. If the results from these two cores are omitted the divergence improves, to 14%.

5 Conclusions

The E-Spott system is intended for use both by operators with little or no technical knowledge of GPR technology as well as by experienced users. The system therefore has to be easy to use and interpret. It has succeeded in being easy to use in that the interface is simple and quick. Also, the interpretation does not require prior knowledge of GPR technology or even knowledge that the system is based on GPR. However, this assessment has shown that in order to interpret the readings correctly some knowledge of the pavement construction is required. Given a target market of pavement and utility engineers, these users should have a good knowledge of pavement construction and reinstatement techniques. Therefore they may be able to judge situations in which the E-spott is suitable as a standalone tool, as situations where readings should be confirmed with direct measurements such as coring. Nevertheless, sufficient training would need to be provided to reduce the risks of inappropriate use.

The addition of GPS to aid measurement location makes data logging much more robust. However, problems were experienced during this assessment with the availability of GPS. This was not necessarily a problem with the unit itself; rather the problems often encountered using GPS in an urban environment. It often took several minutes to obtain a fix on first activation, which is not unusual for a low grade GPS unit, but the inability to activate it in advance of wanting to take measurements, and no indication of the status of the GPS until a measurement is attempted detracts from its usefulness. The system may benefit from a higher grade, more sensitive, GPS unit.

The experimental assessment has shown that:

- E-spott is quite repeatable. Over 95% of groups of multiple upper measurements fell within 5mm repeatability. Over 65% of groups of multiple full measurements fell within 5mm repeatability (>90% within 10mm). Best practice suggests that three repeat readings should be carried out. Since single readings can be obtained quickly, this will not significantly affect E-spott's productivity.
- E-spott accuracy is reasonable. Direct comparisons with cores taken on site on the same day showed that, on average, E-Spott readings were within about 10% of the core measurement for flexible pavements with thicknesses greater than 70mm.
- E-Spott compares reasonably well with "traditional" GPR data that has been calibrated by coring. The average percentage difference between the calibrated GPR value for the total bound material thickness and the E-Spott reading was about 10% for thicknesses where the operator was able to identify the E-spott readings which were related to the correct boundary layer. However, the e-spott does occasionally report inappropriate thicknesses related unrequired boundaries.

For example, it can report the base of the subbase material as the most significant interface within the time/depth window, or it can report an internal boundary as the significant interface. Both of these behaviours will result in incorrect measurements if the operator does not apply skills and/or have some existing knowledge of the pavement. It is unusual to obtain a stronger reflection from the base of the subbase than the base of the bound material when using GPR. For these rare cases an alternative method of calibration would be required in order to avoid an incorrect interpretation of GPR data. In any case, the E-Spott could only be used to give an early indication of GPR calibration velocity and should always be confirmed via an alternative method.

- The E-Spott provides a clear advantage over coring in terms of its ability to cover a much wider area quickly and efficiently, to gain a greater understanding of the variability of the total bound thickness at a particular location, which is impractical using traditional coring alone.
- To make it sufficiently robust, E-Spott should not be used without the support of core data. The accuracy of E-spott is insufficient to negate the need for coring. However, E-Spott can be used successfully alongside targeted coring to improve efficiency and obtain higher levels of coverage. As a result, many more reinstatements could be checked for compliance and verification soon after construction. The E-Spott data can also be used to target limited coring resources to confirm the status of reinstatements that the E-Spott data shows to be questionable.

Appendix A : Trunk Road Core Logs

Layers					Aggregate		Comments
No.	Top mm	Btm mm	Thkn mm	Mat'l	Max Size mm	Type	
1	0	40	40	HRA	14	LST	Sound
2	40	101	61	DBM	14	LST	Sound
3	101	274	173	DBM	30	LST	Sound
							E Spott Results
							135,465 135,245 135,240

Visual Condition of Core: Sound

Key: TS = Thin surfacing, HRA = Hot Rolled Asphalt; DBM = Dense Bituminous Macadam, CBM = Cement Bound Material, PQ concrete = PQ conc, TBM = Tar Bound Macadam, SD = Surface Dressing, HFS = High Friction Surface, BST = Basalt, GNT = Granite, GVL = Gravel, LST = Limestone,

CORE LOG	Area 3	Location: **A3 Chalk Hill**		Date:
	Direction: **NB**	Lane: **1**	Offset: **O/L**	**10h March 2011**
	MP: **17/7**			

Layers					Aggregate		Comments
No.	Top mm	Btm mm	Thkn mm	Mat'l	Max Size mm	Type	
1	0	39	39	HRA	14	LST	Sound
2	39	120	81	DBM	14	LST	Sound
3	120	280	160	DBM	30	LST	Sound (debonded) E Spott Results 135,280 135,290 135,290

Visual Condition of Core: Sound

Key: TS = Thin surfacing, HRA = Hot Rolled Asphalt; DBM = Dense Bituminous Macadam, CBM = Cement Bound Material, PQ concrete = PQ conc, TBM = Tar Bound Macadam, SD = Surface Dressing, HFS = High Friction Surface, BST = Basalt, GNT = Granite, GVL = Gravel, LST = Limestone,

CORE LOG	Area 3 Direction: **NB** MP: **18/2**	Location: **A3 Chalk Hill** Lane: **1**	 Offset: **O/L**	Date: **10th March 2011**

Layers					Aggregate		Comments
No.	Top mm	Btm mm	Thkn mm	Mat'l	Max Size mm	Type	
1	0	47	47	HRA	14	LST	Sound
2	47	119	72	DBM	14	LST	Sound
3	119	280	161	DBM	20	LST	Sound (debonded) E Spott Results 135,255 135,240 135,245

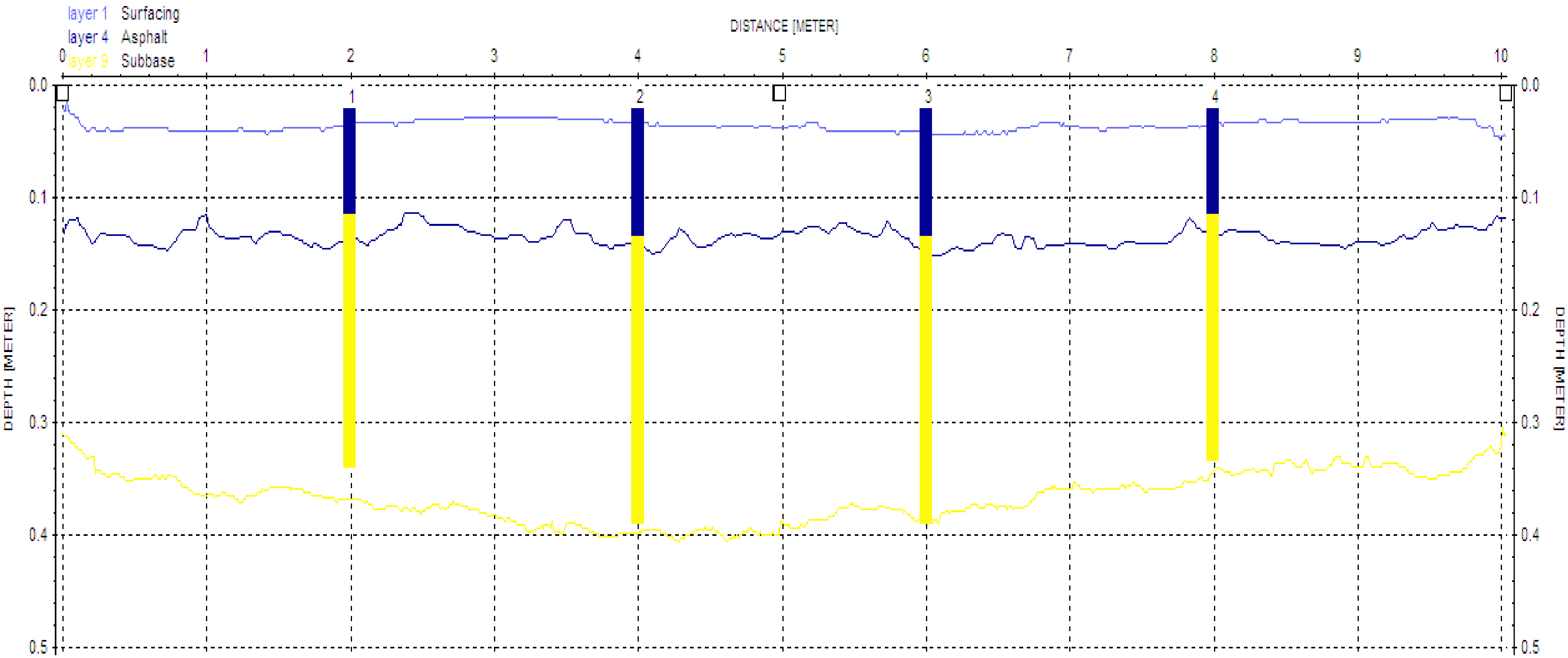
Visual Condition of Core: Sound

Key: TS = Thin surfacing, HRA = Hot Rolled Asphalt; DBM = Dense Bituminous Macadam, CBM = Cement Bound Material, PQ concrete = PQ conc, TBM = Tar Bound Macadam, SD = Surface Dressing, HFS = High Friction Surface, BST = Basalt, GNT = Granite, GVL = Gravel, LST = Limestone,

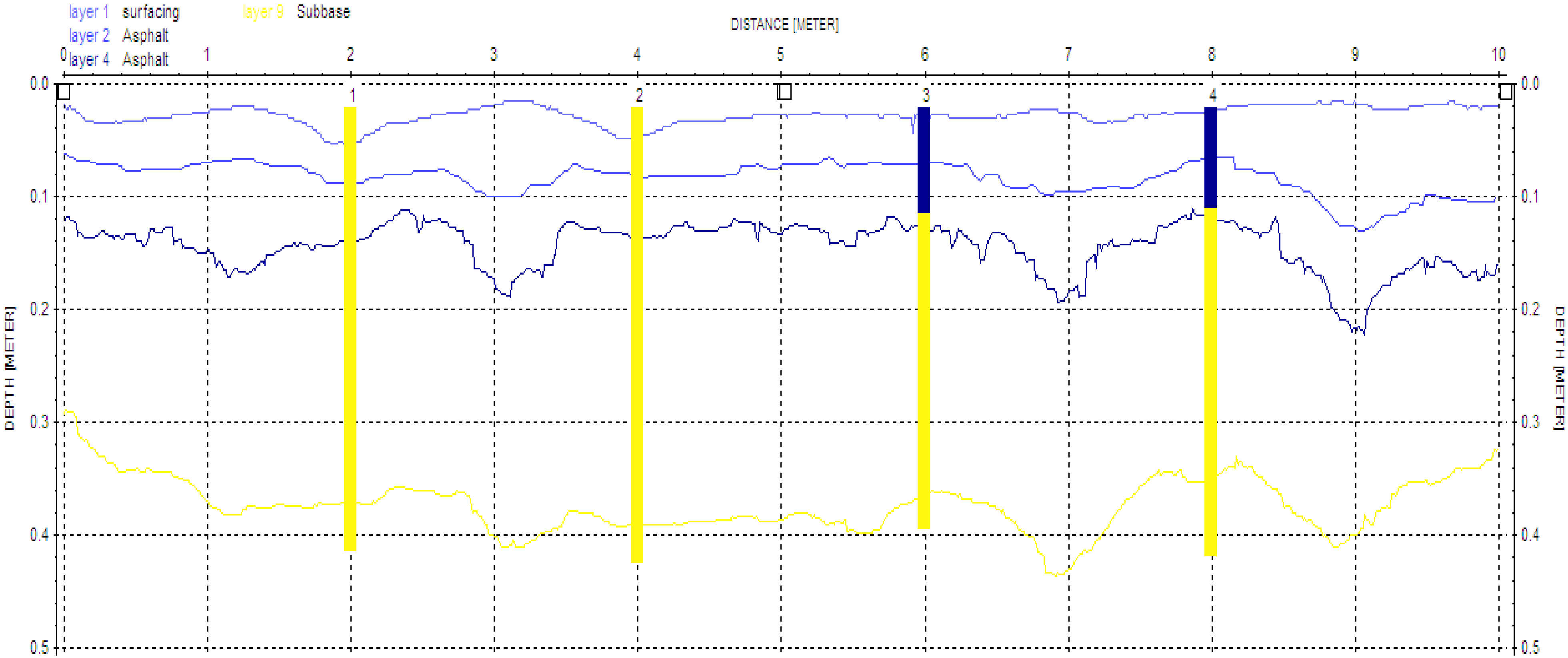
CORE LOG	Area 3 Direction: **NB** MP: **18/6**	Location: **A3 Chalk Hill** Lane: **1** Offset: **O/L**	Date: **10th March 2011**

Appendix B : Calibrated GPR Comparison

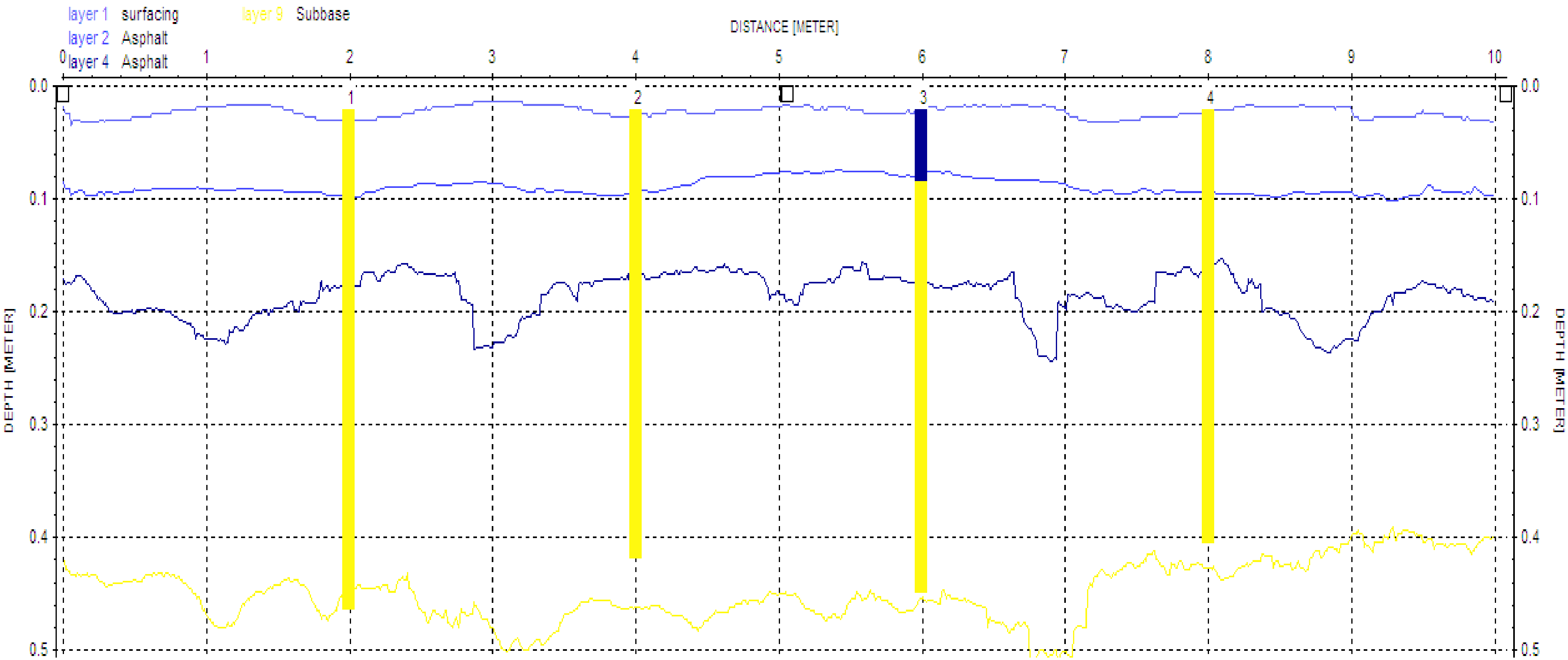
B.1 Interpretation of Pavement Test Section 1



B.2 Interpretation of Pavement Test Section 2



B.3 Interpretation of Pavement Test Section 3



Appendix C : Accuracy Comparison with Core Data, Pre-Drilling

Site Number		Description				Latt.		Long.
1		Junction of Freeborn Way and Shelley Avenue				51.4176		-0.7305
Serial No.	Date	Time	Position	Orientation	E-Spott Upper	E-Spott Full	Core Depth	% Diff from Core
506	24/05/11	No GPS	Centred	Normal	135	450	50	170%
506	24/05/11	No GPS	Centred	90°	130	435	50	160%
506	24/05/11	No GPS	Centred	180°	135	435	50	170%
506	24/05/11	No GPS	+250mm	Normal	125	***	50	150%
506	24/05/11	No GPS	-250mm	Normal	135	130	50	170%
Site Number		Description				Latt.		Long.
2		Junction of Davenport Road and Shelley Avenue				51.4184		-0.7307
Serial No.	Date	Time	Position	Orientation	E-Spott Upper	E-Spott Full	Core Depth	% Diff from Core
506	24/05/11	No GPS	Centred	Normal	130	125	74	76%
506	24/05/11	No GPS	Centred	90°	125	120	74	69%
506	24/05/11	No GPS	Centred	180°	120	115	74	62%
506	24/05/11	No GPS	+250mm	Normal	125	120	74	69%
506	24/05/11	No GPS	-250mm	Normal	125	130	74	69%
Site Number		Description				Latt.		Long.
4a		Jiggs Lane South – Patch 1 – Core Location 1				51.4258		-0.7330
Serial No.	Date	Time	Position	Orientation	E-Spott Upper	E-Spott Full	Core Depth	% Diff from Core
508	24/05/11	11:29:17	Centred	Normal	135	130	145	7%
508	24/05/11	11:31:46	Centred	90°	140	130	145	3%
508	24/05/11	11:32:44	Centred	180°	140	135	145	3%
508	24/05/11	11:33:47	+250mm	Normal	120	115	145	17%
508	24/05/11	11:34:17	-250mm	Normal	140	135	145	3%
Site Number		Description				Latt.		Long.
4b		Jiggs Lane South – Patch 1 – Core Location 2				51.4258		-0.7330
Serial No.	Date	Time	Position	Orientation	E-Spott Upper	E-Spott Full	Core Depth	% Diff from Core
508	24/05/11	11:39:12	Centred	Normal	80	80	120	33%
508	24/05/11	11:40:16	Centred	90°	120	90	120	0%
508	24/05/11	11:41:09	Centred	180°	75	75	120	38%
508	24/05/11	11:42:30	+250mm	Normal	130	120	120	8%
508	24/05/11	11:43:58	-250mm	Normal	125	120	120	4%
Site Number		Description				Latt.		Long.
4d		Jiggs Lane South – Patch 2 – Core Location 1				51.4259		-0.7323

Serial No.	Date	Time	Position	Orientation	E-Spott Upper	E-Spott Full	Core Depth	% Diff from Core
504	24/05/11	12:11:01	Centred	Normal	135	135	145	7%
504	24/05/11	12:11:44	Centred	90°	0	150	145	3%
504	24/05/11	12:13:00	Centred	180°	0	140	145	3%
504	24/05/11	12:14:14	+250mm	Normal	140	130	145	3%
504	24/05/11	12:15:45	-250mm	Normal	110	110	145	24%
Site Number		Description				Latt.		Long.
4e		Jiggs Lane South – Patch 2 – Core Location 2				51.4259		-0.7323
Serial No.	Date	Time	Position	Orientation	E-Spott Upper	E-Spott Full	Core Depth	% Diff from Core
504	24/05/11	12:18:51	Centred	Normal	105	105	110	5%
504	24/05/11	12:19:40	Centred	90°	110	110	110	0%
504	24/05/11	12:20:37	Centred	180°	110	105	110	0%
504	24/05/11	12:21:27	+250mm	Normal	120	115	110	9%
504	24/05/11	12:22:42	-250mm	Normal	120	120	110	9%
Site Number		Description				Latt.		Long.
4f		Jiggs Lane South – Patch 3 – Core Location 1				51.4252		-0.7328
Serial No.	Date	Time	Position	Orientation	E-Spott Upper	E-Spott Full	Core Depth	% Diff from Core
504	24/05/11	13:31:38	Centred	Normal	116	109	150	23%
504	24/05/11	13:31:55	Centred	90°	0	142	150	5%
504	24/05/11	13:32:14	Centred	180°	0	163	150	9%
Site Number		Description				Latt.		Long.
4g		Jiggs Lane South – Patch 3 – Core Location 2				51.4252		-0.7328
Serial No.	Date	Time	Position	Orientation	E-Spott Upper	E-Spott Full	Core Depth	% Diff from Core
504	24/05/11	13:33:57	Centred	Normal	0	153	155	1%
504	24/05/11	13:34:19	Centred	90°	0	143	155	8%
504	24/05/11	13:34:39	Centred	180°	0	153	155	1%
Site Number		Description				Latt.		Long.
4h		Jiggs Lane South – Patch 3 – Core Location 3				51.4252		-0.7328
Serial No.	Date	Time	Position	Orientation	E-Spott Upper	E-Spott Full	Core Depth	% Diff from Core
504	24/05/11	13:37:16	Centred	Normal	142	294	260	13%
504	24/05/11	13:37:34	Centred	90°	134	277	260	7%
504	24/05/11	13:37:52	Centred	180°	137	290	260	12%
Site Number		Description				Latt.		Long.
4i		Jiggs Lane South – Patch 3 – Core Location 4				51.4252		-0.7328
Serial No.	Date	Time	Position	Orientation	E-Spott Upper	E-Spott Full	Core Depth	% Diff from Core
504	24/05/11	13:41:22	Centred	Normal	114	109	120	5%

504	24/05/11	13:41:41	Centred	90°	113	462	120	6%
504	24/05/11	13:42:00	Centred	180°	115	116	120	4%

Appendix D : Accuracy Comparison with Core Data, Post-Drilling

Site Number		Description				Latt.		Long.
5		Kennel Lane				51.4268		-0.7568
Serial No.	Date	Time	Position	E-Spott Upper	E-Spott Full	Core Ref.	Core Depth	% Diff from Core
508	25/05/11	8:51:58	Right	110	110	16099	122.5	10%
508	25/05/11	8:53:04	Left	100	90	16099	122.5	18%
508	25/05/11	9:02:14	Right	100	205	16100	66.17	51%
508	25/05/11	9:03:08	Left	105	235	16100	66.17	59%
508	25/05/11	9:13:15	Right	115	200	16101	204.33	2%
508	25/05/11	9:19:58	Left	95	90	16102	110.33	14%
508	25/05/11	9:26:44	Right	95	90	16105	113.83	17%
508	25/05/11	9:57:28	Left	85	85	16097	100.17	15%
508	25/05/11	9:58:10	Right	85	85	16097	100.17	15%
508	25/05/11	10:01:49	Left	130	135	16098	61.83	110%
508	25/05/11	10:02:41	Right	90	90	16098	61.83	46%
508	25/05/11	10:21:08	Left	115	110	16095	126.33	9%
508	25/05/11	10:21:41	Right	90	70	16095	126.33	29%
508	25/05/11	10:21:08	Left	115	110	16096	112.00	3%
508	25/05/11	10:21:41	Right	90	70	16096	112.00	20%

Appendix E : E-Spott User Manual