AECOM

Sub-Task 2.2 – Investigation into the Detection of Radio Frequency Identification (RFID) Tags Installed in Highways Trials

Collaborative Research Project

Highways England, Mineral Product Association and Eurobitume UK

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Executive Summary

RFID technologies provide a potential method for recording and storing information related to pavement materials, for example, their supplier, mix type, date of installation etc. The technology offers a potential means for improving the accuracy of pavement information which could form part of routine surveys to provide identification and traceability of asphalt pavement materials.

A pilot scale trial was undertaken in December 2013 at a site in Ashford, Heathrow to determine whether readily available RFID tags could survive the mixing and compaction process, and be detected by readily available reading equipment.

AECOM carried out a survey in August 2017 which aimed to identify whether the RFID tags installed in the pavement remained detectable after 3.5 years in service.

Key findings from this work include:

- RFID tags were detectable in 3 out of four trial sections.
- A similar number of tags were identified in 2017 as were recorded in 2013/14, with slightly more tags being recorded in the 2017 survey.
- Though entirely not conclusive due to conflicting evidence of increases and reductions in tags located in different areas, the trial suggested that the number of tags installed is critical to future detection, suggesting attrition with time despite the general increase in the total number of tags read.
- Trends suggest a decrease in the number of tags identified with increasing vehicle speed and antenna height.

This survey utilised identical reading and antenna equipment to the previous survey, however, the original software was bespoke and not available for use during the 2017 survey. The difference in software used is not believed to be the cause of the increase in the number of readings picked up, as the previous software was purpose designed to operate at the highest speed looking for individual tags, maximising the potential speed of survey. AECOM's software was considered to be less aggressive but was also set to detect the specific type of tag to maximise the speed of survey. The additional tags located by this current trial are therefore most likely to be due to the specific profiles surveyed which are not directly repeatable.

Factors which affect the operable speed of the equipment include:

- The amount of information in the tags. More information on tags will require more energy to activate, meaning slower survey speeds would be required. Keeping data to a minimum or to easily compressible numerical data would maximise the effectiveness of tags for high-speed location
- The connection between tag reader and computer – a serial port was used for these surveys, but an Ethernet cable or directly coupled data logger within a purpose-built reader unit would improve this.
- A modern processor should allow greater amounts of data to be collected at a time
- Multiplexed antennas would allow multiple survey sweeps to be collected simultaneously.

1. Introduction

AECOM was commissioned to deliver Collaborative Research Task 1-111 which was jointly funded by Highways England, Mineral Product Association and Eurobitume UK. This sub-task is a follow on from a Collaborative Project delivered by TRL in 2013-14 where RFID tags were installed in a pavement trial in Ashford, Heathrow, UK.

This project aims to assess whether the tags installed in the 2013-14 trials are still detectable and to identify any potential improvements to technology since the 2013-14 trials.

1.1 Background

RFID technologies provide additional benefits that include identification of materials for their warranty or future recycling, for example by storing information related to aggregate and binder type which could potentially enable high-value use (recycling surface course into the surface course) without the need for excessive testing.

As such, a pilot scale trial was undertaken in December 2013 at a site in Ashford, Heathrow to determine whether readily available RFID tags could survive the mixing and compaction process, and be detected by readily available reading equipment.

Full details of the pilot trials and tag detection are publicly available, detailed in TRL Report PPR 698, Pilot Study using Radio Frequency Identification (RFID) Tags in Road Pavement Material Production, 2014.

10 mm SMA with fibres was supplied from West Drayton asphalt plant by Aggregate Industries and installed 50 mm thick using the conventional equipment. 75 tonnes of SMA was produced and the number of tags per vehicle was varied.

The trials demonstrated the practicality and feasibility of adding 16 mm RFID tags into the asphalt surfacing material at time of mixing and found that over 60% of the tags were detectable using a static or slow speed reader and around 30% of tags detectable using vehicle-mounted antenna and ‘long-range’ reader at vehicle speeds up to 45 km/hr. Antenna height was varied which found that an antenna height of 300 mm resulted in a reduction in the number of tags detected.

1.2 Scope

The major aim of this work was to determine whether RFID tags installed during pilot trials in 2013/14 were still detectable after three years in service, and to determine advancements in technology which present opportunities for improvement in the survey.

The project required AECOM to purchase equipment representative of that used by TRL to undertake a vehicle-mounted survey at varying antenna heights and vehicle speeds.

1.3 Trial site

The pilot trial site is located at Woodthorpe Road in Ashford, near Heathrow (see Figure 1) on a single carriageway residential road with 30 mph limit and additional speed control measures in the form of full-width speed humps and partial-width speed cushions as shown in Figure 2. The presence of the speed cushions limited the upper survey speed due to safety and clearance of the antenna.

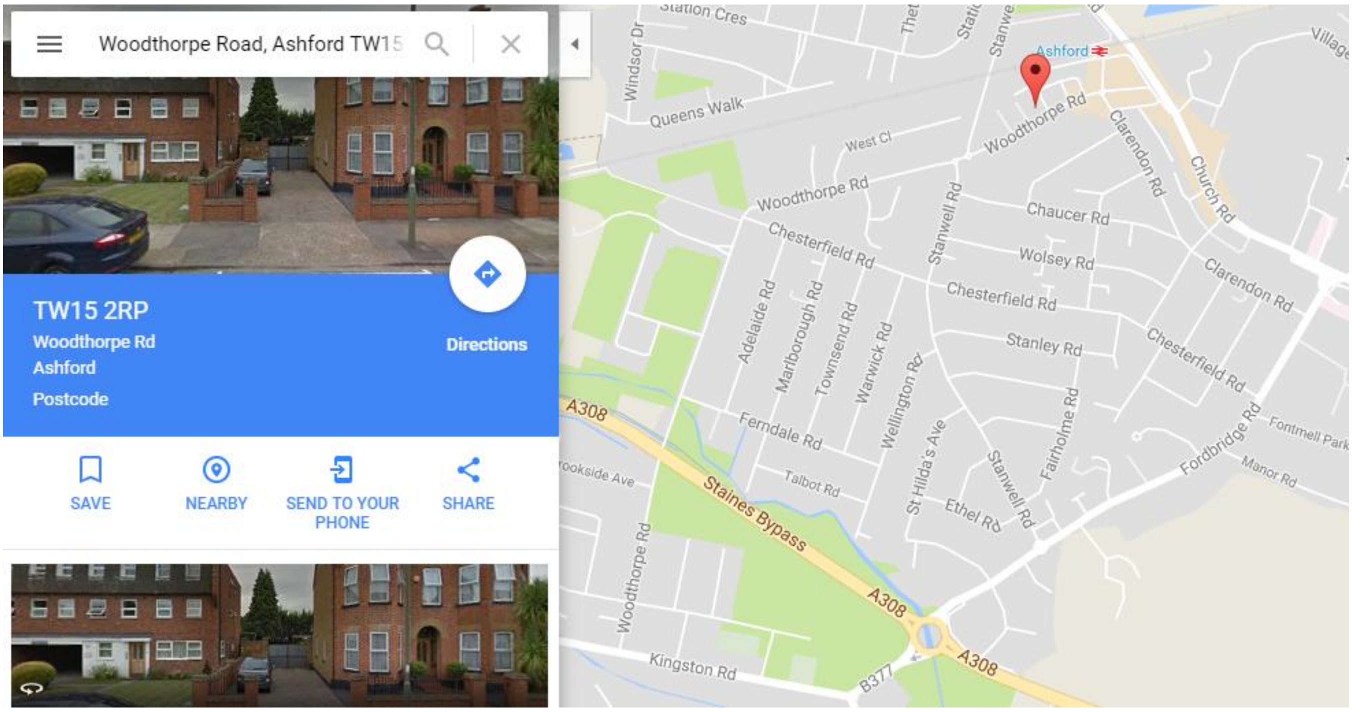

Figure 1: Pilot Site Location (Source: Google Maps, 2017)

Figure 2: Speed Cushions at the Start of the Pilot Trial Section (Source: Google Maps, 2017)

2. Methodology

2.1 The Survey

The survey was undertaken on the 5th September 2017 and was designed to act as a repeat of the original survey conducted by TRL in January 2014 after installation of the RFID tags December 2013, to allow an assessment of the effectiveness of the tags over time.

The site was, as far as was possible, surveyed during repeatable site conditions, in dry weather and at moderate temperatures. An initial attempt to repeat the original January winter survey conditions was aborted due to equipment compatibility issues.

Table 1: Survey Runs

Pass Number	Vehicle Speed (km/hr)	Antenna Position	Antenna Configuration	Antenna Height (mm)
1, 2 , 3, 4	20, 25, 30, 40	Nearside Wheel Path	Single antenna	200
5-8	20, 25, 30, 40	Centreline	Single antenna	200
9-11	20, 30, 40	Centreline	Single antenna	250
12, 13, 14	20, 25, 30	Offside Wheel Path	Single antenna	200

The table above shows the speeds of each survey run over, its position and the antenna height used. Additional calibration was undertaken during testing at the office to assess variance with height. Heights up to 300 mm showed a good correlation in tag identification (not including depth within the layer or lateral variation with respect to the antenna).

The site was flanked by speed bumps to each end of the site. This result of this was that constant survey speeds could not be safely maintained for the full survey extents, with acceleration and deceleration to survey speeds required within the test site. The highest speed runs were not attempted during this trial as this was not deemed safe by the site team given the site conditions. The purpose of the trial was to determine the repeatability of the test over time not the effectiveness of the test with speed, which had already been demonstrated by the previous test regime.

The survey was confined to the running lanes and did not enter the hatched areas or turning lane which did form part of the installation trial and also contains RFID tags.

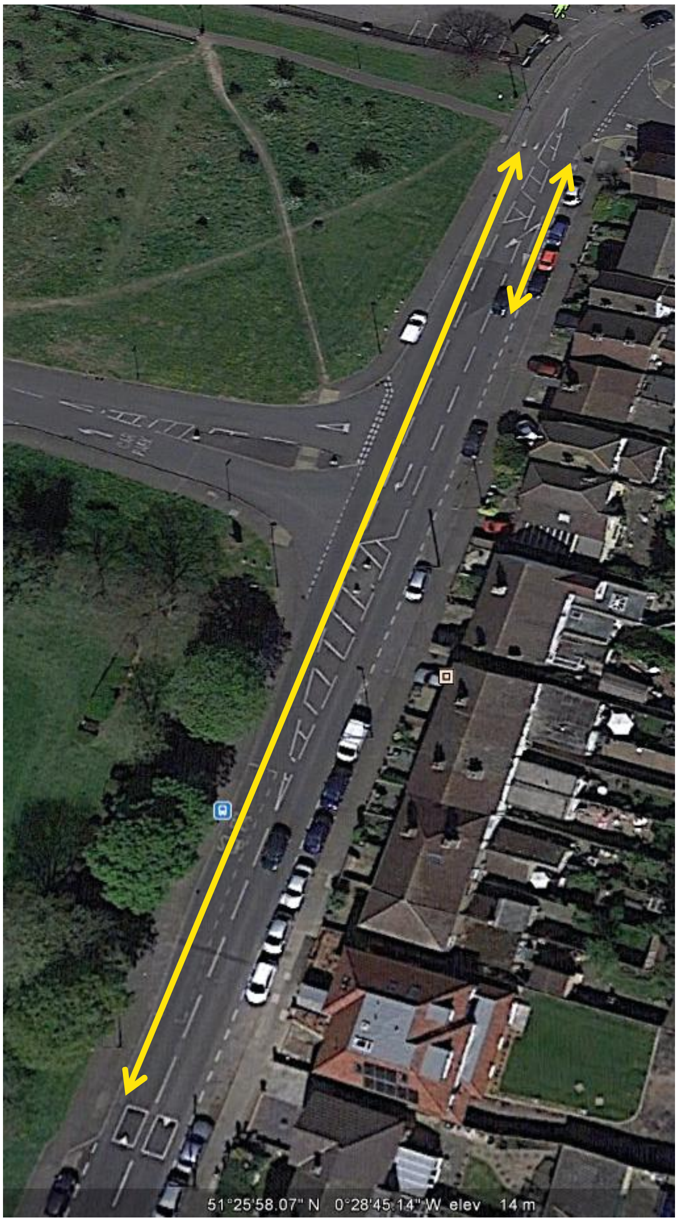

Figure 3: Image Showing the Survey Extents (Google Earth August 2017)

2.2 Equipment

The equipment used was chosen to be the same as that used in the original trial. Some initial lab and site-based trials proved unsuccessful due to a number of issues, including inconsistency of equipment provided by the supplier, compatibility of adapter/link cables and software compatibility with different versions of software proving incompatible with the specific equipment used. AECOM set up a survey vehicle with vehicle mounted antennas for the purposes of this survey, as shown in Figure 4.

Figure 4: AECOM's Survey Vehicle

Of key importance, was that bespoke software was developed for the purpose of the original trial to provide a more aggressive tag reader which in theory should pick up more tags. AECOM was unable to utilise this software during this investigation, instead of using a more standard off the shelf Unidemo (version 3) to operate the equipment.

The equipment used for the trial is listed as follows:

- Survey Vehicle
- Rear Antenna Mounting Bracket
- 0.6m Diameter Loop Antenna
- Control Unit – Scemtec “Long Range” SHL2100 13.56MHz Reader
- Laptop
- 12V Battery
- Tags – Logitag 161

Figure 5: SHL2100 Reader and 0.6 m Diameter Loop Antenna

3. Results

The number of separate tags identified on each pass is shown in Table 2 below.

Table 2: Tags Identified Per Pass

Pass Number	Vehicle speed (km/hr)	Antenna Position	Antenna Configuration	Antenna Height (mm)	Number of Tags Identified
1	20	Nearside Wheel Path	Single antenna	200	40
2	25	Nearside Wheel Path	Single antenna	200	35
3	30	Nearside Wheel Path	Single antenna	200	29
4	40	Nearside Wheel Path	Single antenna	200	21
5	20	Centreline	Single antenna	200	45
6	25	Centreline	Single antenna	200	45
7	30	Centreline	Single antenna	200	43
8	40	Centreline	Single antenna	200	41
9	20	Centreline	Single antenna	250	41
10	30	Centreline	Single antenna	250	31
11	40	Centreline	Single antenna	250	31
12	20	Offside Wheel Path	Single antenna	200	42
13	25	Offside Wheel Path	Single antenna	200	38
14	30	Offside Wheel Path	Single antenna	200	30

Each tag was identified numerous times, becoming less frequent as speed increased

Tags were originally laid by four separate delivery trucks, each containing 20 tonnes of asphalt with different characteristics for each truck. The location of installed material from each truck is presented in Figure 6.

- Truck 1 utilised 200 tags added to the mixer in the plant
- Truck 2 utilised 100 tags added to the mixer in the plant

- Truck 3 utilised 40 tags added to the mixer in the plant
- Truck 4 utilised 100 tags added to the truck

Figure 6: Image is Taken from TRL report PPR 698 Showing the Location of Installed Deliveries

The original trial survey identified a relatively consistent detection rate in tags from Trucks 1-3 as tested at slow speed, though at high speed showed significantly more variability in detection rates with an increased % detection rate from Truck 3 and reduced rate from Truck 4. The 2017 survey successfully identified tags in the material from Trucks 1, 2 and 4, but no tags were identified in the asphalt from Truck 3 on any run conducted. The primary differentiation between Truck 3 and the other areas was the number of tags used in the mix.

4. Analysis

The trends in a number of tags identified with speed are shown in Figure 7 with a gradual reduction in the number of tags identified as speed increased. The higher speeds were not achieved on all passes during this survey due to safety concerns with travelling at higher speeds over the speed bumps with reduced antenna clearance. The raw data shows that each tag was identified numerous times, becoming less frequent as speed increased.

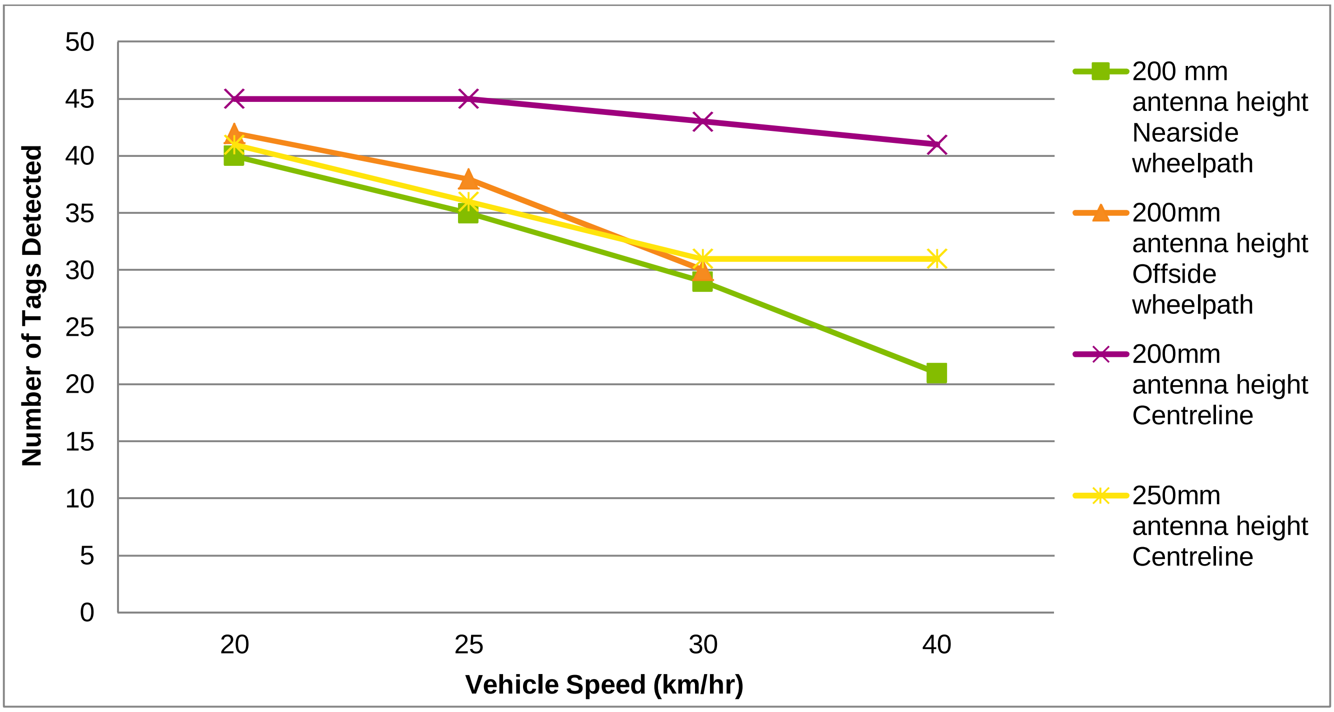

Figure 7: Trend Lines Showing Tags Detected (Vertical) Against Speed (Horizontal) at 200mm Antenna

At 20 kph, typically around 40 tags were identified in each of the wheel paths with 45 tags detected along the centre line. Assuming a relatively even distribution of tags, this is likely to be due to the tags reader picking up adjacent tags as well as those directly beneath the antenna, with the two-wheel path runs having one side where tags were not present reducing the overall number.

For comparison with the original survey, the data were assessed to look at the combined total number of separate tags identified on a combination of the 20kph runs at the 200mm antenna height (nearside wheel path, offside wheel path and centreline), as closely as possible representing data collected across the full carriageway. The summary below shows the number of tags identified against those identified in the original survey.

- 2014 Trial – Trucks 1, 2, 3 & 4 – Tags detected: 109
- 2017 Trial – Trucks 1, 2, 3 & 4 – Tags detected 111
- 2014 Trial – Trucks 1, 2 & 4 – Tags detected: 95
- 2017 Trial – Trucks 1, 2 & 4 – Tags detected 111

As can be seen, the number of tags identified in this trial was fractionally more than had been identified in the original survey. This is despite no tags being identified within the material from Truck 3.

The differences between survey findings could be due to a number of factors, with the most likely reason being the slight variances in the positioning of the longitudinal profiles or different software used. This assumption is based upon the variability in tag identification at high speed identified in comparison with the slow speed survey from the original trial.

The results also found that 16 of the tags were detected during passes in the wheel track as well as the centreline. This suggests an overlap between the runs with good coverage of each lane being achieved.

Trends in height are not clearly demonstrated with this survey due to only one run being completed at a greater height, though the reduction in a number of tags picked up at 250 mm at various speeds corresponds with findings of the previous trial. On assessments undertaken at fixed points and known tag position during this trial, the tags were equally identifiable at all antenna heights up to 300 mm.

5. Key Findings and Lessons Learned

The data collected from this investigation shows a comparable number of tags were found in the surveys at 20 kph. This initially suggests that the tags have not deteriorated significantly since the original trial. However, in the 2014 trial, Truck 3 had fewer tags added but had a higher percentage (%) identified in the original trial. In contrast, the 2017 surveys showed that no tags were found in this location on any run collected.

Despite the variability in the % of tags identified in the survey runs, this shows that there has been a significant change in the number of tags detected in this area and may suggest some degradation of the tags over time. The complete absence of readings from this area suggests that there may be other factors at play which requires further investigation. A detailed slow speed/manual survey would be required to investigate this further. The addition of a further test area where tags from different batches were intermixed would remove any queries over the effectiveness of tags from different batches affecting results.

Tags were identified in the asphalt associated with Truck 4, where tags were added after the mixing process was still found in this survey. The reason for the 2017 survey picking up a higher number of different tags could be due to a number of reasons but appears likely to be primarily due to fractionally different profile locations (i.e. different paths of travel from natural variation or wander). There were a number of variables between surveys, in particular, the change of software (as the original software used was not available for the 2017 survey), which could potentially have improved confidence in this.

At the onset, this second phase of investigations was aimed to be a repetition of the previous surveys to allow direct comparison between data sets. To achieve this end, full documentation of the equipment and software used was required alongside repeatable site conditions.

Throughout the process of undertaking this survey, a number of equipment and software compatibility issues were identified and AECOM discovered that bespoke aggressive detection software had been developed and utilised for the original trials. The software details were not reported in TRL report PPR 698. Ultimately the survey was carried out using a more stable, off the shelf software. This meant that although the results could not be directly comparable with previous trials, ultimately they should facilitate a more easily repeatable survey for future. The most likely variable (beyond variance in the location of the profiles) to cause the increase in the number of tags located is likely to be the scan rate of the equipment induced by the software. From discussions with the equipment supplier and writer of this software, it is understood that the bespoke software used by TRL should have operated at a faster rate than the system used for this 2017 survey.

The temperature variance between the surveys may also have had some effect on the results, though this was not established. The presence of speed bumps to each end of the survey means that some acceleration and deceleration to survey speeds is required within the survey area, particularly at higher speeds. This means that truly repeatable measurements of the effectiveness of the RFID readers at different speeds are not possible for the site without some error.

6. Potential Improvements

A number of factors could aid both the repeatability and the effectiveness of the surveys. These include:

- A purpose built system incorporating the tag reader, operational software and data logger with ports to link to antennas would remove compatibility issues with computers, control units and link cables, minimising variability in data quality and maximising scan speed and survey output.
- Multiplexed antennas would increase the number of simultaneous runs.
- Low energy tags which require less energy to transmit.
- Minimising and simplifying the data stored on the tags will minimise the energy required to activate them. Keeping the data in numerical format should support this as it is more easily compressible.
- On any similar trial, a further test area where tags from different batches were intermixed would remove any queries over the effectiveness of tags from different batches affecting results.
- Scan rates can be maximised by narrowing the search to specific tags, potentially allowing higher speed surveys.
- Linking to GPS would aid in geo-referencing outputs.
- Antenna positioning in front of and behind the vehicle is less practical for operational use. Positioning on a protective sled mounted beneath the survey vehicle could be an operational improvement. However, interference from the vehicle could be a potential issue here and as such a uni-directional antenna would be required to facilitate this. This would require further trials to assess effectiveness.
- Removal of the speed bumps from the survey area or choice of an alternate survey area would allow consistent speeds to be achieved safely and improve repeatability of surveys.
- The reduction in number of tags picked up at 250 mm antenna height at various speeds suggests that height is a factor in the reading of tags, potentially due to tags towards the edge of the field of the reader going out of range rather than those directly beneath the reader, though this was not assessed in detail in this investigation, a greater overlap between antennas may allow the same number of tags to be picked up at greater antenna heights.

7. Conclusions

The investigation suggested that the method of installation of tags is not critical to their operable life. The total absence of readings from tags from Truck 3 suggests either external factors have affected the tags in this location or genuine attrition of the tags with time. External factors which could have affected the tags may include:

- Failure in particular batches of tags used - batches of tags were not intermixed.
- Unrecorded variations in the mixing or laying process, potentially increasing damage to the tags affecting long-term life.

The number of tags located in the other areas suggests a lack of attrition with time with the only recorded difference between areas being the number of tags installed. This discrepancy between the areas could suggest that the number of tags installed within the asphalt is crucial to their long-term detectability.

Consistent with the original trials, the speed of survey and height of antennas again showed that they affected the ability of the reader to pick up the tags, with a consistent trend in reducing tags detected with speed and height.

Multiplexed overlapping antennas would give greater data coverage picking up a greater % of tags and providing more consistency of results. This would minimise the effects of antenna height and higher survey speeds, though the same trends would be present.

The amount of data stored on the tags will be crucial to their effectiveness at being read at high speed. It is important that the information stored is designed to be minimal and easily compressed.

9. Recommendations

The primary recommendation based on this investigation is that the number of tags installed in the mix appears to be a significant factor in long-term detectability. This should be the primary point of optimisation.

The trial has also highlighted a number of potential avenues which may allow improved resolution of tags and aid in their operational use in addition to further assessment of their effectiveness with time using comparable equipment and software.

- Trials with greater antenna overlap would be suggested to look at options for maximising detection rates for greater antenna heights.
- Trials with a unidirectional antenna would potentially allow an under-vehicle mounting, improving the operational use of the equipment.
- Adoption of fixed equipment set up on repeat surveys, potentially including a control unit and data logger (rather than a computer) would minimise issues with direct compatibility on repeat surveys and potentially allow faster rates of operation.
- Minimising the data stored on the tags will allow them to be picked up more effectively at high speeds. Data should be carefully planned and ideally numerical to allow it to be easily compressed.
- A test site where continuous speeds are safely feasible to the full extent would allow more comparable results for repeat surveys.
- Trials looking at the effectiveness of tags during different temperature and weather conditions may prove of value.
- Mixing of tags from different supply batches would minimise the risk of quality issues should they be present.