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PUBLISHED PROJECT REPORT PPR698

Pilot study using radio frequency identification (RFID) tags in road pavement material production.

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Transport Research Laboratory
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Collaborative Research 2013-14

Adam Cook and Geoff Crabb

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Executive Summary

Radio frequency identification (RFID) tags and associated read/write technology has been identified as a potential means of providing a method of capturing and storing information related to the material produced in asphalt plants and making it available to stakeholders. This should improve the accuracy of information held in pavement management databases.

A pilot scale trial has been held to determine whether non-specialist RFID tags can survive being added to materials at asphalt plants, where they will be subjected to risk of both mechanical and thermal damage. The trial also sought to determine whether it is feasible to read a viable proportion of the tags once embedded randomly in the pavement surfacing after transport, laying and compaction.

The trial took place on 12th December 2013 and was located in Ashford near Heathrow. The works involved a full carriageway width overlay for approximately 125m using a 10mm SMA (with fibres) in 2.5T batches. The material was provided by Aggregate Industries' nearby West Drayton plant. Some on-foot RFID measurements were taken immediately after rolling and on the 13th December whilst road marking works were being carried out. Vehicle based measurements were carried out on 9th January 2014.

This trial has demonstrated the practicality and feasibility of adding 16mm tags to asphalt at the time of mixing. Over 60% of the tags were readable using a static or slow speed reader and therefore survived the temperatures and agitation associated with the mixer, survived the sustained high temperatures of storage/delivery and the mechanical pressures associated with laying and rolling of the material. This means that in order for one tag per material batch to be readable by a stationary or static antenna, a dosage rate of 2 tags per batch or 1 tag per tonne of material would be required, based on 2.5T batches.

Approximately 31% of the tags could be read by a vehicle-mounted antenna and 'long range' reader where the total width scanned by the antenna was a little less than the vehicle width. In order for one tag per material batch to be readable by a vehicle-based system, a dosage rate of at least 4 tags per batch or 2 tags per tonne, based on 2.5T material batches, is required.

Over the range of survey vehicle speeds tested during this trial (up to 45km/h) there was little difference in the number of tags read in passes of increasing speed. However, within the antenna field a tag is read multiple times; therefore the number of times an individual tag could be read would also give a good indication of the effect of increasing survey vehicle speed. The average number of times a tag was read (total number of read events / unique tags identified on any given pass) was shown to significantly decrease with increasing survey speed, as might be expected. If this decrease is assumed to be linear, it can be extrapolated that the speed at which the average number of times any individual tag will be read once is approximately 58km/h. This is 22km/h short of the typical 80km/h trunk road and motorway survey speed carried out by traffic-speed survey vehicles.

The trial showed that, for antenna heights of 250mm or less, there was little effect on the number of tags that were read in the surface course. However, for an antenna height of 300mm, the number of tags read dropped dramatically with increasing speed. The effect of tag depth (within the pavement) on readability was not assessed as part of this trial as all the tags were added to the inlaid 50mm surface course material.

Contents

1 Background

Radio frequency identification (RFID) tags and associated read/write technology has been identified as a potential means of providing a method of capturing and storing information related to the material produced in asphalt plants and making it available to stakeholders. This should improve the accuracy of information held in pavement management databases.

Previous work has identified the additional benefits of having detailed information on asphalt materials available centrally and the use of RFID could facilitate this.

The use of RFID tags in asphalt could provide easy identification and traceability of materials during routine surveys of the network using TRACS type vehicles. This could have benefits in later identification of materials for both the warranty and future use (recycling) perspective as the information could include product characteristics such as aggregate type, grading, binder type, content etc. that would be invaluable in assessing the suitability for re-use into a high value application (e.g. recycling surface course back into surface course) without the need for excessive testing.

2 Objectives of Trial

The aim of the trial described in this report was to establish whether non-specialist[1] RFID tags could survive being added to the material at the asphalt plant, where they will be subjected to risk of both mechanical and thermal damage. It also sought to determine whether it is feasible to read a viable proportion of the tags once embedded randomly in the pavement after transport, laying and compaction.

The trial assessed the following:

- Survivability of (or at least ability to detect) a percentage of tags with a stationary reader following pavement construction;
- Maximum speed a survey vehicle could travel and be able to read and identify at least one tag from each material batch; and
- Using the above information, determine a "per batch" or "per tonne" dosage rate to allow enough tags to survive and be read and identified by a traffic speed vehicle-mounted RFID reader.

[1] Readily commercially available RFID tags not specifically designed for this application

3 Trial Site

A suitable plant was needed to undertake the trial with the facility to add tags directly into the mixer. Ideally the site on which the materials were laid should allow for traffic speed measurements to be undertaken. TRL worked with industry to identify potential schemes and suitable plants and Aggregate Industries volunteered their West Drayton asphalt plant and a surfacing scheme that was being laid near Heathrow in December 2013.

3.1 Site details

The minimum journey time between the plant and the trial site was anticipated to be around 20 minutes.

The trial site was located on a single carriageway residential road, with a 30mph limit, in Ashford, Middlesex with additional speed control measures in the form of both full width speed humps and partial-width speed cushions. The scheme itself was a full carriageway width inlay, approximately 125m long. Whilst not ideal from a traffic speed perspective, the site was easily accessible and it would allow both the survivability and dosage rate requirements to be assessed (with traffic speeds up to 30mph).

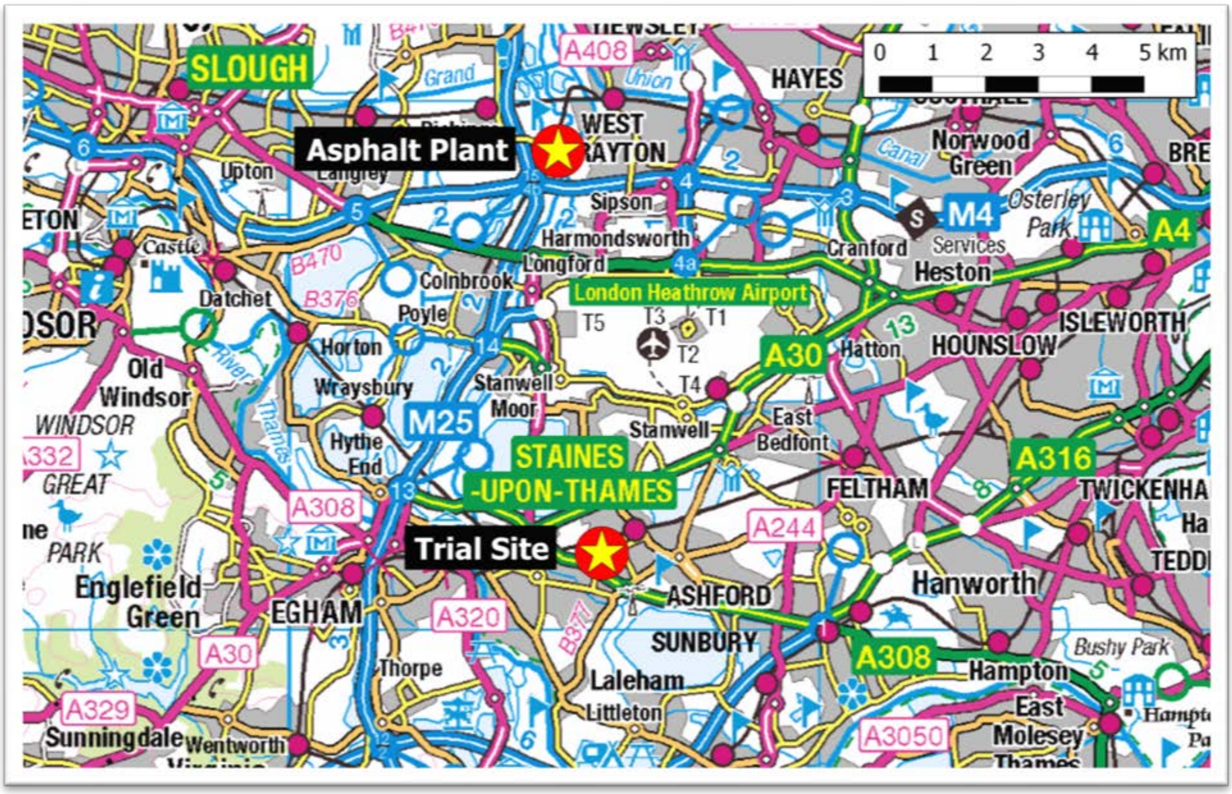


Figure 1 - Trial map showing material plant and works site locations

This site presented some additional issues as it lies between a speed cushion in the south and a full width speed ramp in the north. Given that the RFID antenna has to be mounted with low ground clearance, this also effectively limited the upper survey speed.

The scheme was an inlaid thin surfacing, so it was not possible to assess the ability to read tags at varying depths. This could be accomplished in laboratory tests or with the addition of tags at another site.

Table 1 – Summary of material supplied

Plant	**Aggregate Industries, Thorley, West Drayton**
Material	**10mm SMA (with fibres)**
Batch Size	**2.5t approx.**
Mix Time	**60 sec approx.**
Mix Temp	**165-185°C (limits on plant)**
Site	**Woodthorpe Road, Ashford**

4 Equipment

4.1 Tag Selection

In order to minimise the risk of mechanical damage and for compatibility with the asphalt mixture, the maximum tag dimension should ideally be similar to the maximum aggregate size (10mm) and small in comparison to the nominal layer thickness (50mm). Since larger tags have an increased ability to be read, it was decided to use a 16mm diameter, 3mm thick tag (Logitag 161). The Logitag 161 contains a high-frequency device and antenna and is readily available in large numbers. Their thermal ratings are given in Table 2.

Table 2 - Logitag 161 RFID tag thermal damage thresholds

Temperature (°C)	Endurance
120	100 hours
220	30 seconds
175	100 x 10 minute cycles

Earlier laboratory work using these tags demonstrated they could survive the laboratory mixing and compaction processes (mix temperature of 185°C for over 3 min) and still be read. From Table 2, it is clear that asphalt mixing, storage and delivery temperatures of 165°C to 185°C were very close to those at which tags may start to degrade, so the timing of each part of the process following the addition of the tags was recorded.

4.2 RFID Reader

Figure 2 - Scemtec “long-range” SHL-2100 13.56Mhz

A Scemtec SHL-2100 Long-Range reader (Figure 2), coupled with a 0.6m diameter loop antenna was used. This high-frequency-band RFID system is fully compatible with the Logitag 161. It requires a laptop computer running control software (including the demonstration software provided), and mains or battery power to operate. Power is provided by the host survey vehicle when mounted on this vehicle, or by a battery and voltage converters or a generator if stand-alone. A simple antenna bracket was fabricated to allow the antenna to be easily fitted to the survey vehicle. This allowed quick adjustment of the antenna height and offset position relative to the centre of the vehicle.

4.3 Survey Equipment and Ancillaries

For the static on-foot tag detection survey, a purpose built trolley containing the RFID reader unit, a power supply and laptop computer was used. A survey grade GPS system recorded the spatial position of features on site such as the extent of paving. For the vehicle mounted survey, the RFID reader was transferred from the trolley to the TRL survey vehicle.

5 Trial Procedure

The pavement works took place on 12th December 2013. Some static RFID measurements were taken on the 12th immediately after rolling and on the 13th whilst road marking works were being carried out. Vehicle based measurements were carried out on 9th January 2014.

5.1 Asphalt Plant

Previous research on tag survivability and laboratory measurements of tag orientation relative to horizontal antenna orientation and its effect on tag reabability was used to estimate a likely dosage rate. This work showed that as well as needing to survive the temperatures and mechanical stresses of material production and pavement construction, once in a pavement, a tag had to lie within 60° of horizontal in order to be readable by an antenna in a horizontal orientation. This meant that as many as 26 tags per tonne of material might be required in order to allow an average of one tag every 10m in a 0.5m wide path to be read by a single reading antenna in one 56mph pass. However, the dosage rate could be reduced by making multiple passes or by having multiple antennas fitted to the survey vehicle to increase the effective reading width. Therefore it was proposed that the trial dosage rates should be 10, 5 and 2 tags per tonne. Based on a perceived batch size of 2T, and 20T delivery trucks, the predicted tag batches were as outlined in Table 3.

Table 3 - Tag batches and predicted dosage rates

Truck	Truck Load (T)	Tag batch No.s	Tags per Tonne	Per batch (2T)	Tags per truckload	Added to	Per 10m lane length
1	20	1-10	10	20	200	Mixer	≈29
2	20	11-20	5	10	100	Mixer	≈15
3	20	31-40	2	4	40	Mixer	≈6
4	20	21-30	5	10	100	Truck	≈15
		Total batches in trial		**40**	**440**	**Total tags required**	

The ID codes of the tags in each batch were recorded in advance using the Scemtec RFID reader and the batches placed in small labelled Ziploc plastic bags to avoid cross contamination between batches.

Upon arrival at the plant, the size and number of material batches was not as expected. Instead of 2 tonne batches, 2.5 tonne batches were produced, therefore Table 4 shows the actual tag batches cross referenced with the material batches and dosage rates achieved in the trial.

Table 4 - Tag batches and actual dosage rates

Truck	Truck Load (T)	Tag batch No.s	Material batch No.s	Tags per Tonne	Per batch (2.5T)	Tags per truckload	Added to	Per 10m lane length
1	20	1-8	1-8	8	20	160	Mixer	≈23
2	20	11-18	9-16	4	10	80	Mixer	≈12
3	20	31-38	17-24	1.6	4	32	Mixer	≈5
4	15	21-30	25-32	5.3	10	≈80	Truck	≈16
				Total batches in trial	**34**	**≈352**	**Total tags**	

At the asphalt plant each of the tag batches 1 to 8, 11 to 18 and 31 to 38 was added by TRL, under the supervision of plant staff, to a separate asphalt batch during the mixing process. The tags were added in with the fibre pellets at the dry mixing phase. The object was to achieve a uniform distribution of tags within the mix. One of the dosage rates was repeated but with the tags added to the truck rather than the batch mixer. This was done to allow the survivability and distribution of tags to be directly compared between the two methods. Therefore the remaining tags (batches 21 to 30) were added to one truckload after mixing. These batches will have been subjected to slightly lower temperatures for a shorter time. The tags were scattered by hand over the material once in the truck; the objective was to achieve a uniform distribution between and within the batches added to the truck.

Figure 3 – Tags added through chute with fibre mix pellets

Figure 4 – Tags scattered on material in fourth truck

5.2 Works Site

The first material truck arrived at the works site at approximately 12:20, followed closely by the 2nd and 3rd trucks. Material laying did not start until 14:15 due to a delay in the arrival of the fourth truck (four trucks were required for a complete rip, so laying did not commence until the fourth truck had arrived on site). Table 5 shows details on the material delivery schedule. The departure temperature was measured using a probe in the material in the back of the truck.

Table 5 - Material delivery information

Truck	Batch Mix Time	Departure Time	Departure Temp (°C)	Tip Time
1	11:45 – 12:05	12:08	177	14:15
2	12:06 – 12:23	12:45	176	14:32
3	12:24 – 12:40	12:50	176	14:50
4	12:41 – 13:00	13:45	176	15:05

Figure 5 – Material extents per truck recorded using GPS

The extents of the area covered by each of the four trucks containing tagged material were located using the survey GPS (Figure 5). The material hopper doors were folded in after each truck finished unloading with the aim of keeping the tags within a known section of pavement. The location of the boundary between the material from different trucks was estimated from the location of the paver auger when each truck began unloading. Therefore the accuracy of this transverse 'join' is likely to be high, within 1m; however some mixing between truckloads is inevitable. Figure 7 shows the surveyed extents of the material from each of the four trucks containing tagged material.

It should be noted that it was not possible to see any of the tags present either in the material hopper or in the surfacing material after laying.

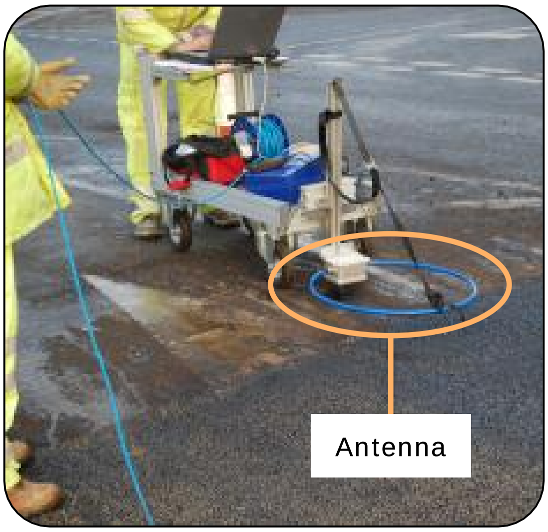


Figure 6 – Trolley mounted RFID reading equipment

Access to the material surface was granted in short sections (around 30m long) immediately after rolling. The trolley mounted RFID system (Figure 6) was pushed longitudinally over the site in parallel lines. The offset of the parallel lines was such that the entire width of the material was covered. The system logged each unique tag detected in each pass against time. It was intended that the position of each detected tag would be recorded using the GPS device. It became apparent that this was not practical in the time given. Instead the start and end position of each trolley pass was recorded with the GPS. It was then possible to longitudinally locate a detected tag later by using the elapsed time from the start of the pass in which it was logged by the reader.

Unfortunately it became apparent that the purpose built trolley was leaving lines on the material surface. Therefore TRL were instructed to allow the material to cool further before accessing it. This meant that there was insufficient time to complete all measurements within the first visit. TRL took the opportunity to return to site the following day to collect the remainder of measurements whilst road marking operations were being carried out. This meant that all areas were covered with the exception of the second rip from Truck 4 on the southbound lane.

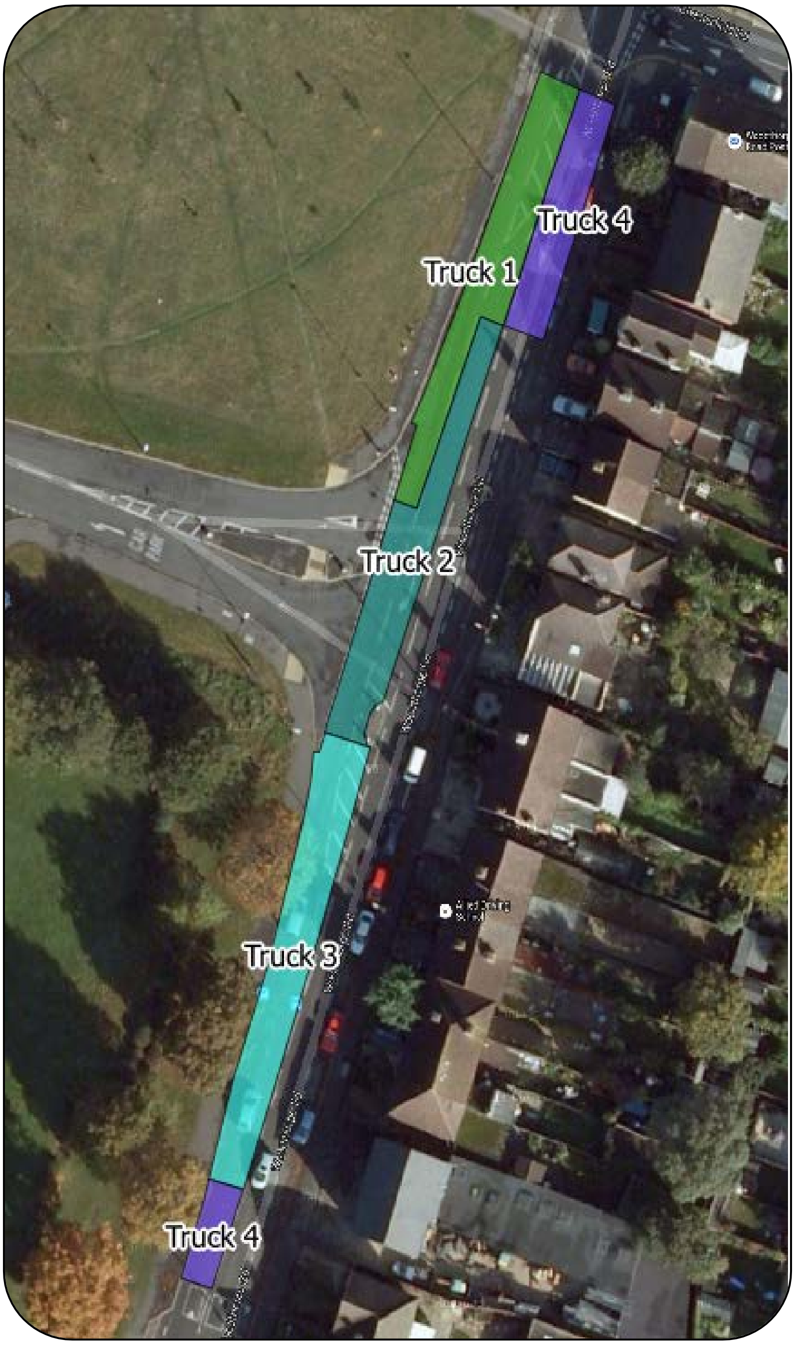


Figure 7 - Surveyed material extents per truck

Figure 8 – Survey vehicle with front mounted RFID antenna

The RFID system and antenna was mounted on TRL's survey vehicle and vehicle measurements were carried out on 9th January 2014. For these measurements TRL made use of RFID logging software that it had specially commissioned for other traffic speed RFID measurement trials. This software removes certain data transfer overheads that can increase the time required to read tags; this represents the fastest possible read rate and increases the likelihood of success in reading tags at speed. It should be noted that in this trial no data had been written to or was attempted to be read back from the tags. Reading was limited to the unique identification number recorded on each tag by the manufacturer, which is much faster than when user data is read.

A total of 21 passes were completed over the site, in both lanes, at various vehicle speeds and with different antenna offset positions and heights. In each pass, the software read the unique ID of each tag it detected as many times as it was able to whilst the tag was in the field of the antenna. Vehicle speeds ranged from 13 km/h to 50km/h. Table 6 shows the passes completed with vehicle speed, offset and antenna height.

Table 6 - Vehicle RFID detection passes completed

Run Numbers	Vehicle Speed (km/h)	Antenna Offset Position	Antenna Height (mm)
1 - 5	45, 40, 30, 20, 13	Nearside wheelpath	200
6 - 9	45, 40, 30, 20	Vehicle centreline	200
10 - 13	45, 40, 30, 20	Offside wheelpath	200
14 - 17	50, 40, 30, 20	Offside wheelpath	250
18 - 21	50, 40, 30, 20	Offside wheelpath	300

6 Results

The log files from both the trolley scans and the vehicle scans have been entered into a database containing the unique IDs of the tags linked with the tag and material batch information. This allowed the data to be easily queried.

6.1 Tag detection rate and dosage rate

The tag detection rate, also referred to as survivability, is the proportion of tags that can be read by the trolley mounted antenna following pavement operations. Strictly speaking it is not tag survivability as there are likely to be tags that have survived but could not be read. For example, tags that are orientated with their flatter plane near vertical will not be read as easily if at all as those that are lying flat or close to flat. This information will help us determine a minimum dosage rate for tags in asphalt batches such that enough tags from each batch can be detected.

6.1.1 Dosage rate from trolley data

The log files have been queried firstly by delivery truck to ascertain how many tags from each truck could be detected. This data is presented in Table 7. Unfortunately not all of the area covered by material from truck 4 (tags scattered in the truck) could be accessed by the trolley therefore to avoid skewed results, tags detected from this truck have been omitted.

Table 7 – Trolley based tag detection rate by delivery truck

Delivery Truck	Tags Added	Tags Detected	Detection Rate (%)
1	**160**	**106**	**66**
2	**80**	**55**	**69**
3	**32**	**19**	**59**
TOTAL	272	180	65

An average detection rate of 65% and a minimum detection rate of 59% suggest that if only delivery trucks are required to be identified from the tagged material and the full carriageway width can be scanned effectively, it is likely that at least 1 in every 2 tags added will be detected. This would mean that a dosage rate of 2 tags per truck or 1 tag every 10T of material. However, it may be beneficial to be able to identify material at a batch level in some cases. In normal operating circumstances at an asphalt plant, several batches of material will be produced and stored in hot bins. This will mean that the material can be stored at an elevated temperature for an extended period and when the material is loaded into trucks this will invariably lead to mixing of individual batches.

The tag database was queried to show tag identity grouped by material batch, this information is shown in Figure 9. At the statistically determined dosage rate of 10 tags per batch, at least 5 tags from every batch could be detected by the trolley mounted RFID reader. This suggests that assuming the full carriageway width can be read, the dosage rate can be less than 10 per batch or 4 per tonne of material. Unfortunately there was one batch of material from the low tag dosage rate tests (4 per batch or 1.6 per tonne of material) where no tags were detected. For the remaining low dosage batches, at least one tag from each batch was detected. This suggests that a dosage rate between 1.6 and 4 tags per tonne is appropriate, assuming the full lane width can be scanned. It is therefore likely that the originally estimated ‘low’ dosage rate of 2 tags per tonne should be sufficient.

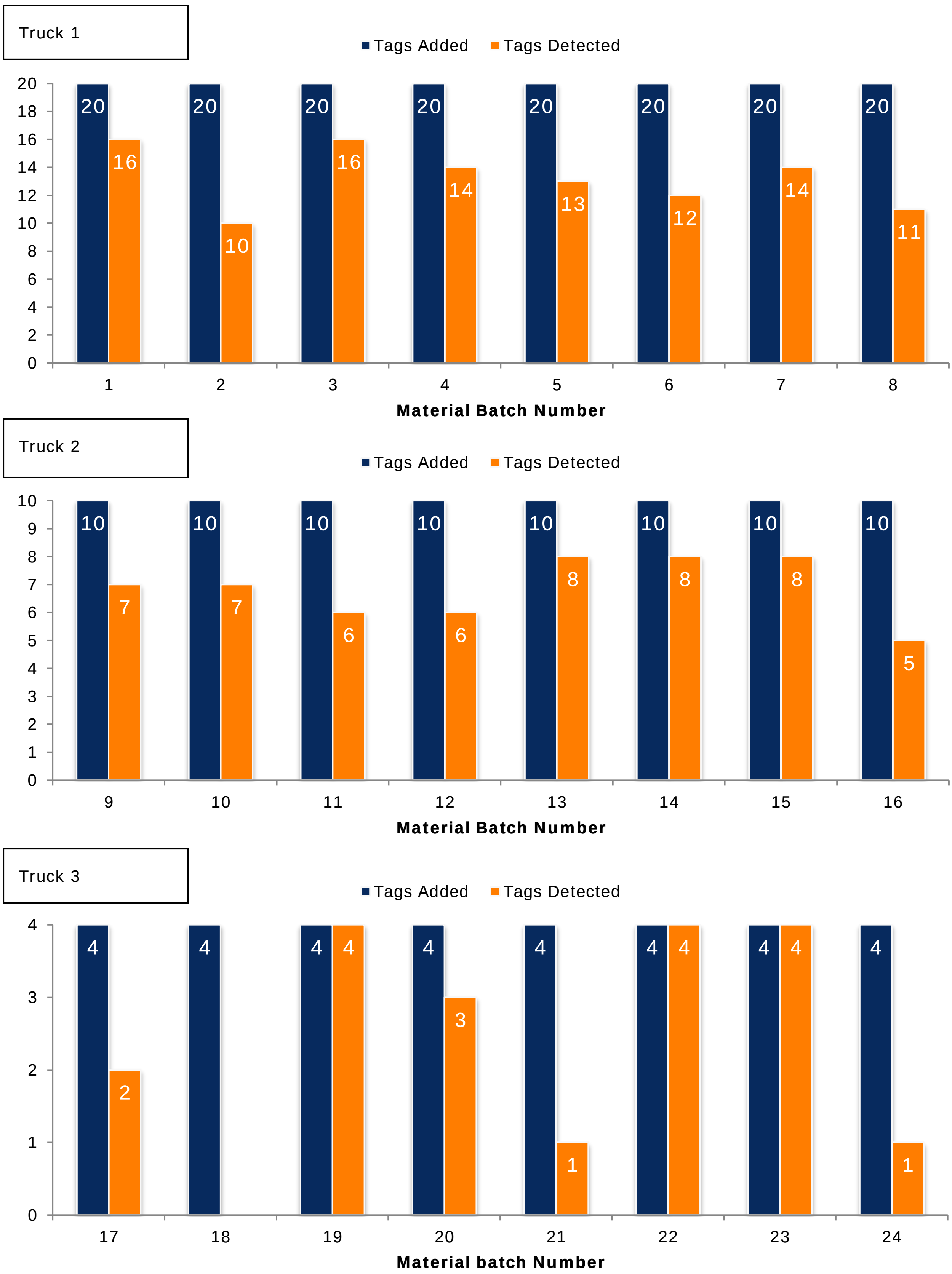
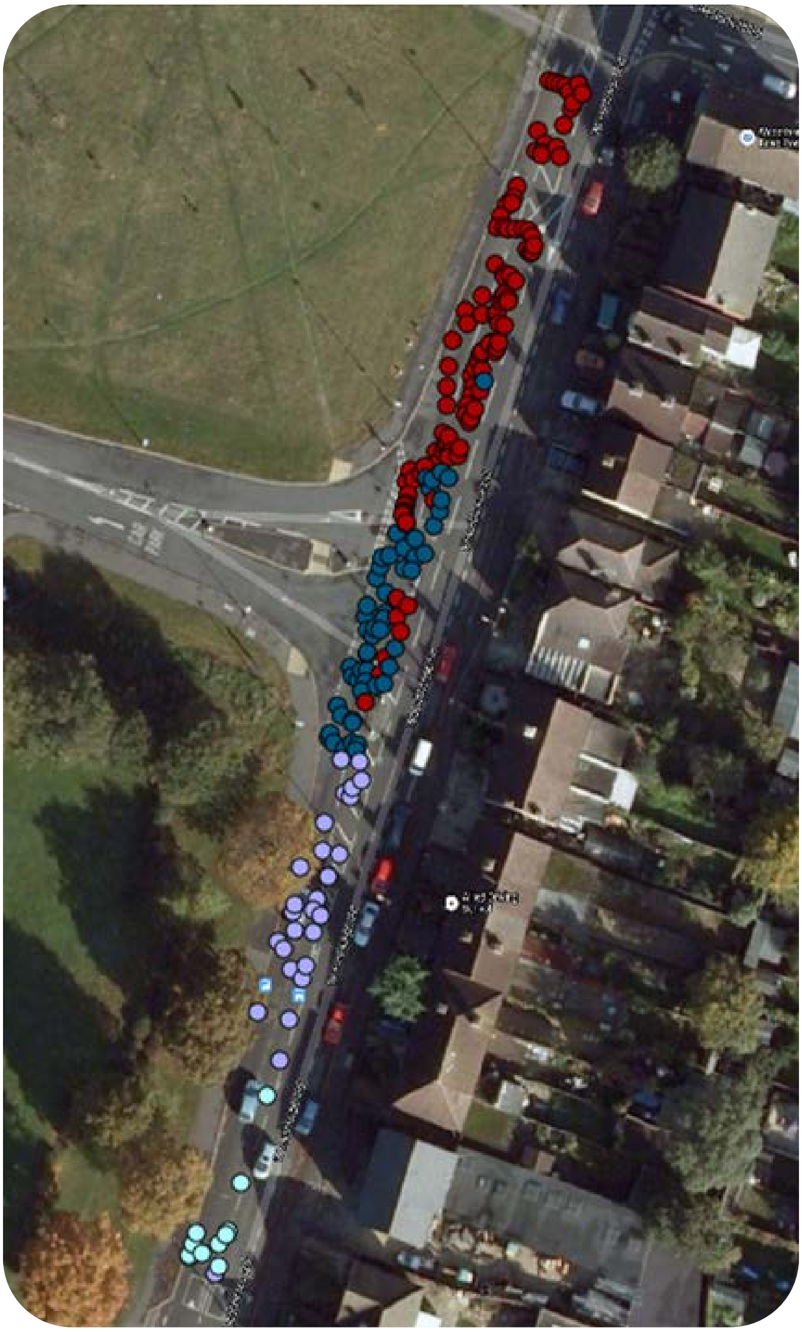


Figure 9 – Trolley tag detection by material batch

6.1.2 Tag distribution from trolley data

Although not a key objective of this pilot trial, having the tag location information presented the opportunity to assess how materials are distributed in a site where continuous laying is used. By plotting the approximate (within 5m) positions of the detected tags using a plan of the site it was possible to see how much migration there was both between truck loads and between batches. Figure 10 shows the approximate locations of detected tags coloured by delivery truck. The tag distribution generally aligns with the surveyed truck coverage areas shown in Figure 7; some migration occurs between truck 1 and 2 mainly with tags for truck 1 being deposited in the area where material from truck 2 was being laid. It is likely that some material from truck 1, and hence tags, remained in the paver whilst truck 2 was being unloaded.

Figures 11-13 show the tag distribution by material batch for each of the first three delivery trucks. Note that the colours used relate to the different material batches. All these figures show that tag distribution at a batch level within the delivery truck is completely random.



KEY

- Truck 1
- Truck 2
- Truck 3
- Truck 4

Figure 10 - Tag distribution by delivery truck

Figure 11 – Tag distribution by material batch (truck 1)

Figure 12 - Tag distribution by material batch (truck 2)

Figure 13 - Tag distribution by material batch (truck 3)

Note:

Tags are coloured by material batch to show effectiveness of mixing.

6.1.3 Dosage rate from vehicle data

It is unlikely that a survey vehicle such as a TRACS type vehicle would be able to safely scan an entire lane width as antennas would have to protrude from the vehicle and be in close proximity to the pavement surface. Therefore the optimum scan width in this case would approximate to the vehicle width. Therefore the same analysis of the vehicle data was performed as was done with the trolley data to ascertain detection rate and therefore dosage rate. A vehicle width antenna is not currently available but is theoretically possible so to simulate this, the nearside, centreline and offside runs were combined into one full vehicle width dataset and the number of unique tags detected was assessed. Table 8 shows tag detection rate per truck for passes carried out at 20km/h with the antenna mounted at 200mm above the pavement surface. This set of passes represents the best chance of detecting tags as it was the lowest speed (carried out on all offsets) and the lowest antenna height.

Table 8 – 20km/h, 200mm antenna height vehicle based tag detection rate by delivery truck

Delivery Truck	Tags Added	Tags Detected	Detection Rate (%)
Truck 1	160	57	36
Truck 2	80	22	28
Truck 3	32	14	44
Truck 4	≈80	16	≈20
TOTAL	**≈352**	**75**	**≈31**

This data shows that even at full vehicle width, a vehicle based antenna will pick up a significantly smaller proportion of tags when compared to a full 'sweep' of the area using a handheld or -in this case- a trolley mounted antenna. A detection rate of 31% suggests that in order for a vehicle based system to have a good chance of reading at least one tag from each delivery truck would require at least 4 tags per truck (i.e. at low speed and with a low antenna height).

The vehicle logs for the 20km/h and 40km/h passes were also interrogated and plotted against material batch number as shown in Figure 14. Of the 20km/h passes, all tag material batches were accounted for with the exception of batch 18 which was also missing from the trolley passes so this is not unexpected. Only two batches from the low dosage rate truck (4 tags per batch) were not detected in the 40km/h passes, one of which was batch 18. The second was batch 24 which was only detected in the 20 km/h passes. However, this difference may be due to a slight variation in driving lines between passes. Other than these minor differences which can be explained through driving line variations, there was little performance difference between 20km/h and 40km/h passes.

Assuming a scan width equating to an average vehicle width, the data suggests that a dosage rate of between the assessed dosage rates of 4 and 10 tags per 2.5t batch would be required in order to read at least 1 tag per material batch. For this trial, that would equate to between 1.6 and 4 tags per tonne of material. It is therefore likely that the original targeted 'low' dosage rate of 2 tags per tonne would be sufficient to identify individual batches.

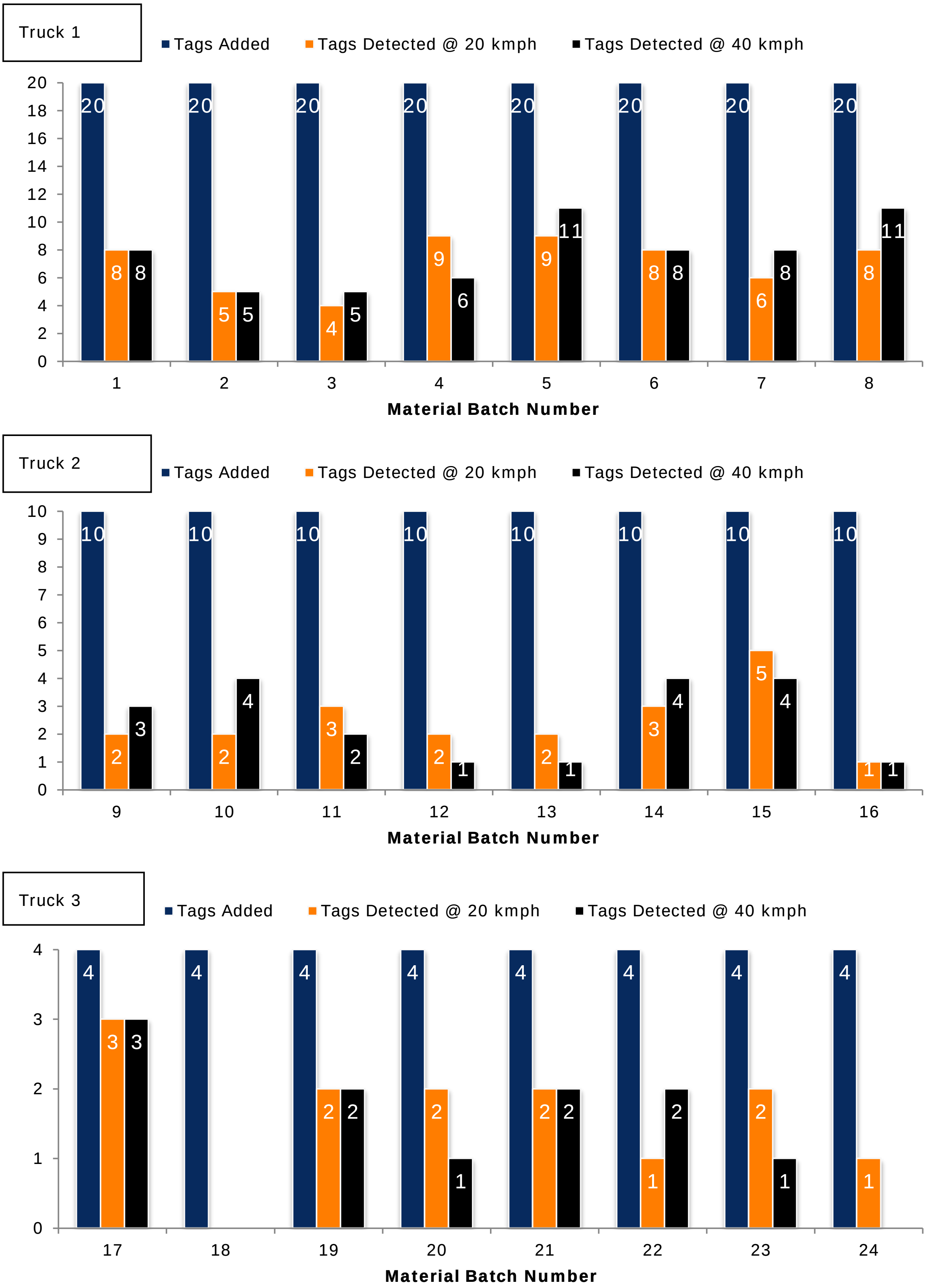


Figure 14 - 20kmph & 40kmph, 200mm antenna height vehicle based tag detection rate by material batch

6.2 Vehicle speed

Two methods were used to assess maximum read speed. In both cases the passes carried out with the antenna at 200mm height at various speeds have been used for the analysis. The results from the northbound passes undertaken at 20, 30, 40 and 45km/h have been used as these contained the most tags. The first method assessed variation in the number of tags read versus increasing speed of the passes.

From Figure 15, it can be seen that there appears to be little variation in the number of tags detected versus survey speed up to the 40km/h. There is a slight drop in the average number of tags detected at 45km/h but the number detected in the centreline is actually at its peak at 45km/h. This suggests that variations are more likely to be due to differences in driving line rather than vehicle speed. There is certainly no obvious downward trend that could be used to predict how many tags would be read at a typical maximum survey speed of 80km/h.

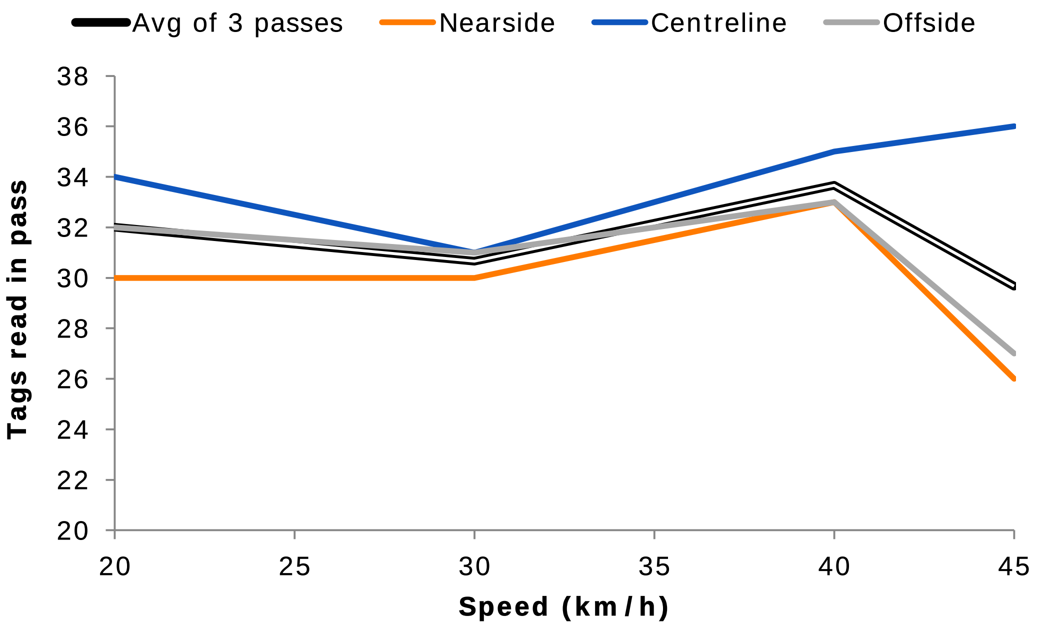


Figure 15 – Number of tags read versus survey speed, 200mm antenna height, northbound passes

The second method used to assess performance versus vehicle speed was the number of times each tag was read during each pass. The custom software TRL used will try to read a detected tag as many times as possible so long as it is within the antenna field. As vehicle speed increases, the time a tag will spend in the antenna field is reduced. However, due to the use of a circular antenna, the driving line can also affect this.

Figure 16 shows a plot of this data. There is a clear downward trend in the number of times a tag is read versus increasing survey speed in all passes. Over the range of speeds investigated, the relationship between the number of times that a tag is read and

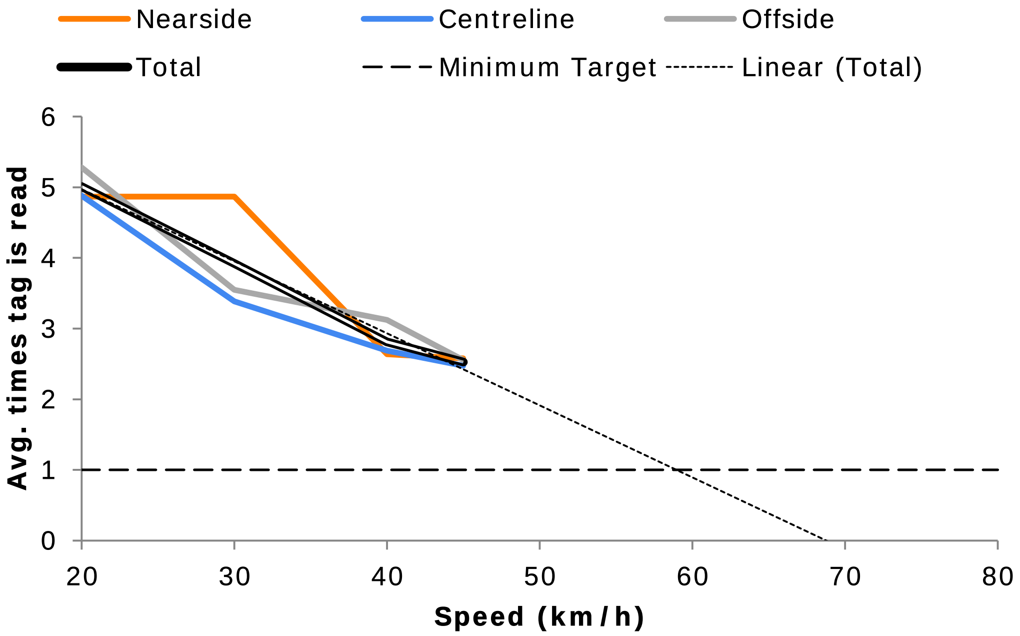


Figure 16 - Avg. times a tag can be read in a pass versus speed, 200mm antenna height, northbound passes.

survey speed appears broadly linear. A simple linear extrapolation using the series “total” that contains the data from the combined passes indicates that the maximum speed possible (where the number of times a tag is read at least once based on this average) is around 58 km/h. This is short of the 80km/h traffic speed target. However this assumes that the linear relationship assumed holds for higher survey speeds.

6.3 Antenna height

The effect of antenna height was assessed by carrying out repeat passes with the antenna in the offside position but at two different heights above the pavement surface. As well as the 200mm standard passes, 250 and 300mm antenna height passes were carried out at 20, 30, 40 and 50km/h. In order to assess the effect of antenna height, the number of tags detected in these passes was compared. Figure 17, which shows the results at 20, 30 and 40km/h, shows that there is very little difference in the number of tags read against vehicle speed whether the antenna is at 200 or 250mm. However, at 300mm there is a large drop off between 30km/h and 40km/h.

The average number of times a tag was read was also compared against antenna height and survey speed. Figure 18 shows that there is a clear downward trend in the number of times a tag can be read with increasing speed at all heights. At 300mm antenna height there is a slight reduction in the number of times a tag is read at any speed and it also appears that the downward trend against survey speed may be slightly steeper.

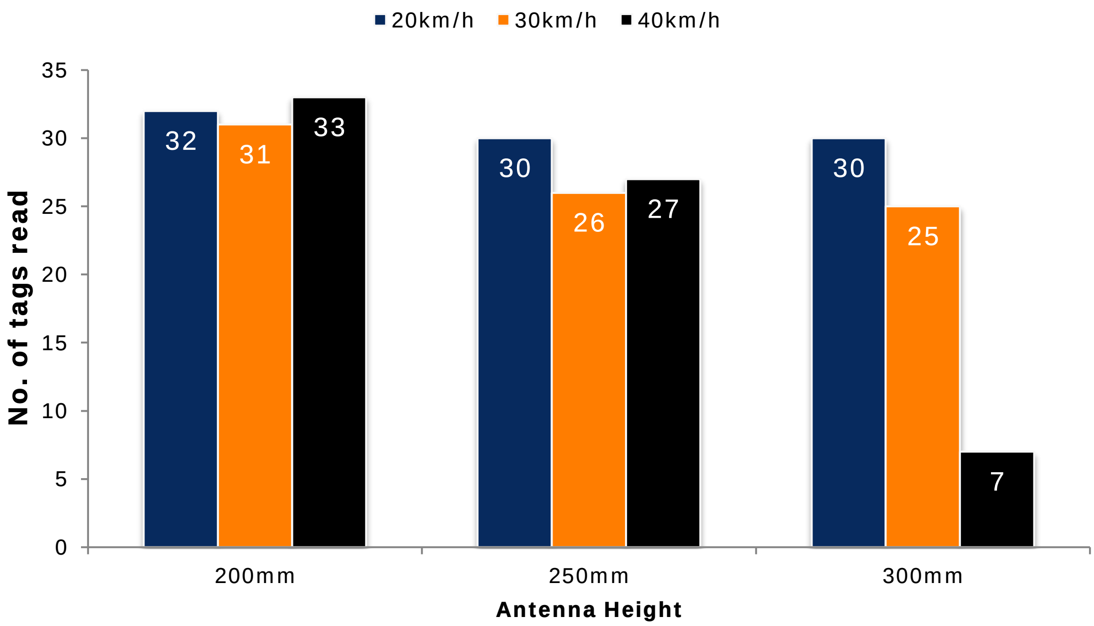


Figure 17 - The effect of antenna height on number of tags read (antenna in the offside position)

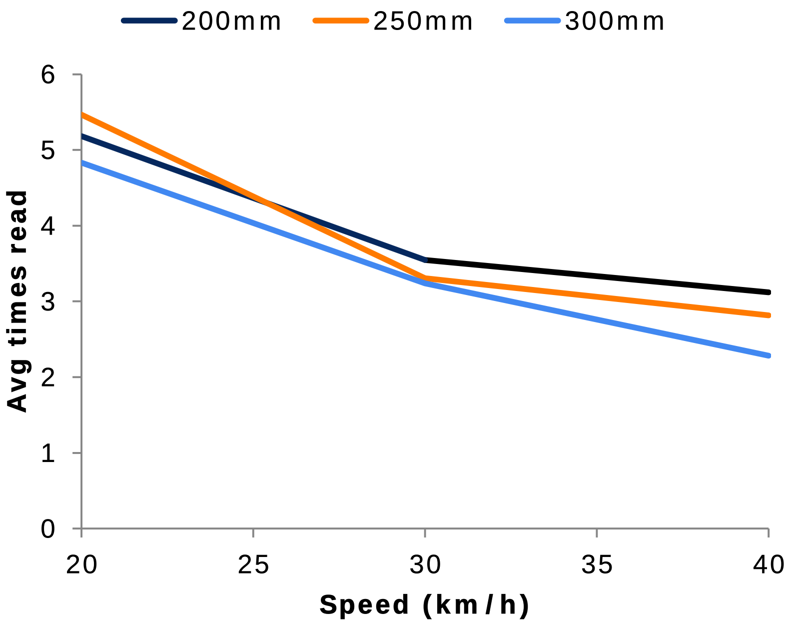


Figure 18 - Avg. times a tag is read per vehicle pass (antenna in the offside position)

7 Conclusions

This trial has demonstrated the practicality and feasibility of adding radio frequency identification tags to asphalt during the mixing process and directly to the delivery truck. A significant proportion of the tags survived the temperatures and agitation associated with the mixing process, the sustained high temperatures of storage/delivery and the mechanical loads associated with laying and compaction of the material. Over 60% of the tags could be read by a static (or slow moving) antenna and 'long range' reader. Approximately 31% of the tags could be read by a vehicle mounted antenna and 'long range' reader where the antenna scan width equated to the vehicle width (1.8m comprising 3x60cm passes). This means that over 60% of the tags:

- Survived the mixing process
- Survived the delivery and storage temperatures
- Survived the paver and rolling, and
- Lie at an orientation relatively horizontal compared to the pavement surface (estimated to be less than 60° from horizontal).

The results also mean that 31% of the tags:

- Lie within a measurement width approximately equal to the vehicle width and approximately equal to 50% of the rip width.

From this information we can calculate dosage rates required for static or slow moving as well as vehicle based traffic-speed reading of tags using 'long range' reading equipment. However, the dosage rates quoted below only apply to the circumstances of this trial. For any given scheme where RFID tagging is being proposed, consideration should be given to:

- *Material thickness and Depth.* A thicker material layer will cover less surface area per tonne so therefore it is possible that fewer tags per tonne will be required. However, a tag located at a greater depth than the tags in this trial may be beyond the effective reading range of the antenna and therefore a greater dosage rate may be required.
- *Rip Width.* A material laid using a larger rip width will potentially contain a greater proportion of tags outside the reading width of a survey vehicle, therefore if traffic speed reading is required the dosage rate would need to be increased.

7.1 Dosage Rates

Based on the results of this trial it can be assumed that for one tag per material batch to be readable by a stationary or static antenna requires a minimum dosage rate of 2 tags per batch. Where batch sizes were 2.5T as was the case with this trial, this would equate to a minimum dosage rate of 1 tag per tonne of material.

Similarly, in order for one tag per material batch to be readable by a vehicle based system, a minimum dosage rate of at least 4 tags per batch would be required. Where material batches were 2.5T as was the case in this trial, this would equate to a minimum dosage rate of 2 tags per tonne.

7.2 Vehicle Speed

In the range of speeds available to test under this trial (up to 45km/h) there was little difference in the number of tags read in passes of increasing speed. However, the average number of times a tag was read was shown to significantly decrease with increasing speed. If this decrease is assumed to be linear, it can be estimated that the speed at which the average number of times a tag will be read once will be approximately 58km/h. This is 22km/h short of the typical 80km/h trunk road and motorway of traffic-speed survey vehicles.

7.3 Antenna Height

For the particular circumstances of this trial, antenna height had little effect on the number of tags read for heights of 250mm or less. At 300mm, the number of tags read dropped off dramatically with survey speed which suggests that the antenna is less effective at this height.

7.4 Burial Depth

Depth of installation or burial depth is anticipated to be a factor in determining readability, but it was not possible to investigate this factor in the limited trial, laid only in surface course.

8 Further Considerations

This trial has effectively demonstrated that RFID tag and reader technology exists in the marketplace that can fulfil many of the identification and traceability requirements of the asphalt material production and pavement construction industry. However, the scope of this trial was small compared to the wide range of situations in which the technology may be applied.

8.1 Burial Depth and Survey Speed

This trial did not investigate the effect of burial depth on tag readability. From the data available, the maximum speed for reading the tags was estimated, but the trial was not able to fully quantify the effect of vehicle speed on readability. Further trials are recommended in order to gain a better understanding of these variables to ascertain application limitations. For example data is needed to determine whether the tags can be detected in base course materials due to the increased burial depth, and on motorways due to increased survey speed. Future improvements in reader and/or antenna technology should overcome these issues.

8.2 Implementation

Given that tags *can* be included in asphalt material production, the possible short comings of read/write technology should not be a barrier to implementation. Even if traffic-speed read capability proves to be difficult at present with existing technology, there are plenty of benefits of tagging materials now.

Therefore it is recommended that material tagging should be considered for implementation as soon as practical. This will need to be staged and an implementation action plan produced. The plan will need to consider:

- Which materials should be tagged and how?
- Who should implement the central database?
- Who should be responsible for the central database and the data within it?
- Implementation timescales.
- The effects of tagging on material production costs and the knock on effect on the pavement construction industry as a whole.

8.3 Technology Development

Along with the tags tested in this and preceding trials, there may be other tags models that are suitable for material ID requirements; but there are also likely to be many that are not. Consideration should be given to a range of tags being laboratory tested/certified with material production and pavement construction applications specifically in mind. This will allow material producers/specifiers to make an informed choice when deciding on which tag to use for different materials. It may also motivate tag manufacturers to improve their device capabilities specifically for this application.

By far the weakest link in terms of technology, but also the biggest scope for improvement, is the available reading devices. No read/write devices are currently specifically designed for this application. However, this could improve if tagging of materials is implemented on a significant scale. Manufacturers may be motivated to specifically design antennas or readers for this application.

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Pilot study using radio frequency identification (RFID) tags in road pavement material production

Radio frequency identification devices (RFID) are increasingly being used in a range of applications. Their use in asphalt could have advantages in terms of the asset inventory and to aid future recycling of material. A trial pavement section was laid using RFID tags added directly into the asphalt mix and delivery trucks. The aim of the trial was to see whether the tags would survive the mixing, laying and compaction process and to establish the dosage rates needed to allow the tags to subsequently be read at traffic speed. The tags were read using a walking speed device and a vehicle mounted system with surveys speeds of up to 30mph.

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