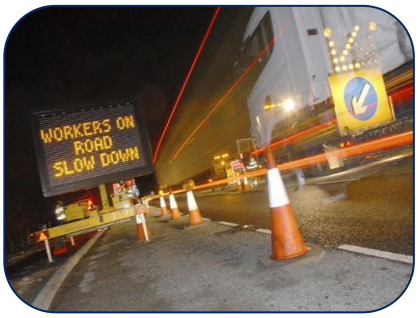
Creating the future of transport

Published Project Report
PPR618

Trial of the use of RFID tags in highway pavement maintenance

G I Crabb and A Cook

Transport Research Laboratory
Creating the future of transport



PUBLISHED PROJECT REPORT PPR618

Trial of the use of RFID tags in highway pavement maintenance

G I Crabb and A Cook

Prepared for:	Enterprise Mouchel, Area 3 Management
Project Ref:	EM-TO-9237

Quality approved:

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

Disclaimer

This report has been produced by the Transport Research Laboratory under a contract with Enterprise Mouchel. Any views expressed in this report are not necessarily those of Enterprise Mouchel.

The information contained herein is the property of TRL Limited and does not necessarily reflect the views or policies of the customer for whom this report was prepared. Whilst every effort has been made to ensure that the matter presented in this report is relevant, accurate and up-to-date, TRL Limited cannot accept any liability for any error or omission, or reliance on part or all of the content in another context.

When purchased in hard copy, this publication is printed on paper that is FSC (Forest Stewardship Council) and TCF (Totally Chlorine Free) registered.

Table of contents

Executive summary

This project arose from a proposal from TRL to Enterprise Mouchel entitled "Use of RFID tags to improve surfacing construction records". This highlighted that information relating to the material laid in pavement surface construction is not necessarily stored centrally and securely for future reference.

A possible tool to aid in solving this problem might be presented by the advent of robust radio-frequency identification (RFID) tags, which can be laid with the pavement material during construction. Each tag has a unique identification (ID) code and most types can store a small amount of user-recorded data.

This project followed an earlier limited trial on the TRL test-track which showed that a high proportion of a range of tags inserted into the pavement during construction could be detected and had therefore survived the construction of the test pavement. It was found that the ID codes could be read from tags at speeds of up to 20km/h. Several unknowns remained, including whether tags would be readable at higher speeds, how much data can be read in the short time available and the effect of depth of burial on these factors.

The current project was designed to build on the earlier trial by a practical demonstration of the burial and subsequent reading of tags in a small motorway re-surfacing scheme. The trial was to discover whether the tags could be read (and how much data could be read from the tags) using a vehicle-mounted antenna measuring at practical traffic speeds.

The results provide a significant advance in our understanding of the ability to read RFID tags inserted into road pavements. This project has shown that, with the specific equipment used:

- It is possible to insert RFID tags during pavement construction.
- Tags inserted as described can survive the pavement laying and compaction process.
- By developing a suitable bespoke reading system it has been possible to read over 60% of the tags at speeds up to 70mph.
- Up to 64 bytes of data can be read from the tags at these speeds
- Larger diameter tags (50mm) can be read more successfully than smaller diameter tags.

There is clearly a strong potential for the use of RFID tags to assist the asset management process. They could be used to provide a semi-permanent *in-situ* record of pavement construction and maintenance. Having demonstrated that tags can be applied in practice TRL is now in a position to design and implement an RFID asset tagging facility using tags buried in surface pavement layers. This would utilise tags holding basic data, a linked data table in a remote asset management database, and reading/writing equipment.

Further development work into their application could include:

- Further tests to develop the insertion and reading process, e.g. investigating their use to label lower pavement layers and the systems required to read these tags.
- Establishing a suitable system of data encoding, to determine the essential data to store on the tags and how this could be used to assist the management process.
- Establishing a process to link the tags to the network database, including the data transmission and storage requirements and potential for live communication, for example by linking the tag reader to the database by GSM telephone network.
- Determining, in trials, whether it will be possible to update the tag data in-situ (and at what speed) so that changes could be recorded (e.g. recording of local maintenance activities such as routine safety inspections).

1 Introduction

This project arose from a proposal from TRL to Enterprise Mouchel dated 26 October 2009 entitled "Use of RFID tags to improve surfacing construction records". This highlighted that information relating to the material laid in pavement surface construction is not necessarily stored centrally and securely for future reference. This is partly due to the complexity of maintenance schemes and the challenges of establishing a robust regime for record keeping during construction.

A possible tool to aid in solving this problem might be presented by the advent of robust radio-frequency identification (RFID) tags, which can be laid with the pavement material during construction. These tags have been in use for some years in industry for labelling products and consignments and as security tags in retail. Each tag has a unique identification (ID) code and most types can store a small amount of user-recorded data.

This project followed an earlier limited trial on the TRL test-track which demonstrated that current tag technology was sufficiently robust for pavement material identification. This trial showed that a high proportion of the tags inserted into the pavement during construction could be detected and had therefore survived the construction of the test pavement. Further tests demonstrated that the tags could be read (ID code only) at speeds of up to 20km/h. Several unknowns remained, including whether larger tags would be readable at higher speeds, how much data can be read in the short time available and the effect of depth of burial on these factors.

The current project was designed to build on the earlier trial by a practical demonstration of the burial and subsequent reading of tags in a small motorway re-surfacing scheme. The trial was to discover whether the tags could be read (and how much data could be read from the tags) using a vehicle-mounted antenna measuring at practical traffic speeds.

2 RFID tags

RFID tags are either passive or active. Passive tags acquire the energy required for activation and data transfer from the electromagnetic field surrounding a reading/writing antenna in relatively close proximity. Active tags are powered by an internal battery or an external power source. This work has concentrated on passive tags as they are considered more practical for use in pavements being relatively cheap and having no requirement for a continuous power source.

A typical RFID tag comprises an "inlay" and encapsulation. The inlay comprises an electronic microcircuit "chip" electrically connected to a small antenna, typically bonded to a thin substrate. The encapsulation provides physical and environmental protection, and must prevent damage during incorporation in the pavement. The temperature resistance of a tag is critical when laying in or under hot asphalt. This will depend on the maximum temperature that can be withstood by the inlay components and the insulating properties and thickness of the encapsulation. The physical damage resistance required to withstand compaction in a pavement will depend primarily on the encapsulation material and size and shape of the tag. Figure 2-1 shows, from left to right, a 16mm diameter tag, a 25mm x 25mm inlay, a 50mm diameter encapsulated tag and a flexible plastic tag of about 55mm x 80mm.

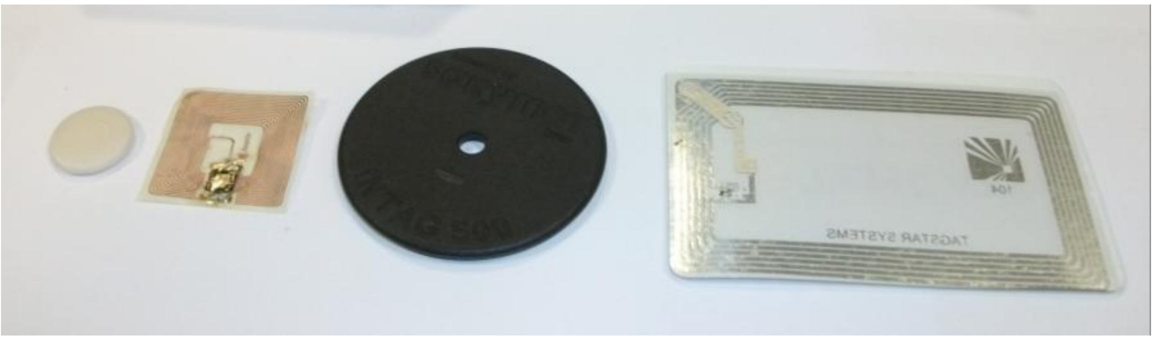


Figure 2-1 HF inlays and tags

Passive RFID tags are available to operate in three internationally-agreed frequency bands (Table 2-1). In theory the higher the frequency of operation the higher the potential data-rate for reading and writing, but this is offset by greater attenuation of higher frequencies by materials, such as the surface layers of a pavement..

Table 2-1 RFID frequency bands

Band	Frequencies	Maximum transmission power/field strength (Europe)
Low Frequency (LF)	125kHz to 135kHz	72 dBµA/m
High Frequency (HF)	13.553MHz to 13.567MHz	60 dBµA/m
Ultra-High frequency (UHF)	400MHz to 960MHz depending on national legislation	2W ERP

In the UHF band the reader and tags are radiatively coupled, using dipole antennas on both tags and reading/writing equipment. As a result the detection range in air can be large. However, the radio waves are highly attenuated by the presence of materials, in particular water, between the tag and the antenna. In the LF and HF bands the reader and tags are inductively coupled, which is effective at close range, with little interference from material or water in between. In this mode a loop antenna is required, which is coupled to the tag antenna in a similar manner to the windings of a transformer.

The microcircuit chip in an RFID tag typically includes a small amount re-writable non-volatile memory. Part of this is reserved for system use, including a unique ID code. The remainder can be written to by the user. All of the data stored on the tag can be read, and the user memory written to using a RFID reader/writer coupled to an antenna.

3 Desk study and procurement

The first task was to identify the type of tag likely to be most suited to the application. The selection has built on the experience gained in the previous trial.

3.1 Previous TRL trial

The previous TRL work experimented with a range of LF and HF tags of diameters between 12 and 26mm. These were buried in 40mm thick layers of both 14mm (aggregate size) thin surfacing and 20mm (aggregate size) HRA. The tags chosen for the trial were developed for tagging laundry and so were designed to be heat resistant and reasonably robust. Some of the tags were introduced into the paver's feed hopper, so were laid in random orientation and at unknown depths within the material layer, while others were hand-laid flat at the base of the layer. While a large proportion of the tags survived laying and rolling (80% to 100%) the results of trials using a moving vehicle with an RFID antenna attached to the front (Figure 3-1) showed that detection fell off rapidly with increasing speed. It was clear from the results (Figure 3-2) that a large tag diameter is a significant advantage, with up to 77% of the 16mm HF tags being detected at 20km/h. It should be noted that the trial only attempted to read the ID codes of the tags, no user data was transferred.

This work demonstrated that the installation and reading of RFID tags in the wearing course of a typical pavement is achievable with currently available technology and at low cost. The best compromise in the trial between reading range and interrogation speed was achieved with 16mm tags operating in the HF band.

Figure 3-1 HF antenna mounted on vehicle

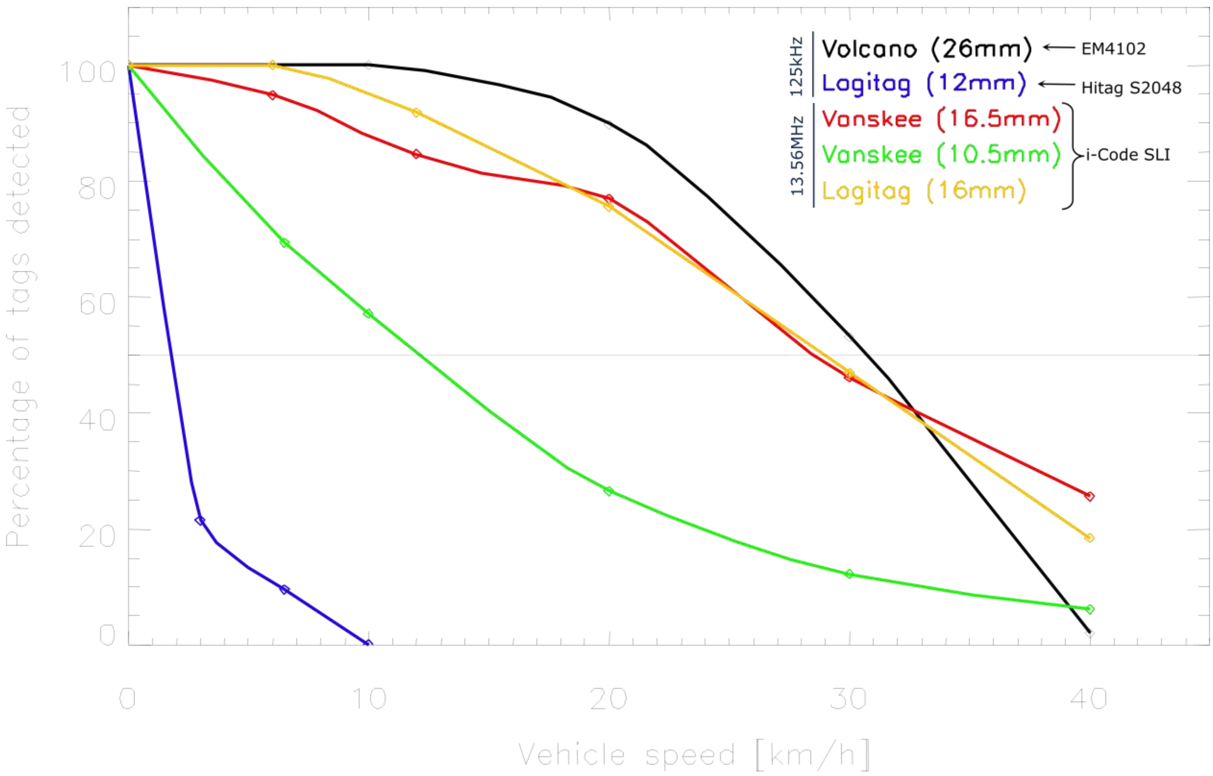


Figure 3-2 Results of speed test

3.2 Available types of tag

The current trial was designed to build upon the earlier work. To this end the use of larger diameter tags was investigated. The available memory capacities, temperature resistances, reading rates and predicted useful lives of different tags were also considered. Literature was also searched to discover relevant useful experience gained elsewhere which might provide guidance.

3.3 Procurement

Following the work carried out in Section 3.2 it was decided to use HF tags in the current trial. Although in theory it is possible that UHF tags might give a longer range and reading at higher speeds there are concerns that water could adversely affect the performance. Proprietary UHF tags are also relatively large, expensive and not suitable for burial.

Two types of tag were selected, as detailed in Table 3-1. These tags are specified to withstand a temperature of at least 120°C for 100hr and can withstand higher temperatures for much shorter periods. During asphalt laying, tags may be subjected to up to 180°C for a short time. Larger tags were discounted for this trial due to customer concerns about their relative size causing structural problems such as de-lamination in thin pavement layers.

Table 3-1 Encapsulated disc RFID tags

Tag	Diam (mm)	Thick (mm)	IC	bits	Speed (kbits/s)	Data retention (years)	Material
HID Logitag 161	16	3	nxp i-Code SLix	1024	Up to 53	50	Modified thermoplastic
HID Epoxy disc 50mm x 1mm	50	3	nxp i-Code SLi	1024	Up to 53	10	PA6 modified

For the trial 100 "Logitag 161 i-Code SLi" and 100 "Epoxy Disc 50mm x 1mm i–Code SLi" tags were obtained.

The i-Code SLi tag's 1024 bits (128 bytes) are organised into 32 blocks of 4 bytes each. Four blocks are reserved for system use including two to hold a "Unique Identifier". The remaining 28 blocks are available to the user for data storage. When used for storing encoded human-readable text, each byte can hold one character. The maximum possible length of text string that can be stored is therefore 112 characters.

3.4 Equipment

The equipment used for writing and reading the HF tags in the trial was a Scemtec 13.56MHz SHL-2100 long range reader with a Scemtec SAT-A11-LR-O-13MHz 60cm diameter open loop antenna (Figure 3-3). The power output of the long-range reader is required to penetrate the pavement material, which due to attenuation, was expected to reduce the detection range substantially. This relatively bulky equipment is designed for fixed installation but can be mounted on a vehicle. The transmitter/receiver unit can be mounted remotely from the antenna, connected by co-axial cable. Figure 3-1 shows a slightly smaller rectangular antenna used in the previous TRL trial mounted on a vehicle. This equipment shown in Figure 3-3 was hired from Codeway Ltd to write data to the tags used in the trial and to manually test-read some of the tags after installation. The equipment was controlled by Scemtec's "UniDemo" demonstration software running on a laptop computer.

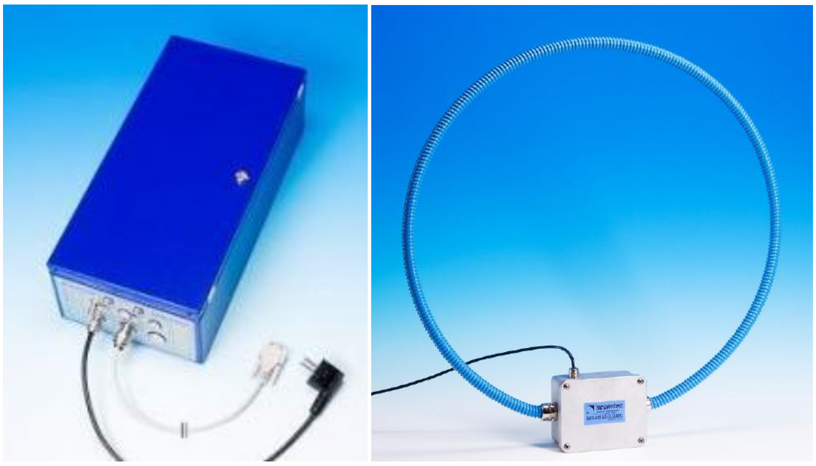


Figure 3-3 Scemtec reading/writing equipment

4 Field installation

A suitable site was identified by Enterprise Mouchel where re-surfacing of 250m of the hard shoulder and 500m of Lane 1 of the M4 Eastbound east of the Chieveley interchange were to take place on the night of 12 November 2010 (Figure 8-1). The operations to be carried out included the removal of 50mm of the surface by planing, followed by the spraying of a bituminous tack-coat and the laying of a 50mm Tarmac Masterflex inlay (20mm aggregate size) to Clause 942 ("Thin Surface Course Systems") of the Specification for Highway Works.

4.1 Preliminaries

In consultation with Enterprise Mouchel it was agreed that tags would be laid on the centrelines of both lanes at 10m intervals. Tags were to be placed by TRL on top of the tack-coat and immediately in front of the delivery trucks feeding material to the paving machine. This lateral position would reduce the likelihood of the tags being displaced by the wheels of the delivery trucks. This method ensured that the depth of material above the tags was known and that the tags were in a known, optimum horizontal, orientation. Prior to attending the site a 96-character example character string, which contained the parameters listed in Table 4-1 was encoded and written to each tag. The text string segments were concatenated into a single string. This was converted to a series of hexadecimal ASCII codes and written to the tags using the UniDemo software. This string filled 24 of the 28 available data blocks. This string was a simple example of what is possible. It would be possible to devise a more compact encoding system which could permit more data to be recorded.

Table 4-1 Details written to tags

Parameter	String segment	Length (Characters inc. separators)
Motorway	*M4*	2
Direction	*EB_*	3
Between junction (a) and	*J13_to_*	7
Junction (b)	*J12_*	4
Start Location (MP number)	*MP90/3_to_*	10
Finish Location (MP number)	*mp89/8_*	7
Layer thickness (mm)	*50mm_*	5
Material spec (SHW Clause)	*CL942_*	6
Aggregate size (mm)	*20_*	3
Pavement layer	*surf_*	5
PSV number	*PSV65_*	6
Material name	*Tarmac_Masterflex_*	18
Mixing plant	*Hayes_*	6
Date	*2010-11-12_*	11
Tag written by	*TRL*	3
Total characters		**96**

4.2 Laying of tags

On site, chainages were measured from the centreline of an overbridge between mp90/4 and 90/3 (Figure 8-1). Tag positions were measured from the start of each inlay using a measuring wheel travelling on the edge of the adjacent lane. Tags were not placed until the paving operation was under-way to minimise the risk of displacement by site activities. Tags were placed at 10m intervals on the approximate centreline of each lane. During the discharge of each delivery truck tags were placed in front of the truck as it was pushed along by the paver. A small number tags may have been disturbed by empty trucks driving over them as they manoeuvred into the adjacent lane to allow the next full truck to reverse into position. Most of the tags were observed to have remained in place, although observation of dark grey tags was difficult against the similar surface. Table 4-2 shows the positions of the tags laid in both the hard shoulder and Lane 1. Ten 50mm tags and eight 16mm tags were laid in the hard shoulder, while 24 of each type were laid in Lane 1.

Table 4-2 Locations of RFID tags placed
M4 J13-J12 EB between mp90/3 and mp98/8

Milepost	Site chainage (m)	Distance from start (HS) (m)	Hard shoulder	Distance from start (L1) (m)	Lane 1
90/3	65	0			
	85	20			First 50mm tag (1)
	95	30			50mm tag (2)
	…………	…………			Tags 3 - 23
	315	250			Last 50mm tag (24)
	325	260			First 16mm tag (1)
90/0	360	295		0	Tags 2 -23
	375	310	First 50mm tag (1)	15	
	380	315	50mm tag (2)	20	
	…………		Tags 3-9	………..	
	460	395	Last 50mm tag (10)	100	
	470	405	First 16mm tag (1)	110	
	…………		Tags 2-7	………..	
	540	475	Last 16mm tag (8)	180	
	555	490			Last 16mm tag (24)
89/8	557	492			End of both inlays

4.3 Preliminary reading check

The re-surfacing of Lane 1 was completed first. Once rolling of this surface was completed and vehicular access was available, trial reading of 50mm tags 3 to 6 and 16mm tags 2 to 5 in this lane was carried out with the antenna hand-held. A search for each tag was carried out at the measured position, and once located the data was read from the tag and the height of the antenna above the surface at which the tag was no longer detected was assessed.

Four out of the five 50mm tags searched for were detected, one could not be found, while three out of four 16mm tags were detected. It was found that the 50mm tags were easier to find and the maximum height of the antenna above the pavement for their detection was about 150mm, which was greater than for the 16mm tags.

5 Surveys at speed

5.1 Software

The demonstration software provided with the equipment to write and read tags did not have a readily usable function to read tag data at high speed. Codeway Ltd was commissioned to write a Microsoft Windows compatible program to facilitate this for iCode SLi tags, using the Scemtec SHL-2100 reader/writer and a single antenna. The specification required the software to attempt to read up-to the full amount of data recorded on each tag, automatically on detection of the tag. The number of data blocks to read was to be user-selectable. The raw data was to be displayed on-screen and stored in memory until written to hard disc. It was specified that the fastest possible reading method should be used.

5.2 Field trials

In order to determine the maximum speed at which tags could be reliably detected the 60cm diameter antenna was mounted horizontally in the centre of the front of a survey vehicle at a height of 125mm above the ground. Trials were initially carried out on the TRL test-track and then on the M4 on 9 November 2011, during dry weather.

5.2.1 At TRL

As a preliminary test of the software, three of the 50mm tags were laid on the pavement surface, in a straight line spaced about 10m apart. A number of passes were then made over these tags at different speeds each requesting different numbers of blocks of data to read. The results are shown in Table 5-1. This demonstrated that tags laid on the surface could be reliably read at up to 80km/h as long as no more than 16 blocks of data were requested. It also appeared that adding a request for the ID code made the reading less certain with this number of blocks at this speed. (The ID code occupies two blocks).

5.2.2 On the M4

Following the encouraging result on the test-track a number of passes were then carried out in Lane 1 on the M4 where the tags had been laid. To provide the best chance of reading data initial passes asked for a small number of blocks without the ID code. For these passes it was not possible to differentiate between the two types of tag as all tags held the same data other than their ID codes. During subsequent passes the number of blocks requested was increased in stages up to 24 and the ID was added in the last two passes. The results shown in Table 5-2 demonstrate that at 75km/h up to 16 blocks of data could be read from 24 (50%) of the tags of both sizes, if the ID code was not requested. When the ID code and 16 blocks were requested, 15 (62.5%)of the 50mm tags and 8 (33.3%) of the 16mm tags were read. When 24 blocks and the ID code were requested only nine of the 50mm tags and one of the 16mm tags were read, but these included one 50mm tag which had not been read in the previous passes.

Figure 5-1 60cm antenna mounted on HARRIS2

Table 5-1 Results from tags on the surface at TRL

Pass	Speed (km/h)	Requested data blocks	Tags detected and read
1	15	16	3
2	32	16	3
3	64	16	1
4	64	4	3
5	74	4	3
6	64	4 + ID	2
7	64	8	3
8	80	8	3
9	80	12	3
10	80	16	1
11	80	12+ID	3
12	80	12 multi-blocks	1
Antenna lowered to 65mm clearance			
13	80	16+ID	2
14	80	16+ID	2
15	80	16	3

Table 5-2 Results from buried tags on the M4

Pass	Speed (km/h)	Requested data blocks	Tags detected and read		Percentage detected and read	
			50mm	16mm	50mm	16mm
1	75	4 (no ID)	29		60.4	
2	75	8 (no ID)	24		50.0	
3	75	16 (no ID)	24		50.0	
4	75	24 + ID	9	1	37.5	4.2
5	75	16 + ID	15	8	62.5	33.3

These results indicate that it should be possible to read at least 16 blocks of data and the full ID from a high proportion of 50mm diameter iCode SLi tags buried horizontally at 50mm depth, at this speed. If less than the full ID code is requested then it may be possible to read one more block of data (the data is read in full blocks). The read rate for the smaller tags is significantly lower, as expected.

6 Conclusions

The results of this project pr ovide a significant advance in our ability to utilise RFID tags as a tool to label road pavement assets. It was previously unknown whether it would be possible to insert the tags during routine works and then read back data (including the ID) from the RFID tags buried in the pavement at traffic speed. This project has shown that, with the specific equipment used:

- It is possible to insert RFID tags during pavement construction.
- Tags inserted as described can survive the pavement laying and compaction process.
- By developing a suitable bespoke reading system it is possible to read over 60% of the tags at speeds up to 70mph.
- Up to 64 bytes of data can be read from the tags at these speeds
- Larger diameter tags (50mm) can be read more successfully than smaller diameter tags.

There is clearly a strong potential for the use of RFID tags to assist the asset management process. They could be used to provide a semi-permanent *in-situ* record of pavement construction and maintenance.

7 Current capability

As a result of this work we are now in a position to design and implement an RFID asset tagging facility utilising tags buried in surface pavement layers.

A potential complete system for pavement asset tagging could include the following:

- 50mm RFID tags routinely inserted into the pavement surface during maintenance works.
- A data table within an asset management system to hold the relevant information. This could include approximate location, who undertook the installation, date of works, maintenance materials etc. according to the needs of the customer. This information would be linked to the unique ID of each tag.
- One or more reading/writing systems tailored to the use required (e.g. either hand-held or vehicle-mounted), integrated with GPS receivers.
- Use of the reading systems to monitor the tags and synchronise the collected information with that held on the central asset management system, either by wired connection or possibly by a wireless remote-access system.
- Use of the collected data to monitor the performance of the maintained pavement by pavement condition data to the pavement maintenance date and maintenance method/materials recorded using the tags.

8 Further development

Further work into the application of RFID tags could include:

- Further tests to develop the insertion and reading process, e.g. investigating the use to label lower pavement layers and the systems required to read these tags.
- Establishing a suitable system of data encoding, to determine the essential data to store on the tags and how this could be used to assist the management process.
- Establishing a process to link the tags to the network database, including the data transmission and storage requirements and potential for live communication, for example by linking the tag reader to the database by GSM telephone network.
- Determining, in trials, whether it will be possible to update the tag data in-situ (and at what speed) so that changes could be recorded (e.g. recording of local maintenance activities such as routine safety inspections).

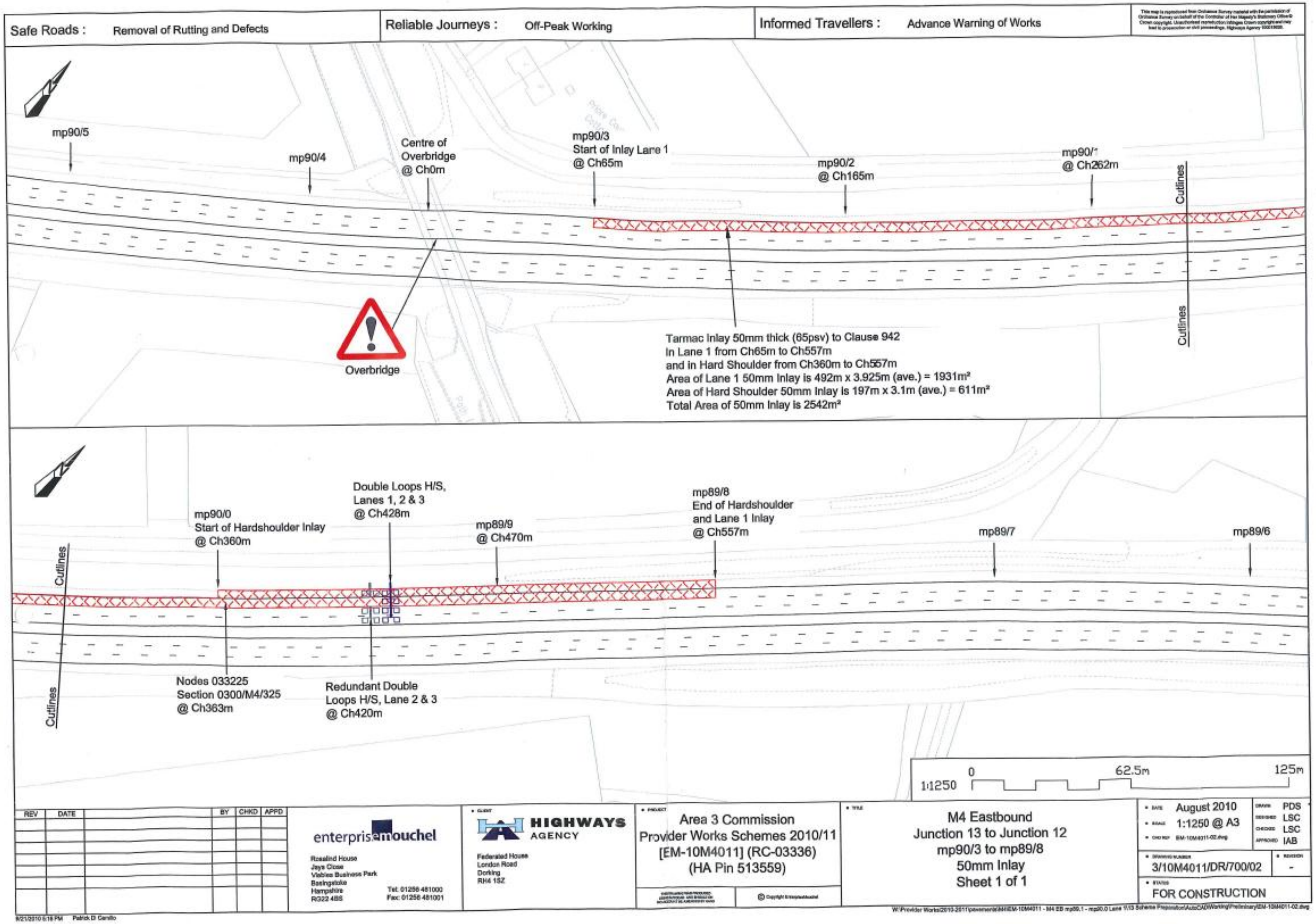


Figure 8-1 Plan of site location

Trial of the use of RFID tags in highway pavement maintenance

This project investigated the potential for radio-frequency (RFID) tags, containing data relating to pavement materials and construction, to be buried in road surfaces during their laying, and subsequently read at traffic speed. The objective was to determine the feasibility of a new method of recording, and improving access to, data relating to pavement surface construction. A number of RFID tags containing a limited amount of data were buried in a short length of the M4 motorway during re-surfacing. The tags had previously been written with a number of bytes of information. Trial reading was later carried out at traffic speed using a long-range RFID reader and antenna mounted on a vehicle. To do this it had been necessary to develop custom software to read tag data at the highest possible rate, due to the very limited time available. The results showed that data could be successfully read from a high proportion of the tags at motorway traffic speed. This confirms that the system is viable for use in the asset management process, providing an in-situ record of pavement construction and maintenance which could be further linked to remote pavement management databases.

Other titles from this subject area

TRL674 Durability of thin surfacing systems. Part 4: Final report after nine years' monitoring. J C Nicholls, I Carswell, C Thomas and B Sexton. 2010

PPR497 GripTest trial – October 2009 including SCRIM comparison. A Dunford. 2010

PPR468 Enhanced levels of reclaimed asphalt in surfacing materials: a case study evaluating carbon dioxide emissions. M Wayman and I Carswell. 2010

PPR458 Review of UKPMS core functionality – the minimum functionality all PMS should embody in the UK. B V Cleave, R A Cartwright, K A Gallagher and T Rasalingam. 2010

PPR457 SCANNER accredited surveys on local roads in England – accreditation, QA and audit testing – annual report 2008–09. P Werro, I Robinson, E Benbow and A Wright. 2010

PPR437 Highways Agency 2009 Falling Weight Deflectometer Correlation trials. S Brittain. 2010

Price code: 2X

ISSN 0968-4093

TRL
Crowthorne House, Nine Mile Ride
Wokingham, Berkshire RG40 3GA
United Kingdom

T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

Published by

IHS
Willoughby Road, Bracknell
Berkshire RG12 8FB
United Kingdom

T: +44 (0) 1344 328038
F: +44 (0) 1344 328005
E: trl@ihs.com
W: http://emeastore.ihs.com

ISBN 978-1-908855-13-8

9 781908 855138

PPR618