Electronic Data Monitoring of Resurfacing Works

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Scottish Road Research Board (SRRB)

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Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
BIM	Building Information Modeling
FHWA	Department of Highway Administration
GPR	Ground Penetrating Radar
GPS	Global Positioning System
HDS	Highway Data System
IC	Intelligent Compaction
MCHW	Specification for Highway Works
PMS	Pavement Management System
SRRB	Sottish Road Research Board

1. Introduction

The trunk road network is a key piece of economic infrastructure and is Scottish Ministers' single biggest asset with a gross asset value of over £18 billion. The trunk road network is an enabler of economic activity and growth, and maintaining the network is vital to the smooth operation of the economy. The performance of the pavement is fundamental to deliver this growth.

This research is a review of methods currently in use for specifying electronic data capture for quality control and as-built record collection purposes. The aim of this research is to identify best practice already being used in other countries with respect to data capture technologies and to align with SRRB's delivery priorities:

Better Journey Times, Better Reliability, Quality and Accessibility
Journey times will be shortened because improved transparency and quality control will lead to more durable surfaces with a consequential reduction in pot holes and reduced frequency of reactive road works.

Low Carbon Technology & Infrastructure, Reduced Emissions
The investigation could lead to a more efficient method of data collection and facilitate better monitoring. Better monitoring of supplied goods could lead to reduced emissions by reducing waste and increasing efficiency.

Increased Safety, More Innovation
Use of automatic electronic data capture on road maintenance and construction sites would reduce the staff required on site. This means less potential for human injury due to collisions with plant, slips/trips etc.

Continuously Improving Performance and Organisation
Using electronic data capture for quality control conformation would allow better monitoring of compliance with quality control requirements. This will lead to improved performance and durability and the improved transparency will encourage positive behaviours from the supply chain.

2. Literature Review

Monitoring and recording of as-built information is key for the successful management of an asset, to ensure they are operated, maintained and upgraded cost-effectively. It can take place during several stages of the resurfacing process to ensure quality of the asphalt and finished surface adheres to current standards and specifications, this also allows for any non-conformances to be picked up during the operation or at a later date if problems arise. Data monitoring and collection also allows for as-built records to be stored, allowing for data to be accessed in the future if required.

The monitoring method commonly used for resurfacing works requires filling out paper laying records that must then be scanned and stored. To ensure compliance, these operations must be manually assessed and recorded, allowing for several drawbacks, including the following:

- Time-consuming process
- Non-conformances can be easily overlooked
- Records can be left incomplete
- Open to human error

- Increased number of staff required on site to undertake testing

Overtime new technology and procedures are becoming increasingly available to continuously monitor surfacing operations. Involving the use of electronic records with automatic detection of non-conformance that can be scanned, which is a more reliable and time efficient method compared to traditional “spot test” sampling for compliance purposes. However, this technology is generally not specified in current contracts.

2.1 Monitoring of Resurfacing Works

Electronic data monitoring devices can be used to capture data for quality control to ensure compliance with requirements and the collection of as-built records, allowing for accurate storage of data together with a fast and effective method of picking up non-conformances. Electronic data monitoring can be used during several stages of the resurfacing process including; asphalt transportation, paving operation and compaction as well as ensuring surface irregularities and texture measurements conform to the standards using laser controlled devices. Using electronic data monitoring devices also makes it possible to store a limitless amount of data which can be used at a later stage to analyse the resurfacing process and find reasoning if future problems arise.

Increased control of the laying operation will not only increase the pavement’s life, it will reduce the destructive testing requirements for compaction testing of the lower structural layers, which will improve durability. Utilising such technology will also reduce the number of operating staff on site, reducing the likelihood of injury especially to lone workers and night shift workers who are highly vulnerable to being struck by on-site vehicles.

2.1.1 Quality Control

Quality control during resurfacing works is key to ensure the pavement provides the required design life. During the resurfacing operation, monitoring procedures should be undertaken at several stages to control quality and provide as-built construction records. Monitoring procedures are used to collect information about the pavement including a number of qualities, examples of these include:

- Delivery times and temperatures of asphalt
- Delay times and location of paver stoppages
- Wind speed, surface and air temperatures
- Asphalt density
- Number of passes for the roller compactor
- Texture depth and surface regularity

The methods used to monitor these operations and qualities are described within the current standards and specifications. However, advances within pavement construction technology has changed the way monitoring procedures can be performed, improving frequency, quality and reliability together with several health and safety benefits. It is therefore in the best interest of authorities to utilise these methods within their standards, specifications and contracts.

2.1.2 Asphalt Transportation

Electronic technology including GPS can inform the paving crew with information about the asphalt delivery truck including; their location, which material they are transporting, how much and their estimated time of arrival. It can also provide the temperature of the asphalt batch to ensure the asphalt arriving on site is at the required temperatures for laying. Keeping track of the delivery can also allow the paving crew to be aware of any delays and an increase in temperature loss which will reduce the time available for compaction, as well as helping to avoid the material being stored in delivery vehicles for excessive periods.

2.1.3 Paving Operation

During the paving operation, there is the option to use 3D technology together with a GPS system to permanently indicate the position of the screed and compare it to a ground(design) model, which has been loaded into an on-board computer. If the comparison of the results deviates in grade or cross slope, the system can automatically level out the screed. This makes it possible to integrate automatic height control and cross-slope regulation removing the risk of non-conformances.

Asphalt delivery temperature can be measured within the tunnel of the conveyor system and at both augers together with an infrared line scanner just behind the screed. This helps to continuously measure the temperature of the asphalt to ensure it is homogenous and to log potential thermal segregation. The asphalt temperature should be kept consistent to allow uniform compaction of the asphalt. Varying asphalt temperature can result in cold spots which result in a lower compaction degree leading to stone loss and raveling. Continuously monitoring the asphalt temperature behind the screed can also inform the crew of any issues and they can look for the cause and correct when possible.

A weather station can also be added to the paver to provide ambient weather conditions such as; wind speed, air temperature and precipitation to allow the paving team to calculate the cooling speed of the asphalt. A weather station also allows for continues weather records to be taken and saved electronically for future reference.

The data collected during the paving process can be saved electronically on a server for analysis and future reference if any problems arise. This combined with ticket data can be used to produce an electronic data set which can then be used to construct a conventional laying record but can also be available in various file formats and incorporated into the PMS.

2.1.4 Compaction

The roller can be provided with an asphalt temperature sensor, so the operator can see the actual temperature of the asphalt surface they are compacting. It is also possible to send the data of the temperature scanner on the paver to the roller, this allows the roller operator to know the asphalt temperature behind the screed. Allowing the operator to adjust their compaction scheme to the temperature window which helps provide consistent compacting at the same temperature.

A Continuous Compaction Control System with GPS can also be added to the roller to assist the operator by providing the following:

- Stiffness values as a map
- Values of: temperature of asphalt, speed of roller, amplitude & frequency as a map
- Trend of stiffness values
- Exact geographical position
- Number of passes
- Date and time of passes

Data from the rollers can be presented in graphical and tabular format to produce evidence of compaction throughout each site. This data can then be stored for analysis and made available for the incorporation into the PMS.

2.1.5 Post Paving Testing

There are two surface characteristics, mean texture depth and surface regularity, which will need to be measured following the surfacing works.

The mean texture depth and surface regularity can be measured using a laser texture meter and laser straight edge respectively, both of which can be attached to a vehicle to take measurements along the complete length of a site. These electronic data collection methods have several benefits compared to the conventional tests, including:

- Accurate repeatable data
- Location data can be automatically recorded
- Data can be viewed alongside video of the test
- Data can be exported to BIM / PMS
- Operator can perform testing from inside the vehicle
- Testing can be carried out at normal traffic speed

2.1.6 Post Processing of Data

All the electronic data collected during the paving and testing processes including other surveys such as; GPR, video surveys and grip testing can be combined to produce a single report. This report can be used to control quality and be uploaded into the PMS.

2.2 Case Studies

Electronic data monitoring has already been rolled out in several counties including Norfolk County Council and Northumberland County Council. A trial of implementing the technology has also been undertaken by a MATtest subsidiary company named Highway Data Systems on the A77 from Littlehill to Burnside Farm for Aggregate Industries, Scotland Transerv and Transport Scotland.

2.2.1 Norfolk County Council

Norfolk County Council appear to be at the forefront of this technology working closely with Tarmac to implement automated paving technology and develop BIM level 2 compliant laying records. In order to accurately record and aid the consistent laying of asphalt materials, with a combined goal of reducing defects and improving durability therefore reducing whole life costs.

Currently Norfolk County council and Tarmac have a ten-year maintenance contract with the requirement to complete the works using electronic data monitoring. Together they have already delivered a system which meets BIM level 3 but so far only delivered a BIM level 1 and possibly BIM level 2 project.

Norfolk County Council and Tarmac have seen several benefits from implementing the technology including:

- Improved safety on site
- Better understanding of optimum laying patterns and work practices to minimise defects

- More reliable and accurate data records
- Meets Government requirements to deliver construction projects at BIM level 2 to support future funding

Through these benefits of implementing electronic data monitoring Norfolk county council are hoping to reduce patching by 10% and increase their replacement cycle period from 25 to 30 years.

2.2.2 Northumberland County Council

In 2015, Carillion and Tarmac commenced work on the Morpeth Northern Bypass, as part of this contract, they made a commitment to develop and deliver an automated paving technology which could accurately record and aid the consistent laying of asphalt materials.

The objective was to reduce the occurrence of in-built highways defects to cut the cost of repairing early failures.

Carillion, Tarmac, Northumberland County Council and Highway Data Systems (HDS) worked together to deliver a bespoke process which combines data capture during surfacing projects and advanced analysis with reporting to inform client asset management plans.

Throughout this project the partners continually tried to anticipate the requirements clients will have in the future from Building Information Modelling (BIM) purposes and working together implemented emerging technology to the paving process.

Northumberland County Council now has an accurate data collection system that reduces inbuilt defects resulting in much greater accuracy when predicting future maintenance works and costs.

2.2.3 A77 Littlehill to Burnside Farm

A trial was undertaken on behalf of Aggregate Industries, Scotland Transerv and Transport Scotland by MATtest and HDS to assess the differences in results between using conventional methods and remote logging methods for monitoring the laying of bituminous materials in Scotland.

The trial compared the variation between the two methods for the following characteristics:

- Laying records and temperatures
- Compaction monitoring
- Rolling temperatures
- Surface irregularity

Overall the trials proved to show good correlation between the results from the two methods, it did however indicate a few areas where improvements could be made. This was mainly during the compaction process and the instrumentation used on the rollers, the issue they encountered was they had three rollers on site but only one was instrumented. The instrumented roller was always used behind the other two and therefore no real comparison could be made between the in-situ air void content and the asphalt temperature. This highlighted the point that two rollers would need to be instrumented so that the data could be combined to establish the minimum number of passes to achieve a given air void.

2.2.4 M8 Junctions 29 to 28, Eastbound

An on-site trial was undertaken on the M8 Eastbound carriageway between junctions 29 and 28 to compare the results from the conventional on-site quality control test methods to those from the remote systems developed by Highway Data Systems in conjunction with Mattest. Full details of the works and testing carried out can be found in the comparison report prepared by HDS and MATtest (Report to Demonstrate Highway Data Systems / MATtest Automated Systems and Compare with Existing Methods of Test and Reporting).

The report identified comparisons between results from conventional methods to those from electronic data monitoring during several stages of the works, these included:

- Laying records and temperatures
- Compaction records
- Texture depth
- Surface irregularities

On a whole, the report shown that the remote monitoring system from HDS has the potential to bring several improvements in comparison with the conventional on-site devices. The laser texture depth as well as the discharge temperatures presented very comparable results to the conventional measuring methods. However, the rolling temperature obtained from the HDS system presented results mostly below the minimum rolling temperature of 130 °C, while the conventional temperature measurements displayed results above. Traditionally rolling temperature is measured mid mat whereas IR systems measure the surface temperature which will always be lower.

Some limitations to the laser system were also identified, as it was not able to test in standing water. Nonetheless as no traffic management is require, it is possible to deploy the system when conditions are suited, without the need for costly lane closures. The HDS server also picked up when details from a lorry were entered incorrectly due to human error.

The report also identified several benefits of using electronic data monitoring these included the following:

- Health and safety – by removing the technician from site who would usually perform duties close to both the moving paver and rollers.
- Efficiency – By gathering more data and reporting it in a more dynamic format we can use the new automated system to produce better KPIs and monitor trends such as lorry waiting times and paver stoppages to improve the quality and efficiency of the work being carried out on site.
- Better data – The generated data can be inputted easily and directly into pavement management system (PMS) or another BIM platform where it can be incorporated with other data sets to build up a complete understanding of the road network.

2.2.5 Automatic Data Collection Review

A report has been issued by WSP reviewing the systems and methodology for Automatic Data Collection. The main aim of this was to carry out a comparative study of new tracking, recording and testing technology designed to replace current procedures and testing methodologies. Four schemes were chosen from the South West Unit Structural Maintenance programme to trial the new technologies against current established processes, procedures and specified test methods. The four schemes were:

- M8 Junction 29 to 28 Eastbound
- M8 Arkleston Westbound
- A82 Gartshake Southbound
- A76 North of Garleffan Roundabout

The main purpose of the study was to compare the data and findings provided from automatic data collection to check its credibility, transferability, reliability and objectivity against traditional and current methods.

A summary of the report highlights several issues which need to be resolved to roll out automatic data collection as a standard. The automatic data collection methods used on the projects did reveal a close relationship between the results from the traditional methods but some discrepancies do exist. It would therefore be recommended that more work is undertaken to demonstrate that the systems can provide comparable, repeatable and reproduceable results.

The reporting of the results has shown to supply a vast amount of data fulfilling the “big data analytics” concept but does not make immediately obvious what data is relevant. Therefore some sort of clear framework needs to be developed to ensure the data is formatted effectively so it can be easily interpreted by the engineer.

2.3 Standards and Specifications

There is currently no provision for the use of electronic data monitoring during resurfacing works for roads and highways in the UK Specification for Highways Works (MCHW). However, several data capturing products are readily available that can be used on any manufacturer’s equipment. Indicating that the software and hardware is already out there but needs a push in the right direction to enable it to be a part of everyday resurfacing works. The production of a specification for Electronic Data Monitoring of Resurfacing Works can define the project requirements to the contractor including; references to specific standards or clauses in standards to address specific issues and performance properties.

Since electronic data capture is generally equipment-based technology, new specifications must be developed in order to take full advantage of its benefits. These specifications must also be flexible enough to handle the varied capabilities of the data capturing technologies.

Current standards and specifications used around the world vary with respect to data capturing methods used during resurfacing works. This may include contractual requirements and incentives in place to encourage more consistently laid materials, including financial bonuses or penalties. The National Institute of Building Services has published a specification (Section 32 12 16, Hot-Mix Asphalt for Roads) developed to provide a quality control testing programme to be used as a basis of pay.

Currently the only countries to have adopted electronic monitoring and collection methods into their specifications and practice is the United States and Sweden. In particular, the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) have both developed specifications for the use of electronic data monitoring and collection during the compaction process.

There is one British Standard, PD CEN/TS 17006:2016, this technical specification provides guidance, specifications and requirements on the use of Continuous Compaction Control (CCC) as a quality control method in earthworks by means of roller integrated dynamic measuring and documentation systems. Although this is used during a different stage of the construction process and the material properties are different, the concept is very similar in that electronic data capturing is used to monitor the compaction of a material.

2.3.1 Continuous Compaction Control (CCC)

A specification has been developed to continuously measure the compaction of soils, granular materials and rockfill materials which can be compacted using vibratory rollers. The technology is based on the measure of propel energy necessary to overcome the rolling resistance and can be used as a quality control method in earthworks. The propelling power of the compactor provides an indication of the material stiffness and it is measured as a function of the machine ground speed, slope angle and rolling resistance.

The standard provides several details to carry out CCC including: requirements for the surface layer, equipment and the documentation system, its applications and calibration methods. Although this standard is available, CCC is not a requirement in current contracts and is very rarely used.

2.3.2 FHWA Generic Asphalt IC Specification

The Federal Highway Administration has developed a generic specification for Intelligent Compaction Technology for Asphalt Applications which can be modified by the Department of Transport from each state to meet local specifications. The specification provides guidance on equipment requirements, quality control, construction processes, method of measurement and basis of payment. It is also flexible enough so it can handle the varied capabilities of Intelligent Compaction (IC) rollers and the properties of compacted materials.

Intelligent Compaction is the compaction of asphalt pavement materials, using modern vibratory rollers equipped with an integrated measurement system, an onboard computer reporting system, Global Positioning System (GPS) based mapping, and optional feedback control. IC rollers facilitate real-time compaction monitoring and timely adjustments to the compaction process by integrating measurement, documentation, and control systems. Intelligent compaction rollers also maintain a continuous record of color-coded plots, allowing the user to view plots of the precise location of the roller, the number of roller passes, and material stiffness measurements. During the compaction process the data collection can be electronically stored and made available in the future, allowing for detailed laying information to be available if issues arise.

This specification has been provided by FHWA as a guideline to contractors for the implementation of intelligent compaction and is currently only permissive or optional. The FHWA does however offer financial incentives to using intelligent compaction via MAP-21 under section Sec. 1304: Innovative Project Delivery Methods, which states “The Federal share payable may be increased by up to 5 percent of the total project cost, not to exceed 100 percent, for projects determined to meet the requirements specified in 23 U.S.C. 120(c)(3).”

2.3.3 AASHTO

The American Association of State Highway and Transportation Officials (AASHTO) is a standard setting body which publishes specifications, test protocols and guidelines which are used in highway design and construction throughout the United States. They have recently developed three standards for using electronic data monitoring during the resurfacing process and file formatting procedure of reporting data, these include:

- Standard Specification for File Format of Intelligent Construction Data
- Standard Practice for Continuous Thermal Profile of Asphalt Mixture Construction
- Standard Practice for Intelligent Compaction Technology for Embankment and Asphalt Pavement Applications

Like the FHWA specification, the AASHTO standards are just guidelines for the use of electronic data monitoring procedures during construction and are optional, although the standard can be specified by the client for the contractor to follow.

The three standards together provide best practice procedures for electronic data monitoring during the laying and compaction of asphalt. They cover quality control, best operational practices and the file formatting required for the collection of as-built records.

2.3.4 Standard Specification for File Format of Intelligent Construction Data

The standard specification for File Format of Intelligent Construction Data (AASHTO Designation: MP NN-17) describes a tagged file storage format used for geo-referenced intelligent construction data. The type of data includes, but is not limited to, intelligent compaction data and paver-mounted thermal profiling data. It provides the standard layout and file format for recording data to be input into a standardised intelligent construction data management software. The standard itself advises the use of Veta, a software for importing the data file to validate it.

Veta is a standardised intelligent construction data management software that stores, maps and analyses intelligent compaction and associated geospatial data imported from various intelligent compaction machines and MOBA PAVE-IR thermal bars and scanners to perform editing, data layering, point testing, and analysis. It can then display the compaction information in easy-to-read formats, including graphs and maps to evaluate the uniformity of compaction as part of the project quality control operations.

2.3.5 Standard Practice for Continuous Thermal Profile of Asphalt Mixture Construction

This standard practice is intended for quality control during construction, all tasks covered in the practice are the responsibility of the contractor, unless otherwise designated. It provides the construction requirements and calibration procedures for monitoring the continuous thermal profiling of the asphalt mat temperature immediately behind the paver during placement operations. The standard also includes the requirement to use a system that includes a display allowing the operator to view a pavement surface temperature contour plot and automatically store and save the data for later review.

2.3.6 Standard Practice for Intelligent Compaction Technology for Embankment and Asphalt Pavement Applications

This standard practice document is designed to be used by the contractor for controlling quality using electronic data measuring devices during the compaction of asphalt pavements. It describes a process that uses rollers equipped with a measurement-documentation system that automatically records compaction parameters in real-time during the compaction process. The rollers are equipped with accelerometers that use roller vibration measurements to assess mechanistic material properties and to ensure that optimum compaction and uniformity is achieved through continuous monitoring of operations. The standard provides guidance for the contractor to follow including; the equipment, construction and reporting requirements.

2.3.7 Section 32 12 16, Hot-Mix Asphalt for Roads

This specification utilises a Quality Assurance and Quality Control (QA/QC) construction management philosophy. Quality Assurance refers to the actions performed by the Government or designated representative to assure the final product is in accordance with the requirements set out in the specification. Quality Control refers to the actions of the Contractor to monitor the construction and production processes to allow for corrections to be made when out of spec. In order to ensure the quality of the product, this specification suggests a penalty scheme. Where a pay factor is applied to the contractor if materials are not to specification and do not meet the requirements of the client. This will then result in a discounted payment to the contractor.

3. Operations

The key aspect of implementing electronic data monitoring during the construction stage is how the data collected can be used and integrated into existing pavement management systems, together with its relevance to contractual requirements, quality control and future decision-making processes. This also includes considering the application and adoption of electronic data monitoring, and the associated implications / impact on operations.

3.1 Data Integration and Management

Asset management and data integration is key for the successful maintenance of pavements, this includes keeping records of as-built information and any routine maintenance or interventions which has been carried out. Electronic monitoring improves the asset management process by increasing the amount and accuracy of information that can be recorded during a resurfacing operation, including the transportation, paving, compaction and post testing phases of construction.

The data recorded during the resurfacing operation, detailed in Section 2, needs to be successfully integrated into a pavement management system for it to be useable in the future. A pavement management system is a database used to record and view road condition and construction records of the trunk road network. Having an up to date pavement management system is vital for maintaining a record of trunk road assets in terms of location, hierarchy, asset owner, quantity, dimensions, materials, asset manufacturer and maintenance history.

Introducing the use of electronic data monitoring during resurfacing works means digital as-built data records can be obtained from the laying and compaction records, which in turn can be input into existing pavement management systems (PMS) or fully integrated into a BIM model. This would require the client and contractor working together to adapt to electronic data monitoring to ensure compatibility with PMS and BIM systems.

In 2011 the Government mandated all their projects would be required to be delivered with BIM at level 2 by 2016. Building Information Management (BIM) is a construction management system whereby all parties to the successful delivery of a project, collaborate and share data to a common digital environment in an agreed format so that defects and unforeseen costs are minimised through the entire asset lifecycle, from project conception, design, construction, operation and maintenance to deconstruction and reuse.

3.2 Contractual Requirements, Quality Control and Future Decision Making

Adopting and applying electronic data monitoring has the potential to bring several benefits for both the client and contractor in terms of meeting contractual requirements, proving quality and supporting future decisions. Compared to the current control methods in place, it provides several much more detailed records through increased frequency of checks, introduction of live monitoring and the reduction of human error.

Introducing new technology into resurfacing works will bring with it several contractual implications as some of the technology is not accepted in current standards and specifications, therefore deeming the results as void. This means any electronic data monitoring that is undertaken will require traditional testing methods to be undertaken at the same time to verify results.

Introducing live data monitoring does however, allow for key quality aspects to be checked frequently by the client and contractor ensuring contractual requirements are met. These may be contract specific or relating to the Standards for Highways or British Standards and can include, but not limited to, as-built information or material properties. Live monitoring also allows for any non-conformances to be identified immediately on site and rectified straight away, ensuring the finished pavement is fit for purpose and suitable to provide its proposed design life.

Producing detailed construction records of a pavement also has the potential to help with future decision-making processes which could include; designs for rehabilitation, improvement works, widening of the pavement or material choice on future projects based on historical performance. An up-to-date record also allows the age of the pavements surfacing to be known which enables intervening maintenance to be planned and carried out to ensure the pavement doesn't deteriorate causing surface defects and unplanned repairs. Reducing the number of unexpected repairs such as potholes and cracking, has the potential to reduce costs significantly and the need for unplanned road closures.

3.3 Benefits and Implications of Adoption and Application

The application and adoption of electronic data capture will provide several positive and negative influences on both the client and contractor. Table 1 below highlights the benefits and implications that may occur from the application of electronic data monitoring during resurfacing works.

Table 1: Implications and Benefits of Adoption

	Client	Contractor
Benefits	• Reduced construction delays • Assurance about their contractors' quality of workmanship • Supports case for applying for additional funds for highways maintenance • BIM record provided • Supports improved procurement of highway work • Delivers long-term savings for taxpayers • Provides highly detailed build information of an asset	• Efficient laying and compaction process • Reduced remedials – long term understanding of reasons for failure • Additional work through supporting local authorities to access more funding • BIM level 2 compliance • Provides ability to prove the durability of materials and installation practices • Reduced staff on site reducing health and safety aspects • Reduced risks of incorrect manual data entry
Implications	• May reduce the number of contractors available • Additional software and staff training will be required • Cost of quotes from contractors may increase due to additional requirements • Increased initial cost • Data needs to be reviewed to get any benefit	• High initial cost to buy or rent equipment • Staff will need to undergo training • Discrepancies may occur between electronic and manual data recorded on site • If a common data environment is not possible a standalone option will not be BIM compliant • Some of the electronic data monitoring methods involved are not currently accepted under current specifications and standards.

As can be seen from Table 1, several of the implications are short term and generally related to initial cost and training. However, once the contractor and client have the initial necessities in place, electronic data monitoring will bring several benefits to the overall auditing process including the operation stage, storage and future usage of the data.

On top of the general benefits from electronic data monitoring, it has the potential to provide several efficiencies that could ultimately support future cases for additional funding. Efficiencies are measured and monitored based on three components: economy, productivity and effectiveness. Electronic data monitoring has the potential to provide efficiencies by:

- Reducing risks by identifying errors early through live monitoring and instant feedback
- Producing higher quality/longer lasting products through live monitoring

- Improving whole life costing through improved quality and accurate recording of as-built information
- Improved planning of future works through accurate recording and improved management of as-built information

Ultimately, electronic data monitoring has the potential to provide the client with best value for money through improved monitoring of data by reducing the risk of imperfections and providing accurate as-built information.

However, there is always the risk element that the electronic monitoring system may fail, whether it be the piece of equipment itself or the data corrupting following extraction. This sort of failure could result in the loss of the collected data and therefore not validate the pavements characteristics to meet specific standards and specifications. These potential problems would have to be considered and a back-up system may need to be put in place to ensure the works can be checked to ensure they meet the required standards and specifications. This system may include ensuring two pieces of equipment are employed during each stage of the works or ensuring manual data collection is carried out at the same time. There could also be the possibility of feeding live data from the equipment to a totally separate system, this way back-up data will always be available for viewing.

3.4 Contractual Implications

Introducing electronic data monitoring into a contract has the potential to be a burden when sourcing contractors, as finding a contractor and agreeing terms may be problematic due to the reduced number of contractors who can offer electronic data monitoring. A reduced number of available contractors also means the bidding process may become less competitive resulting in increased costs.

A key aspect to the adoption of this technology is the contractual implications, and associated challenges from contractors, a culture of win/ win needs to be adopted by all parties to ensure that the benefits of the adoption of such technology are fully realised. This essentially means that if both parties come to the table with goals that are mutually compatible and they can reach a middle ground, there is a good chance that the negotiation can result in a win for both sides. Of course, there is nothing stopping a negotiator from trying to press an advantage and push the other side into a losing position, risking the other walking away from the negotiation.

It is therefore vital that the chosen contractor is eager and willing to put electronic data monitoring into practice and that they fully understand the capabilities and principles behind the technology and its outcomes. It is also highly important that both parties are able to provide a common data environment, as a standalone option will not be BIM level 2 compliant.

Due to the technology being in its early stages of development and implementation, it adds a risk factor to both the client and contractor that implementing the technology may be more expensive or time consuming than originally thought. This may make it difficult for both parties to agree on who is contractually responsible for any financial loses.

3.5 Pay Factors

As electronic data monitoring can be used as a tool to measure quality and record information during the paving process, it can allow for pay factors to be added to the contract. Pay factors can be applied to the quality control process and a penalty can be applied to the whole or a portion of the payment to the contractor depending on the quality of the work produced.

The penalty scheme can be applied, but not limited, to the delivery temperature of the asphalt, the rolling temperature of the asphalt, weather conditions during laying, coverage of the roller, compacted thickness, number of surface irregularities, in place density, laboratory air void content and texture depth.

Scandinavian countries have been using pay factors for the past 10 years and currently has the following in place:

- Substantial bonuses are paid if the half pipe truck is used. This gives better temperature consistency of delivered material.
- Bonuses are paid where risk areas are almost zero – risk areas are when the thermal imaging process records compaction temperatures below minimum.

Implementing this has resulted in all trucks delivering asphalt being changed to half pipe trucks within 5 years.

This shows that pay factors can benefit both the client and the contractor as the contractor gets paid more for producing higher quality work and the client gets a higher quality pavement which can result in lower future maintenance costs.

Pay factors can be added to the specification or contract and can be accepted by both the client and the contractor to ensure the contractor is rewarded for monitoring data efficiently and ensuring the material laid is above and beyond requirements.

4. Conclusion

Electronic data monitoring of resurfacing works is slowly seeing its way into the paving process, not only in resurfacing works but also new construction. And although The UK Specification for Highways Works (MCHW) currently makes no provision for the use of electronic data monitoring during resurfacing works for roads and highways, there is clear evidence that it can be specified by the client in order to improve data monitoring and achieve BIM level 2 requirements.

Achieving BIM level 2 requirements is key as it is well known that local authorities are increasingly being put under pressure by central Government to develop highly detailed and holistic views of assets, which can be used now and into the future. To facilitate the implementation of focused asset management plans, it’s important for authorities to be able to record and analyse, in real-time, the work that contractors are undertaking on their road network

Through this, better data-led, informed asset management plans can not only help Local Authorities with long-term planning and financial management, but can additionally unlock additional funding through the Department for Transport. Furthermore, future spending decisions on networks can in turn be more accurately managed by analysing lifecycle predictive modelling.

It has already been proven by AASHTO and FHWA that it is possible to implement new technology into current standards to provide guidance in using new technology to control quality and capture data. Although they are not currently a must they can be specified contractually by the client. Providing both the client and contractor the option to use the new data capturing technology.

Before producing and releasing a new specification, electronic data monitoring needs to be proven to be efficient for infrastructure assets to be built, maintained and operated effectively. The specification must also support innovation, drive best practice and improve whole life value. It also must not lack asset management strategies and inconsistent approaches to the application because this can lead to inefficient bespoke solutions that block innovation, add to whole life costs and fail to deliver the required performance and service improvement.

Overall electronic data monitoring is seen by many as a progression in the right direction for asphalt paving and asset management, as it has the potential to provide several build quality and record keeping benefits. However, the technology is still in its early stages of being employed on regular highway projects and its feasibility has not yet been proven.

4.1 Practical Considerations

There will be several practical considerations for the adoption and deployment of this technology, these may relate to the feasibility of the technology, funding, resources, methodology and data analysis. It is therefore important to consider what financial resources will be needed for the project and are all expenses accounted for in the project budget, including:

- Equipment and software
- Personnel available for collecting, processing, analysing data and consulting
- Achievable and realistic objectives
- Sources of funding
- Appropriate methodology to achieve desired results

These are just a few of the key considerations that will require investigation before a specification is produced and put into practice. As making sure these are available and suitable for undertaking the project are vital for reducing potential blockages and delays.

4.2 Recommendations

Before a specification is finalised and electronic data monitoring is put into practice the following should be considered:

- Consider the practicality of the adoption and deployment of the technology
- Consider contractual requirements and incentives to encourage more consistently laid materials, including financial bonuses or penalties.
- Finalise a technical specification and recommended contract specification relevant to both maintenance and new-build contracts

Once the technology has been proved to work and is feasible a specification will need preparing, detailing specific requirements needed from electronic data monitoring.

4.3 Development of a Technical Specification

Developing a technical specification is key to the successful roll out of electronic data monitoring during surfacing works that is useable for both maintenance and new-build contracts. The specification also needs to be adaptable for different construction types and techniques, this may include material type, layer thickness, brand and type of equipment and available software. This means the specification needs to be relatively open by describing required performances without mandating how those performances are to be achieved, leaving a great deal of freedom for the contractor to satisfy the specifications. The specification must also coincide with current standards and specifications relating to the laying of asphalt material.

Example specification clauses are given below for both Paver Digital Technology and Roller Digital Technology.

Example Specification Clauses for Paver Digital Technology

Provide paver technology that captures a full electronic laying record including; ambient weather conditions at the time of laying and the following for each load: material, load temperature and start/end location, date/time laid.

- Data must be provided to the Service Manager as a compiled laying record in a csv file format.
- GPS accuracy is required to within 20cm.
- Minimum 95% availability of data capture for schemes over 1200m^2 and 200m in length.

Example Specification Clauses for Roller Digital Technology

Provide roller technology that captures first pass temperature and pass count data for the compacted mat. The system must be capable of producing a single combined compaction record where multiple rollers are used in tandem. The system will include an in-cab display to aid roller drivers with effective compaction.

- Data must be provided to the Service Manager as a geospatial colour coded shape file incorporating captured metadata.
- GPS accuracy is required to within 20cm.
- Minimum 95% availability of data capture for schemes over 1200m^2 and 200m in length.'

Using these example clauses and the AASHTO specifications already available, a draft specification has been prepared in Appendix A.

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Appendix A. Draft Specification

Electronic Data Monitoring during Resurfacing Works

1 Scope

1.1 This specification sets out the requirements for the use of electronic data capture during resurfacing works for quality control and as-built records purposes.

1.2 The specification is intended to be used throughout all stages of the construction process; asphalt transportation, paving operation, compaction, post paving testing and processing of data.

1.3 All tasks are the contractor's responsibility, unless designated otherwise.

2 Equipment Requirements

2.1 The contractor shall ensure that the equipment holds built-in provisions to facilitate the calibration and verification of the test results.

2.2 The equipment shall be calibrated at intervals not exceeding 12 months in conjunction with a calibration protocol. These recurrent calibrations shall ensure the accuracy of the data**.**

2.3 The contractor must maintain the equipment for the duration of the contract (this includes necessary hardware and software upgrades).

2.4 A qualified representative for on-site technical assistance should be provided during the project to maintain equipment within specifications and requirements.

3 Asphalt Transportation

3.1 Live tracking of asphalt delivery vehicles should be available to the paving crew via a secure web portal.

3.2 The tracking information shall include, as a minimum, an identification number for the delivery vehicles, record of the plant supplying the material, departure time from the plant, unload time on site, weight and type of material on board.

3.3 Locations details of where the asphalt was unloaded shall also be recorded.

3.4 A report detailing all the above information shall be available following the construction process for future reference.

4 Paver Digital Technology

4.1 Paver technology shall capture a full electronic laying record including; ambient weather conditions at the time of laying and the following for each load: supplying plant, material, load temperature, start/end location road layer (base, binder or surface) and date/time laid.

4.2 Each load of bituminous material shall be identified and tested for temperature compliance at the point of discharge into the paver.

4.3 A record of the discharge location shall be taken using both GPS and a linear chainage system.

4.4 Continuous temperature scans of the full width of the material being laid immediately after the rear screed of the paver shall also be recorded.

4.5 GPS tracking of the paver shall be available to an accuracy to within 20cm, and with the ability to identify any stoppages.

4.6 A minimum 95% availability of data capture for schemes over 1200m^2 and 200m in length.

4.7 Data must be provided to the Service Manager as a geospatial colour coded shape file incorporating captured metadata.

4.8 An example paver summary report is provided in Annex A and an example Pave-IR report is provided in Annex B.

5 Roller Digital Technology

5.1 The contractor shall supply sufficient numbers of rollers, and other associated equipment, necessary to complete the compaction requirements for the specific materials.

5.2 Roller technology must capture first pass temperature and pass count data for the compacted mat.

5.3 The system must be capable of producing a single combined compaction record where multiple rollers are used in tandem.

5.4 The system must include an in-cab display to aid roller drivers with effective compaction.

5.5 GPS accuracy is required to within 20cm.

5.6 A minimum 95% availability of data capture for schemes over 1200m^2 and 200m in length.

5.7 Data must be provided to the Service Manager as a geospatial colour coded shape file incorporating captured metadata.

5.8 An example compaction report is provided in Annex C.

6 Post Paving Testing

6.1 Measurement of Surface Macrotexture

6.1.1 The contractor shall provide a vehicle mounted macro texture laser system which is capable of measuring texture depth of the surface course.

6.1.2 The vehicle must be capable of measuring scheme chainage together with recording GPS locations.

6.1.3 Supporting software must be capable of combining the data and building a 3D profile of the surface of the carriageway.

6.2 Measurement of Longitudinal Surface Regularity

6.2.1 The contractor shall provide a vehicle mounted laser straight edge (LSE) comprising of a Doppler radar distance measuring device, a laser height measuring system and an accelerometer (used to exclude vehicle movement).

6.2.2 The vehicle must be capable of measuring scheme chainage together with recording GPS locations

6.2.3 Supporting software must be able to constantly calculate a running 3m averaging line and compare it to the measurement at the midpoint.

6.2.4 An example of the raw data collected during the post paving testing is provided in Annex D.

7 Processing of Data

7.1 Data must be provided to the Service Manager as a compiled laying record in a csv file format.

7.2 The reported data must be compatible with the Pavement Management System (PMS)

8 Quality Control Penalty Scheme

8.1 As part of the quality control process a penalty can be applied to the whole or a portion of the payment to the contractor if the work carried is not in accordance with the specification.

8.2 The penalty scheme can be applied, but not limited, to the delivery temperature of the asphalt, the rolling temperature of the asphalt, weather conditions during laying, coverage of the roller, compacted thickness, number of surface irregularities, in place density, laboratory air void content and texture depth.

8.3 To implement the penalty scheme into a contract, several example pay factor tables have been prepared for each construction process, see Annex E.

Annex A

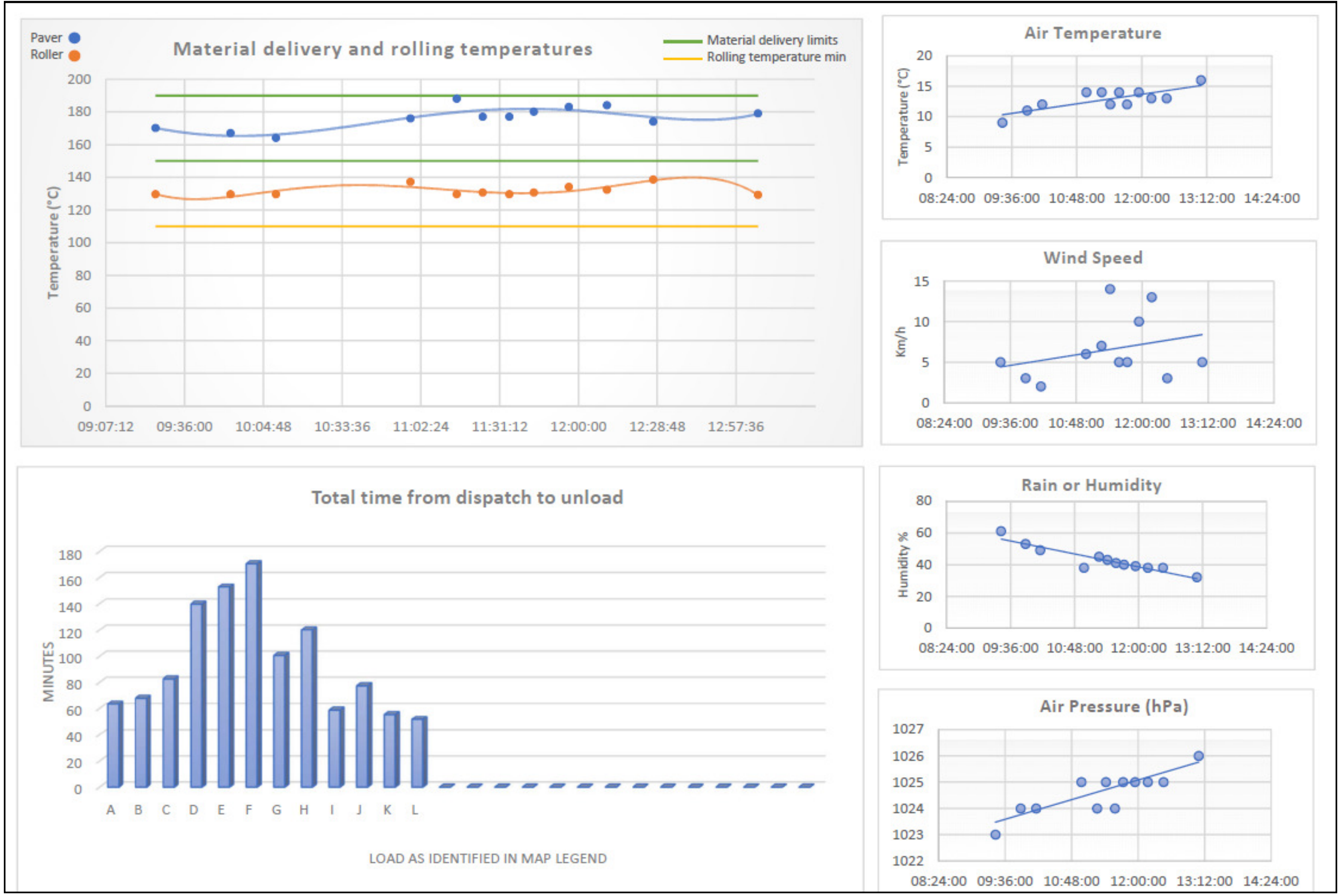
Example Paver Summary Report

Job No.	Date	Paver ID	Ticket ID	Registration	Plant	Product Code	Material	Tonnage	Load Time	Time at Paver	Latitude/ Easting	Longitude/ Northing	Distance	Material Temp (°C)	Rain/ Humidty	Air Temperature (°C)	Air Pressure (hPa)	Wind Speed (km/h)	Comments
19325260	22/10/2017	PAVERPC009	75175927	R700 JJJ	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.54	07:25	08:25	55.85914	-4.4452	23	182	88	10	1000	14	NA
19325260	22/10/2017	PAVERPC009	75175972	T12 TLM	Chryston	1697	AC_14_EME2_base/bin_15/25	19.98	07:30	08:40	55.85919	-4.44499	47	179	85	12	1000	17	NA
19325260	22/10/2017	PAVERPC009	75175960	M6 WMW	Chryston	1697	AC_14_EME2_base/bin_15/25	19.94	07:35	08:44	55.85923	-4.44477	71	175	83	12	1000	12	NA
19325260	22/10/2017	PAVERPC009	75175971	E20 AJH	Chryston	1697	AC_14_EME2_base/bin_15/25	19.82	07:35	08:50	55.85932	-4.44438	95	197	81	13	1000	12	NA
19325260	22/10/2017	PAVERPC009	75175959	K600 JJJ	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.8	07:40	08:53	55.85937	-4.44423	119	179	77	14	1000	12	NA
19325260	22/10/2017	PAVERPC009	75175982	V700 JCB	Chryston	1697	AC_14_EME2_base/bin_15/25	19.9	07:45	08:56	55.85946	-4.44395	145	182	76	13	1000	9	NA
19325260	22/10/2017	PAVERPC009	75175996	W10 AJH	Chryston	1697	AC_14_EME2_base/bin_15/25	19.9	07:55	09:02	55.85938	-4.44413	167	194	76	13	1001	20	NA
19325260	22/10/2017	PAVERPC009	75175981	W26 JCH	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.48	07:55	09:09	55.85946	-4.44387	191	193	74	14	1001	14	NA
19325260	22/10/2017	PAVERPC009	75176012	R30 JCB	Chryston	1697	AC_14_EME2_base/bin_15/25	19.8	08:05	09:14	55.85955	-4.44364	212	191	74	14	1001	26	NA
19325260	22/10/2017	PAVERPC009	75176019	X6 TYS	Duntilland	1697	AC_14_EME2_base/bin_15/25	26.54	08:05	09:22	55.85963	-4.44337	239	195	72	14	1001	16	NA
19325260	22/10/2017	PAVERPC009	75176055	R18 NGG	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.5	08:40	09:30	55.85969	-4.44319	263	199	72	13	1001	14	NA
19325260	22/10/2017	PAVERPC009	75176079	SN16 NWS	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.77	08:49	09:37	55.85977	-4.44295	289	198	74	13	1002	22	NA
19325260	22/10/2017	PAVERPC009	75176125	SY67 RYM	Duntilland	1697	AC_14_EME2_base/bin_15/25	24.2	09:19	10:06	55.85984	-4.44274	311	195	71	13	1002	13	NA
19325260	22/10/2017	PAVERPC009	75176105	R700 JJJ	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.54	09:30	10:26	55.85944	-4.44383	333	194	75	13	1002	19	NA
19325260	22/10/2017	PAVERPC009	75176178	K600 JJJ	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.72	09:50	10:38	55.85945	-4.4438	360	190	74	13	1002	19	NA

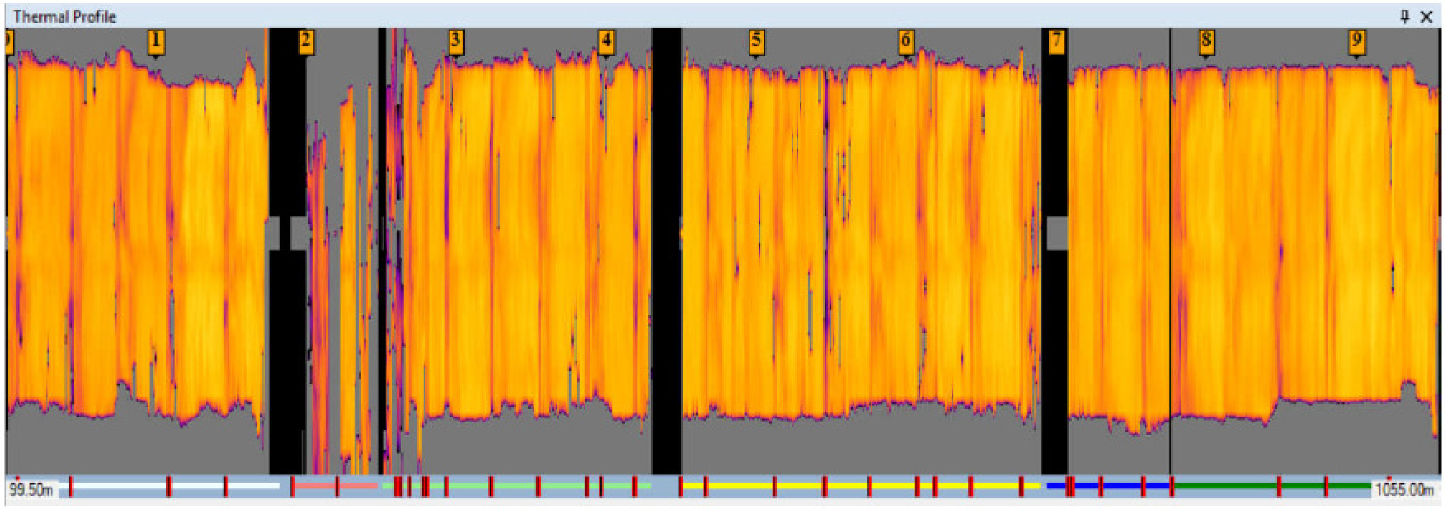
19325260	22/10/2017	PAVERPC009	75176185	V700 JCB	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.6	10:05	10:54	55.8595	-4.44363	383	186	71	15	1002	18	NA
19325260	22/10/2017	PAVERPC009	75176193	W26 JCH	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.5	10:30	11:22	55.85958	-4.4434	407	191	69	15	1002	17	NA
19325260	22/10/2017	PAVERPC009	75176190	W10 AJH	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.76	10:45	11:31	55.85967	-4.44315	431	188	62	15	1003	26	NA
19325260	22/10/2017	PAVERPC009	75176196	X6 TYS	Duntilland	1697	AC_14_EME2_base/bin_15/25	27	10:35	11:35	55.85986	-4.44263	455	180	67	15	1003	10	NA
19325260	22/10/2017	PAVERPC009	75176197	R18 NGG	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.54	10:45	11:45	55.85991	-4.4425	480	185	68	14	1003	27	NA
19325260	22/10/2017	PAVERPC009	75176199	SN16 NWS	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.76	10:55	11:50	55.85995	-4.44239	22	187	69	14	1004	17	NA
19325260	22/10/2017	PAVERPC009	75176200	SY67 RYM	Chryston	1697	AC_14_EME2_base/bin_15/25	26	10:50	12:00	55.85917	-4.44526	45	190	74	13	1004	21	NA
19325260	22/10/2017	PAVERPC009	75176205	T12 TLM	Chryston	1697	AC_14_EME2_base/bin_15/25	20	11:23	12:13	55.85922	-4.44499	67	196	70	14	1005	13	NA
19325260	22/10/2017	PAVERPC009	75176203	R700 JJJ	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.6	12:00	12:48	55.85926	-4.44479	91	195	65	14	1005	19	NA
19325260	22/10/2017	PAVERPC009	75176206	K600 JJJ	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.86	12:19	13:07	55.8593	-4.44459	113	187	62	14	1005	15	NA
19325260	22/10/2017	PAVERPC009	75176213	X6 TYS	Chryston	1697	AC_14_EME2_base/bin_15/25	27	12:33	13:21	55.85936	-4.44439	137	187	61	15	1006	12	NA
19325260	22/10/2017	PAVERPC009	75176210	V700 JCB	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.6	12:30	13:35	55.85942	-4.44417	162	186	60	14	1006	24	NA
19325260	22/10/2017	PAVERPC009	75176216	SN16 NWS	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.84	13:10	13:58	55.85948	-4.44398	183	192	59	14	1006	32	NA
19325260	22/10/2017	PAVERPC009	75176215	R18 NGB	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.58	13:10	14:02	55.85934	-4.44437	205	195	60	14	1006	12	NA
19325260	22/10/2017	PAVERPC009	75176218	SY67 RYM	Chryston	1697	AC_14_EME2_base/bin_15/25	26	13:15	14:06	55.85943	-4.44404	229	193	61	15	1006	17	NA
19325260	22/10/2017	PAVERPC009	75176214	W10 AJH	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.68	13:30	14:20	55.8595	-4.44378	252	188	61	16	1006	17	NA
19325260	22/10/2017	PAVERPC009	75176221	T12 TLM	Chryston	1697	AC_14_EME2_base/bin_15/25	19.98	13:25	14:30	55.85945	-4.44384	275	192	63	15	1006	20	NA
19325260	22/10/2017	PAVERPC009	75176219	W26 JCH	Duntilland	1697	AC_14_EME2_base/bin_15/25	19.56	13:30	14:35	55.85958	-4.44341	300	187	59	15	1006	13	NA

Annex B

Example Pave-IR Thermal Scanner Report



Thermal profile (non filtered)

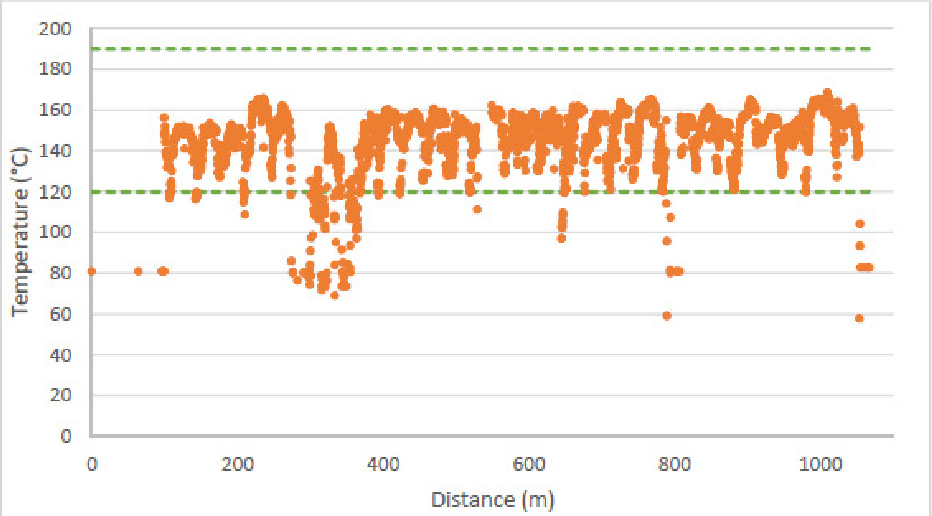


Report Summary

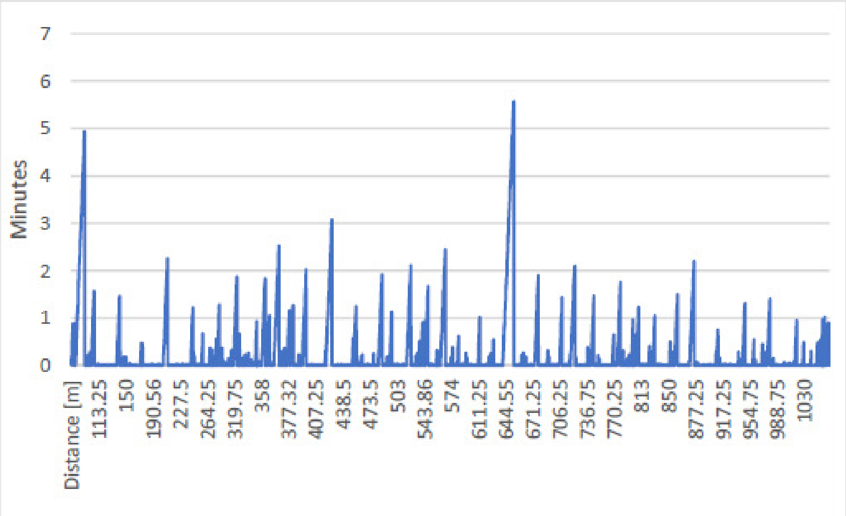
Temp limit lower	150 °C
Temp limit upper	190 °C
Tolerance (%)	20
Total Passed (%)	**93.6**

Below 80% - Poor
80 - 90% - OK
90 - 100% - Good

Thermal profile (filtered)

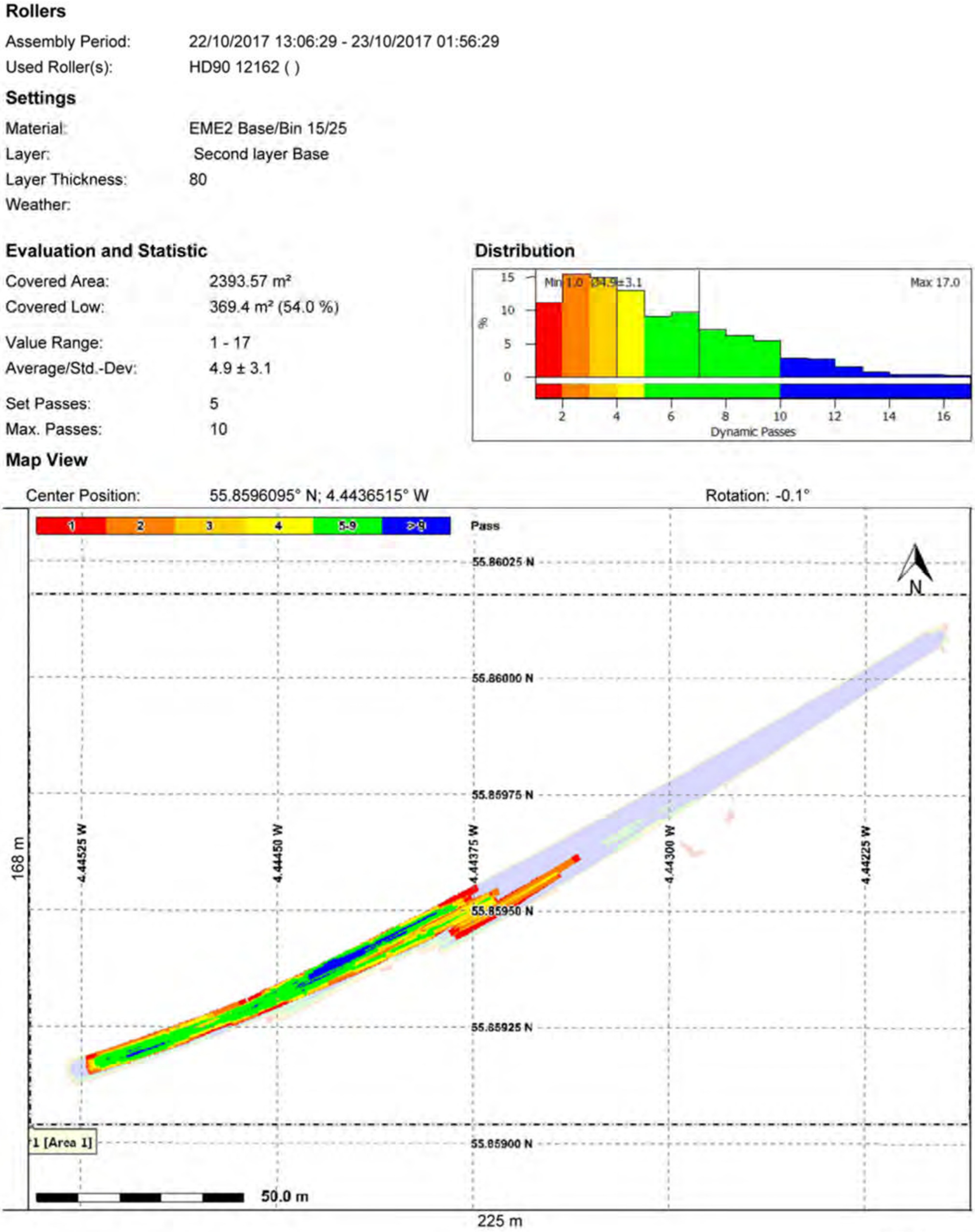


Paver stops



Annex C

Example Compaction Report



Rollers

Assembly Period:	22/10/2017 13:06:29 - 23/10/2017 01:56:29
Used Roller(s):	HD90 12162 ( )

Settings

Material:	EME2 Base/Bin 15/25
Layer:	Second layer Base
Layer Thickness:	80
Weather:	

Evaluation and Statistic

Covered Area:	2393.57 m²
Covered Low:	369.4 m² (54.0 %)
Value Range:	1 - 17
Average/Std.-Dev:	4.9 ± 3.1
Set Passes:	5
Max. Passes:	10

Distribution

Map View

Center Position: 55.8596095° N; 4.4436515° W

Rotation: -0.1°

Annex D

Example Raw Data from Post Paving Testing

Timestamp	Distance Travelled (m)	GPS Latitude	GPS Longitude	Surface Regularity Max Deviation (mm)	Texture Depth (mm)
04/12/2017 11:06	1	55.8594175	-4.4439365	0	0.92
04/12/2017 11:06	2	55.8594175	-4.4439365	0.54	0.92
04/12/2017 11:06	3	55.8594175	-4.4439365	0.75	0.89
04/12/2017 11:06	4	55.8594175	-4.4439365	1.57	0.89
04/12/2017 11:06	5	55.8594175	-4.4439365	0.97	0.86
04/12/2017 11:06	6	55.8594175	-4.4439365	0.85	0.86
04/12/2017 11:06	7	55.8594175	-4.4439365	0.90	0.81
04/12/2017 11:06	8	55.8594175	-4.4439365	1.83	0.81
04/12/2017 11:06	9	55.8594175	-4.4439365	2.39	0.87
04/12/2017 11:06	10	55.8594175	-4.4439365	1.28	0.87
04/12/2017 11:06	11	55.8594175	-4.4439365	0.53	0.9
04/12/2017 11:06	12	55.8594175	-4.4439365	0.95	0.9
04/12/2017 11:06	13	55.8594175	-4.4439365	0.93	0.89
04/12/2017 11:06	14	55.8594175	-4.4439365	0.57	0.89
04/12/2017 11:06	15	55.8594175	-4.4439365	0.36	1.01
04/12/2017 11:06	16	55.8594175	-4.4439365	0.89	1.01
04/12/2017 11:06	17	55.8594175	-4.4439365	0.86	0.96
04/12/2017 11:06	18	55.8595013	-4.4436735	0.79	0.96
04/12/2017 11:06	19	55.8595013	-4.4436735	0.77	0.97
04/12/2017 11:06	20	55.8595013	-4.4436735	4.52	0.97
04/12/2017 11:06	21	55.8595013	-4.4436735	4.77	1.07
04/12/2017 11:06	22	55.8595013	-4.4436735	1.19	1.07
04/12/2017 11:06	23	55.8595013	-4.4436735	0.68	0.9
04/12/2017 11:06	24	55.8595013	-4.4436735	2.78	0.9
04/12/2017 11:06	25	55.8595013	-4.4436735	2.89	0.83

04/12/2017 11:06	26	55.8595013	-4.4436735	1.51	0.83
04/12/2017 11:06	27	55.8595013	-4.4436735	0.81	0.84
04/12/2017 11:06	28	55.8595013	-4.4436735	0.60	0.84
04/12/2017 11:06	29	55.8595013	-4.4436735	1.12	0.83
04/12/2017 11:06	30	55.8595013	-4.4436735	1.41	0.83
04/12/2017 11:06	31	55.8595013	-4.4436735	0.93	0.77
04/12/2017 11:06	32	55.8595013	-4.4436735	1.39	0.77
04/12/2017 11:06	33	55.8595013	-4.4436735	1.52	0.84
04/12/2017 11:06	34	55.8595013	-4.4436735	0.85	0.84
04/12/2017 11:06	35	55.8595013	-4.4436735	1.40	0.89
04/12/2017 11:06	36	55.8595013	-4.4436735	1.49	0.89
04/12/2017 11:06	37	55.859588	-4.4434137	1.18	0.88
04/12/2017 11:06	38	55.859588	-4.4434137	1.12	0.88
04/12/2017 11:06	39	55.859588	-4.4434137	1.24	0.89

Annex E

Proposed Pay Factor Tables

Table E1: Minimum Temperature Immediately Prior to Rolling
(see BS 594987:2015+A1:2017, Table A.1)

Compliance with minimum temperature immediately prior to rolling, %	Pay Factor, %
≥95	101
>90 - 95	100
>85 - 90	98
80 -85	95
<80	0 (rejected)

Table E2: Coverage of the Pavement After the Specified Number of Roller Passes

Coverage of the Pavement After the Specified Number of Roller Passes, %	Pay Factor, %
≥95	101
>90 - 95	100
>85 - 90	98
80 - 85	95
<80	0 (rejected)