INCREASING EFFICIENCY OF EARTHMOVING & PAVEMENT PROCESSES AT HIGHWAYS ENGLAND
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Errors and omissions remain the responsibility of the authors alone. Please contact authors with any suggestion or comments.

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Executive Summary

This report presents some key recommendations and suggestions for Highways England (HE) to help improve Earthworks operations by re-addressing issues like collaboration, good governance, real-time data sharing and appropriate use of innovation to achieve maximum competence. Department for Transport has decided to spend £15.2 billion on over 100 major schemes to enhance, renew and improve the network over next 5 years that will help increasing user satisfaction, smoothen traffic flow and reduce interruptions on roads. It is critical to spend this money in the most efficient manner to achieve the desired strategic outcomes over the next five years. Highways England is supposed to generate £1.2 Billion worth of savings over the 5 years plan.

Strategic Outcomes
1) Smooth Traffic Flow
2) Less Interruptions Due to Maintenance
3) Safe and Serviceable Network
4) Increased User Satisfaction
5) Achieving Real Efficiency
6) Better Environmental Outcomes

Actions Required
1) Utilizing Innovation efficiently and timely
2) Increased and Improved Collaboration
3) Changing Current Work Styles
4) Feedback from Users
5) Real-time Data sharing among Stakeholders
6) Recycling on Works Sites

Highway construction projects require highly repetitive work sequence throughout the construction areas. Isolated unique activities introduce fragmentation into the repetitive tasks thus making them less efficient. Therefore, any types of delays on those operations may cause delays of the project delivery. This report uses a combination of three separate case studies that were performed to investigate the highways earthworks operations in deep detail and then provide some key recommendations to HE on the base of these study works. Different computer based techniques like Discrete Event Simulation and Geographic Information System mapping along with real-time data capturing, site visits and meetings with stakeholders were applied to investigate some Highways England operations in detail and strive to improve them. These key recommendations based on real life studies, simulated in a computer-based environment and then validated by 10 different interviews with experts will help Highways England to achieve maximum efficiency in future Earthworks operations.
1 Introduction

Road network is critical in urban life. It is intricately connected to social, economic and environmental issues. An efficient road network requires constant maintenance for best possible results; however, rapidly increasing traffic has made it hard for maintenance activities to be performed. The road network in England has been suffering due to lack of investment for some time, and it has damaged the UK’s capability to compete as well as worsened the experience of drivers.

The road sector faces many challenges including ambitious demands like quicker, economical and efficient production, construction, resurfacing and maintenance. To decrease interruption of roads for maintenance activities, it is important to upgrade the quality and methods of construction.

The fragmented nature usually characterises highways sector, the slow pace of change, start-stop funding issues, recycling issues, low productivity compared to other areas and lack of independence from central government. These problems also affect earthworks which are the most important activity in new construction as well as maintenance projects that are carried all around the year.

Now the government’s aim is to upgrade the road network according to the needs of the 21st century; i.e. to improve not only road user’s satisfaction but also increase the quality of service, support a broader economy, safety and environmental goals. UK Government has planned to spend more to maintain, operate and improve 4000 miles of the strategic road network.

“Time slots available for reparation and rehabilitation projects are becoming tighter and tighter, implying that maintenance techniques have to be speeded up.”

(NR2C 2008).
In order to increase the performance and optimise the earthworks operations, this report has included case studies that were investigated to improve with Discrete Event Simulation (DES) and Geographic Information System (GIS) mapping. Application of DES has allowed us to experiment different what-if scenarios that were otherwise not possible in real life and then choose some of the most efficient and practical cases. Similarly, with the application of GIS mapping, it has become easier for HE to decide which part of the road network needs urgent attention and make quick and evidence-based decisions.

Currently, various improvement schemes are trialled by various Highways England stakeholders, but benefits are not often adequately realised because of complex nature of projects, the involvement of a vast number of interested parties and financial issues. This report presents key findings obtained from trials conducted by Salford University research team alongside interviews with different contractors and subcontractors, who were consulted to verify and validate the findings and record their perspective on Earthworks process improvement.

Figure 1 showing projects undertaken by Salford University for Highways England
2 Research Approach

Qualitative & Quantitative Data Collection

- Review of Project documentation. (Contract documents, project requirement and background).
- Collect numerical data from stakeholders involved.
- Conduct workshops with HE staff and its service providers.
- Conduct interviews with stakeholders for detailed data collection and understanding their perspective.

Computer Based Trials

- Converting qualitative and quantitative data into computer based environment.
- Use of Discrete Event Simulation (DES) and Geographic Information System modelling (GIS).
- Perform various what-if scenarios to find best practice.

Validation and Analysis of current schemes

- Review of existing process improvement schemes and their results.
- Review of current innovative technologies to boost earthwork’s productivity.
- Validation of computer based studies from various Highways England experts.
- Focus group with stakeholders for validation purpose.

Best Practice Review

- Review of best practice in new construction and rehabilitation projects.
- Review of best practice from within UK and abroad (California).
- Suggestions for improvement in existing process.
3 Pilot Deployment Case Studies

3.1 Review of Earthworks processes at A556 Scheme

The scheduling of earthworks represents a complex task. The use of different machine configurations as well as alternative scenarios in the site layout (e.g. transport routes and temporary storage areas) must be evaluated and dimensioned consistently. Wrong decisions can lead to delays or an uneconomic solution and hence increase the costs and project duration. Hence, it is vital to optimise earthworks operations from initial stages till the end.

This undertaken project, to build a 4.5-mile new dual carriageway between Knutsford and Bowdon entered a new phase with re-routing of utility services around Bowdon roundabout and traffic management re-alignment along the existing A556, between the roundabout and Bucklow Hill.

The A556 Scheme is located between Junction 19 of the M6 and Junction 7 of the M56. The work involved upgrade from a single lane to 4 lane carriageways. Following the installation of a new dual carriageway, the existing route would be transformed into a single carriageway road.

To achieve desired objectives, a typical improvement approach, namely DMAIC was adopted. The purpose was to define the scope of work, improve the efficiency of earthmoving vehicles, optimise the working style and perform various what-if optimisation scenarios with Earthmoving machines in a computer based simulation environment, to minimise the impact on operations in real life.

3.1.1 Problem Definition

At A556 site offices, Salford University research team arranged a series of meetings with A556 project team and discussed existing processes and new opportunities for improvements within Earthworks processes. The A556 scheme involved moving of 1.1 million cubic meters of earth from excavation for road box and drain pipes, movement of soil, use of dumpers for transportation of soil, trim capping, laying base course and similar activities. Some key identified constraints and measures to mitigate them were:

Key identified measures in terms of Earthworks processes included:
* Improved utilization of resources (e.g. machinery such as excavators and dump trucks).
* Work continuity across different schemes and optimization within each scheme.
* Better value for money.
* Less disruption to travelling public. Improved cost efficiency leading.

Key identified constraints in terms of process improvement included:
* Road users are disturbed due to the movement of heavy vehicles on streets.
* 10,000 m$^3$ of movement of material everyday using 40T, 56T and 76T dumpers and dozers.
* The proposed road is 7.5 km long and work is carried out in patches which affects work flow.
* Weather related factors affecting earthworks.
3.1.2 Data Collection and Measurements

Research team relied on original datasets provided by A556 team, supported by direct observations to verify the data and identify loopholes in practice. The work on the A556 scheme was divided into several different layers, and each layer was further distributed into patches. The reason behind this strategy was to avoid blocking any road or bridge that comes in the way and to apply lessons learnt from one patch to another. From a process improvement perspective, this gives an opportunity to investigate and improve one process in detail, and transfer learnings to next patch of work.

Various processes like excavation of road box, proof roll subgrade formation, LWD testing, and laying CBGM material, etc. were observed to capture data for simulation of the actual process to be developed, in a computer-based environment. Most of the data was provided by the Highways England’s contractor, containing information about timelines, working hours, the sequence of activities, companies responsible for the work, their working style, their shift hours, duration of work and working windows. While, other data was captured at work sites on various days to get more detailed information about how earthmoving vehicles perform work, interact with each other and how their performance can be improved individually and overall as well.

Figure 2: Pictures of A556 Site during data collection at earthworks site
The data that was required to feed into simulation system to analyse properly included:

<table>
<thead>
<tr>
<th>Geometry &amp; Location</th>
<th>Ground Conditions</th>
<th>Equipment database</th>
<th>Overall schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>A description of horizontal haul road geometry and location of load and dump areas via interactive drawing tools - users draw a plan view of the haul system.</td>
<td>Form-based detailing of the characteristics of individual segments and areas. e.g. resistance, ground class, width, grade, and coefficient of traction etc.</td>
<td>Selection of the equipment fleet used in the operation from an updated database, which, details of hauling, loading, and spreading units. Hauling unit characteristics include empty and maximum weight, rated capacity, engine power, maximum speed etc.</td>
<td>General data that applies to the entire job such as random number seed values, maximum simulation time, overhead cost, and output options.</td>
</tr>
</tbody>
</table>

3.1.3 Analysis of Various Activities to Identify Opportunities for Improvement.

Data provided by stakeholders, alongside data collected during site visits was helped to develop a Discrete Event Simulation model. The reason for developing a simulation model was felt to provide a safe working model for experimenting various process interventions, without disturbing the actual process. Simulation development process involved simulating the as-is process, using collected data to identify any visible opportunities for improvements.

Once simulation model has been developed, it was used to run various What-If improvement scenarios. Such exploration was not possible in real world situations, because of impact on ongoing construction processes. Different scenarios like changing the number of dump trucks, changing the number of excavator’s on one site, trying new routes to transport soil and testing new types of vehicles (tracked and wheeled) were trailed in computer based environment.
The motivation was to include BIM models, machines databases and project schedules to simulate them in computer based environment. This helped us in finding out resource utilisation, improved project and better visualizations of the work. There were some collaboration issues in obtaining telematics and equipment related data from HE contractors that stopped further analysis of resource utilisation and the investigation remained on process level.

**Figure 4** Interfaces of the simulation system used. Adapted from (Wimmer et al., 2012)
3.1.4 Suggested Improvements to as-is process.

Research teams engaged with stakeholders in different collaborative workshop sessions, to review findings and to discuss constraints affecting outputs and optimisation of resources and find possible improvements. One key observation during simulation experiments was that productivity is greatly impacted on by working style of the organisation and not so much by type of the machine. Using innovative technologies including modern machinery can positively impact productivity. However, greatest improvement opportunity lies in addressing traditional organisational issues such as matters related to procurement, contracting, recycling and collaboration.

There is a lot of productivity related data produced by contractors and sub-contractors. However, its benefits are limited when it is not shared among the major stakeholders and also with Highways England. No consistency in sharing efficiency related data is a constraint in achieving maximum productivity. Lack of available archival data and productivity records also hinder any improvement initiatives. Simulation studies approved the current design and arrangement of earthmoving equipment by various contractors working with HE. Some issues are addressed by using suggestions provided in this report.

3.1.5 Control the progress

In order to ensure that the improved process can be sustained on future schemes, it is important that all improvement initiatives are carefully achieved and recorded. Different what-if scenarios that were tested on the machines can be replicated on future earthworks projects as well. Issues like recycling and dumping of soil are subject to work sites and will differ from each location and project. However, other aspects of the process e.g. improved value stream maps, equipment utilisation and 4d visualisation can help future projects.
3.1.6 Recommendations for Improving Earthworks

These are some important suggestions that are based on this case study investigation, computer-based simulation trials and interviews with stakeholders of Highways England in earthworks sector.

**Telematics**

- Highways England could benefit more from the latest telematics installed in the earthmoving equipment rather than leaving it to sub contractors. Data lies with contractors and sub-contractors but HE does not use and record it as they should do.
- It will help obtaining important data that can be used for further optimization studies. For implementation, a special department will be required to handle and analyse it.

**Innovation & Automation**

- Earthwork operations can be made more safer and efficient by making use of latest Innovation. Smart helmets for drivers that can inform about nearby hazard, robotic and autonomous vehicles with noise suppressed technology can operate 24/7 remotely in an automated manner.
- This will increase the efficiency of work done and safety aspects but will require further research and possible help from Transport research laboratory.

**Recycling**

- HE need to recycle materials on earthwork sites to save time and energy in transporting and dumping them somewhere. This will require a clear emphasis on a waste minimisation strategy.

**Data Sharing with Highways England**

- Highways England can facilitate open data sharing across all layers within the supply chain. This will lead to research in Best Practices in various operations and will have long term benefits. If all improvement initiatives are carefully achieved and recorded, future projects can be improved using this database.

**Data Sharing between contractos**

- As in November 2016, 12 different tier 1 contractors are working on 12 different areas for Highways England, although they are working autonomously, but there is no data sharing and communication among them. This could be addressed by providing a uniform platform for data sharing and sharing of best practice.

**VR Management**

- Virtual Reality can help manage the site with the help of drones and fixed cameras on site. This will be more accurate, updated and interactive. It will also display the live progress of work, whilst minimising safety exposure.

**Quality assurance**

- Quality assurance and implementation needs to be re-assessed in Highways England.

**Figure 7: Summary of key findings**
3.2 Improving Roads Resurfacing Operations

3.2.1 Simulation Trial on Pavement Case Study

The resurfacing and rehabilitation of road pavements have become an expensive necessity, due in large part to the enormous volume of commercial and private vehicles using the roads, which cause pavements to crumble rapidly and makes their repair difficult to carry out. The road works incur not only direct labour costs but also has associated indirect costs from factors such as congestion, motor accidents, traffic disturbance and pollution. Within the UK, there are plans to resurface 80% of entire network length by 2020/21. Road surfacing is a major component in Highways Development and Maintenance.

In the first quarter of 2015, the output of road works, as part of infrastructure works, reached up to £1,115 million (ONS 2015). Such output forms about 26.3 percent of infrastructure work and 5.4 percent of all new construction work.

There is an obvious need for cost effective maintenance that minimises the occurrence and duration of disruptions resulting from road works. Furthermore, it is becoming vital to delivering major road schemes in resource-constrained environments, while maintaining safety, cost efficiency, sustainability and minimal impact on road users.

![Diagram of National Infrastructure Plan for 2020-2021 by Department of Transport](image)

**Figure 8 National infrastructure plan for 2020-2021 by department of transport**
3.2.2 Background of case study

The development of Area 9 covers Highways England’s road network in Central England. It comprises some major roads of Herefordshire, Shropshire, Staffordshire, Worcestershire, and Warwickshire, as well as some parts of Derbyshire, Gloucestershire and Leicestershire. It also includes seven metropolitan boroughs of City of Birmingham, Coventry, Dudley, Sandwell, Solihull, Walsall and Wolverhampton. Highways England has to carry out bulk (80% of the network) of resurfacing operations over 5 years whilst keeping 97% of the network free of Traffic Management at any point in time.

3.2.3 Data Collection

Highways context is unique when compared to other industries like manufacturing or processing because of its fragmented nature which requires more in-depth approach. This makes it difficult to obtain the data from all the stakeholders about one project. This 1000 tonne trial was carried out under the supervision of Highways England, private consultants and various relevant companies, who were involved, provided the necessary data. The trial was successful, and the results were better than expected. This case study was rich in relevant data and was used as the base for simulation trial.

“The work carried out by the Agency lacks a clear yardstick to measure performance against, to help show where greater savings could be made.”

Alan Cook in his 2011 review.

M5 scheme near Worcester was chosen as one of the improvement projects to increase the surfacing output. This part of road carried 108556 vehicles in 2013, including which about 20% were HGVs and it required re-surfacing (DfT 2016). The motivation was to deliver efficiency by maximised output and use of resources, improved utilisation of road space and benefit the travellers through fewer road closures. There were inefficiencies noticed in the process and due to the incompetent working style of subcontractors, an enormous amount of resources were wasted, and traffic was disrupted on a daily basis.
3.2.4 Development of Simulation Model

After collecting the relevant data, it was important to define the boundaries of a simulation study. The scope of simulation development in this study is limited to all activities involved from road surfacing activity start (i.e. from the time of road closure for surfacing purpose) till the road is open again. Programming of the project, the constraints of material deliveries or what goes on at asphalt plant/quarry level are beyond the scope of the presented simulation.

After defining the boundaries, it is important to identify key assumptions of how the system being studied, act together with its defined external environment.

Preparation and logistic activities were included in the model, taken as fixed timings as measured on site, and are not part of the analysis. The simulated operation activities included planing, sweeping and pitch spraying, paving, rolling, white-lining, and testing. Any sub-activities within each one of these activities is not considered. All required material in the process is assumed to be always available and delivered on time. Downtime of equipment is not included in the simulation. The Simulation is based on paving 45mm thick surface course and the software used to simulate the process is called Simio. The process was divided into several steps to achieve the desired goals.

Figure 10 shows the standard resurfacing process in the computer aided simulation model. There are different vehicles involved in the operation that is latest and efficient; however, it is usually the working style of the contractor which is not efficient enough.

Figure 10.5 displays the development of simulation model on approximately same location to better understand the traffic flow and other factors at that particular location.
### 3.2.5 Multiple scenarios in Simulation Process

The main purpose of Discrete Event Simulation is to experiment various options that are otherwise not possible in real life situations. Some of them might be very expensive to trial where others are simply not possible; however, they can be trialled in a computer environment which is safe, cost and time efficient and environment-friendly.

A detailed root cause analysis was performed to study the inefficiencies in manpower, machines, methods undertaken and materials used. Different what if scenarios were completed in this case to check the effects of on the actual system and how the process can benefit from these experiments. Some of the cases that were studied, simulated and validated are explained in next section.

**Figure 10: Fishbone diagram showing root cause analysis of earthworks operation to find inefficiencies (adapted from Moore 2014)**
Figure 11 demonstration of improvement in earthworks using DES
Scenario: 1, Creating Zones within the job site and having two Pavers

- The first scenario assumes dividing the job site into two equal zones one behind another. Each zone has its own planer, a paver and both zones share five sweepers and 4 rollers. During this, two lanes are closed for resurfacing and two lanes open to public traffic maintaining the same working window.
- Key expected outcome is increased production in laid asphalt. However, the cost may rise for extra machinery arrangements.

Scenario: 2, Providing a 30 min break from 2:00-2:30 am

- A traditional 30-minute break resulted in a decrease in total production and production rate. A 30-minute break leads to total asphalt laid decreasing to 865 Tonnes in comparison with the previous scenario of 1892 Tonnes output. As a result, staggered break times are suggested, in which each team takes its break in a manner that does not affect the flow of work.
- Key expected outcome is increased output i.e. non-stop paving operation throughout the working window. However, it is usually a challenge to modify the current working style of people.

Scenario: 3, Shutting two parallel lanes at once and using two pavers

- 3rd Scenario assumes limiting motorway closures to a 6 km stretch. Two lanes at a time are closed to public traffic, and 45mm thick asphalt is to be overlaid. Each closure interval (2 lanes) requires one extra hour to complete resurfacing of the closed lanes. The additional hour is needed for the paving operation.
- This scenario will almost double the amount of asphalt laid and will resurface two lanes at once, however, shutting two lanes at once might not be possible in many cases.

Scenario: 4, Closing the Road for 55 hours (like California)

- In California, the road is usually closed for maintenance on weekends for 55 hours starting from Friday night to Monday early morning. There are more room and freedom for paving machines to work, and they do not need to be transported every day which wastes time and resources. The difference in outputs and paver efficacy can be seen in Table 1 below.
- It will save time and cost for TM and transport machinery and will increase the output. However, it will require early planning to shut a road completely and will not be possible at various locations at all.
### Table 1: Showing results of various simulation scenarios and their effects

<table>
<thead>
<tr>
<th>Scenario Description</th>
<th>Paver Total Output (Tons)</th>
<th>Paver Average Output (Tons/hour)</th>
<th>Paver Utilization (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1: Using Two pavers and dividing work into two different zones</td>
<td>1892</td>
<td>276.9</td>
<td>65.3 for each paver</td>
</tr>
<tr>
<td>Scenario 2: Providing a 30-min break from 2:00-2:30 am</td>
<td>865</td>
<td>126.6</td>
<td>59.7</td>
</tr>
<tr>
<td>Scenario 3: Closing two lanes at once and using 2 Pavers</td>
<td>1892</td>
<td>276.9</td>
<td>65.3 for each paver</td>
</tr>
<tr>
<td>Scenario 4: Closing the Road for 55 hours (like California)</td>
<td>15,954</td>
<td>358.4</td>
<td>71</td>
</tr>
</tbody>
</table>

#### 3.2.6 Conclusion

The most significant activity in resurfacing operation is paving, where the paver machine lays asphalt on the road. It was noticed in the case study that paver was being used for only 2.5 hours out of the 8 hours’ working window which reduces its efficiency to only 33%. It can be seen that paver utilisation can be maximised from 33% to 65% by implementing the scenarios described above. In the UK, resurfacing operation is usually carried out overnight, and two lanes are shut for operation, and one paver operates in one lane at a time. During simulation trials, it was noticed that using two pavers in two different lanes is also a do-able scenario that can double the amount of work done in same time.

The factors that can affect this experiment are weather, traffic volume, working styles and planning. The maximum paver efficiency achieved in the UK is 65% that was performed only once during the 1000-ton case study and has never been replicated afterwards. On the other hand, it is common to have more than 70% paver productivity in the USA due to different working window and working style. In California, the roads are shut for the whole weekend (55 hours), and alternatives are provided, but it pays off well at the end of the day.
3.2.7 Recommendations for Improving Earthworks & Resurfacing

These are some important suggestions and recommendations that have been concluded after studying in detail the 1000-ton case study (by Andrew Moore 2014), simulating it in a computer-based environment and after validating the results by interviews and meetings.

The most key activity in resurfacing operation is paving, where the paver machine lays asphalt on the road. It was noticed in 1000-ton case study that paver was being used for only 2.5 hours out of the 8 hours window which reduces its efficiency to only 33%. HE, its contractors and sub-contractors need to change their working style that will not only improve the efficiency of resurfacing, but will also reduce disruption to traffic and wastages.

Literature suggests that construction industry has scored lower than manufacturing in the last few decades. As resurfacing resembles more with a manufacturing process rather than a typical construction process, factory thinking principle can be applied on it to improve health & safety, reduce waste and maximise output.

In UK, resurfacing operation is usually carried out overnight and two lanes are shut for operation and only one paver operates in a lane. If two lanes are shut, they both can be utilized and paved at the same time (where possible) while maintaining health and safety.

HE should perform more Lean case studies to try various what-if scenarios in real life as well to improve the resurfacing operations, because 80% of Strategic Road Network needs resurfacing.

The maximum paver efficiency achieved in UK is 65% and maximum asphalt laid in one night is 1000-ton scenario that was performed only once during this Lean case study and has never been replicated afterwards. HE should investigate the reasons and perform further studies in poor knowledge management.

HE should try a penalty and reward system like United States. Contractors are paid according to the amount of asphalt they lay in one night in California, whereas, there is no such restriction in UK which does not motivate the contractors to improve their working style and perform paving for longer periods than usual. Note: It is a rule of thumb to not lay asphalt more than 130T per hour for quality purposes.

In California, the roads are shut for whole weekend (55 hours) instead of 10 hours each night like UK and alternatives are provided but it improves the maintenance work e.g. Paver utilization is 25% more than of UK case.
3.3 Decision Support Model for Pavement Rehabilitation Strategy

Roads represent a major long-term infrastructure investment. A well-managed and maintained road is, therefore, fundamental to the customer satisfaction, economy, safety and availability of the road network as a whole. In carrying out pavement maintenance functions, Highways England and Local Highway Authorities face growing pressures arising from inadequate budgets and greater accountability, when many of the existing roads have reached the upper limits of their design lifespans while being subjected to increasing traffic.

Many factors influence the decision-making process in pavement maintenance management, including road surface conditions, safety, traffic loading, cost and funding, hence an efficient approach is vital to ensure optimisation and a satisfactory trade-off between conflicting factors.

A Multi-criteria Decision Making (MCDM) approach is used to handle the trade-off between conflicting factors. It is processed in the Analytical Hierarchy Process (AHP) and then imported into GIS, in order to allow ease of query, analysis and visualisation of results. The main key output is the development of a GIS-based pavement maintenance management model to support decision making in pavement maintenance management.

The most important factors influencing decision making in pavement maintenance management are established through a nationwide questionnaire survey, which is undertaken by the UK Local Authorities’ pavement maintenance experts.
3.3.1 Suitability of GIS for Pavement Maintenance Management

Developed a GIS-based road maintenance management tool, which has demonstrated the efficiency in decision making regarding maintenance prioritisation of road networks.

GIS is a suitable choice to base a pavement management system due to the spatial nature of road data, where GIS has the capability of storing, integrating, mapping, displaying, querying, and spatially analysing road data.

The adoption of GIS leads to a better management of road maintenance

The use of GIS in pavement management has proved to be successful due to its capability of data analyses, query, and visual representation

Applying GIS which is a powerful tool that can analyse and manipulate spatially distributed data can make the process easier

Shrestha and Pradhananga (2009)

Ibraheem and Falih (2012)

Yunus & Hassan (2010)

Adeleke et al. (2015)

Panthan et al. (2010)
It is evident that there is a solid agreement that GIS has a major advantage in being able to collect, archive, and analyse road data. Another acknowledged advantage of GIS is its ability to handle spatial data and visualise it using maps.

3.3.2 Factors Affecting Pavement Maintenance Prioritisation Decisions

A thorough review of the literature was performed, and unstructured interviews with experts in pavement maintenance management from different local road authorities were conducted in order to identify and account for the factors influencing pavement maintenance prioritisation decisions. As a result, a total of 14 factors were included in the questionnaire survey for prioritisation decisions in road maintenance schemes. These factors are included in a survey questionnaire to establish a general consensus amongst local road practising professional road engineers and managers, as to the most significant factors affecting pavement maintenance management prioritisation decisions. The factors included in the survey are presented in Table 2.

Table 3 below contains a summary of the factors ratings provided by 67 local road authorities’ representatives. The scores are listed in order from 1 to 5 and are shown along with the total and mean values (rating values) for each factor. Factors are ranked according to the average values of the factors in order to establish a pattern in the attitude of local road authorities to pavement maintenance management.

“You need to be innovative to improve productivity rather than repeating the same and expecting different results”.

Planning Manager, CCP team
### Table 2: Pavement Maintenance Prioritisation Factors included in the Survey

<table>
<thead>
<tr>
<th>No.</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Remaining Service Life</td>
</tr>
<tr>
<td>F2</td>
<td>Road Condition Indicator (RCI)</td>
</tr>
<tr>
<td>F3</td>
<td>Type of Deterioration</td>
</tr>
<tr>
<td>F4</td>
<td>Observed Deterioration Rate</td>
</tr>
<tr>
<td>F5</td>
<td>Traffic Diversion</td>
</tr>
<tr>
<td>F6</td>
<td>Importance of Road/Classification</td>
</tr>
<tr>
<td>F7</td>
<td>Annual Average Daily Traffic (AADT)</td>
</tr>
<tr>
<td>F8</td>
<td>Possible Conflict or Overlap with Other Road Works</td>
</tr>
<tr>
<td>F9</td>
<td>Risk of failure</td>
</tr>
<tr>
<td>F10</td>
<td>Safety Concern</td>
</tr>
<tr>
<td>F11</td>
<td>Accident Rate (related to surface condition)</td>
</tr>
<tr>
<td>F12</td>
<td>Scheme Cost</td>
</tr>
<tr>
<td>F13</td>
<td>Available Budget/Funding</td>
</tr>
<tr>
<td>F14</td>
<td>Whole Life-Cycle Cost</td>
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### Table 3: Breakdown of Responses of Questionnaire

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<th>Total Scores</th>
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<th>Rank</th>
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<tr>
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<tr>
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</table>
Figure 13 provides a graphic illustration of the factor rating scores. It is evident from the graph that the highest rating factor value corresponds to Available Budget/Funding (F13), and the lowest rating score is achieved by Annual Average Daily Traffic AADT (F7).

According to AHP, factor weights are yielded through conducting pairwise comparisons of rated factors with a view to establishing an Importance Matrix (IM). The latter, in turn, yields a more precise ranking of factors organised according to their significance.

The following Figure 14 shows the normalised factors’ weight of importance. The sum of all factors is equal to 1.
3.3.3 Proposed Conceptual Model

The outcome of the calculated Pavement Maintenance Priority Score is integrated into GIS to form the final model. The conceptual distinctions of the model are outlined with an emphasis on the data fed into and out of it. The conceptual diagram of the model is shown below.
3.3.4 Prototype development of the model in GIS

This section presents the prototype development of the model in GIS, and the testing stage of the model, to be utilised as a decision support tool in pavement maintenance prioritisation for the purpose of optimising the use of the limited available resources in pavement management in local road authorities. Initially, 25 roads are used as the case study to test the proposed model. The next step is to assign the data layer of roads to the digital map, and then import the database for the calculated ranking of alternatives (roads) into ArcGIS software.

A scale of 1 to 3 is used for the factors according to their classification, and then the scores of the 14 factors for each factor 1 or 2 or 3 are assigned to each road to form the priority matrix. The base map layer is developed by using ArcGIS 10 software, which is used to add the relevant data for pavement maintenance prioritisation. Figure 10 shows the base map for roads, which concludes the position of the 25 roads.
Table 4: Calculation of PMPS for Each Road

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<th>F3</th>
<th>F4</th>
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<th>F6</th>
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<th>F9</th>
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</table>

![PMPS Distribution of Alternative Roads](image_url)

**Figure 17** Pavement Maintenance Priority Score Distribution of Roads
The features of ArcGIS 10 software have been used to combine the data in Table 4 with data in the attribute table of the base map of the roads layer. Priority values have been classified into 3 classes using the Symbology feature, and natural breaks are selected with three colours to represent each class. The prioritised roads are shown in Figure 19.

In order to visualise each road in accordance with its priority score, priority values are classified into 23 classes as in two occasions two different roads achieved the same priority score value (R2 and R19). Figure 20 shows the 25 roads with a colour scheme where the darkest colour represents the highest PMPS, and the lightest colour represents the lowest PMPS.
3.3.5 Ranking of Alternative Roads

Higher scores indicate the higher need for pavement maintenance. The maximum priority of roads is R12 (B375), and the lowest priority is R2 (A308) and R19 (C125). In order to visualise and demonstrate the ranking of the 25 roads, a GIS analysis has been performed. Therefore, ranking of roads is visualised in the GIS map according to their colour, and ranking is also illustrated in the GIS table of content on the left of the map as shown in
3.3.6 Recommendations for improving Earthworks 3rd Case Study

i.e. GIS based Decision Making in Resurfacing

These are some significant suggestions and recommendations that have been found on GIS model for pavement maintenance selection strategy and after validating the results by interviews with professionals from different LHA.
Despite the major developments in pavement maintenance techniques in the last few years, and the existence of pavement management and maintenance systems in the UK, Highways England (HE) and Local Highway Authorities (LHA) need to adopt a joint effort strategy to develop these systems.

The most effective factors on pavement maintenance prioritisation should initially be identified and rated according to their importance that will be justified by HE and LHA.

Highways England should consider using GIS as a decision-support tool as it is justified to be suitable for tackling problems with spatial data and predicting, which are at the centre of pavement maintenance prioritisation and decision-making.

The developed GIS model should be validated using real-world test cases, and its benefits should be recorded as a Decision Support model. HE should adopt this or similar models for better decision making.

An important aspect of future investigation should consider using GIS as a standalone decision support tool.

“Expanding the network is critical to helping our economy. Maintaining our network is essential to keeping it functioning. Road maintenance affects all aspects of performance – the time that roads must be affected by repairs; the likelihood of accidents; even emissions from vehicles on the network.” (DFT 2015)
4 Conclusions

Earthwork projects are performed in an environment fraught with uncertainty and using expensive machines that interact in complex ways. While the planning of these projects can be improved significantly using discrete-event simulation, most projects are still planned using traditional tools. Earthwork operations involve the excavation, transportation and placement or disposal of materials. They typically involve repetitive work cycles, expensive fleets and large volumes of work. Consequently, even small improvements in planning result in substantial cost and time savings. It is for these reasons that earthwork operations improvement has been the focus of so many studies. The suggestions and recommendations provided in this report are based on evidence, real-time data, interviews with various stakeholders and computer-based analysis. Highways England can benefit from these suggestions by applying in future as well as current projects.

Logistics

What about logistics. I believe that often there are conflicts within the confines of the working area as many activities need to compete for space.
References


Moore, A. Et al., 2015. Area 9 Pavement Process Improvement Improving Road Surfacing Productivity – 1000t project,


UKIPR, 2015. UK Industry Performance Report: Based on the UK Construction Industry Key Performance Indicators.
