THE FUTURE OF TRANSPORT

The new toolkit for highways asset management

An integrated toolkit for understanding the performance of highway assets in the information age





Contents

Understanding the performance of highway assets in the information age

The application of consistent, reliable information has been a key component of highway asset management for over 40 years, stimulated by the recommendations of the Marshall Committee in the 1970s[1]. However, the information, and the tools to help us interpret and apply it, has continuously evolved.

Routine walked inspections gave way to network surveys in the 1990s and 2000s, employing laser and then image based, technologies[2]. Software systems emerged to support the use of information, with databases evolving into Asset Management Systems (AMS) to provide tools to assist engineers planning and carrying out maintenance[3]. Whilst these systems initially supported table, sheet and report-based analyses, they have now been integrated with Geographical Information Systems (GIS), providing links to AMS data via intuitive map-based visualisations.

Technologies with potential to support Asset Management have continued to develop rapidly over the last decade, including condition surveys, intelligent infrastructure monitoring, crowd sourcing, remote sensing, data analytics and visualisation. However, we are not yet fully exploiting their potential in the highway environment. By bringing these components of sensing and measurement together (which have traditionally been considered separately), we could better understand highway assets and improve both reactive and proactive asset management decisions.

In this paper we discuss the tools that are becoming available to understand the performance of highway assets, their current and future capabilities and the benefits they bring. We explore the possibilities that could be achieved through the application of these tools as part of an integrated toolkit.

Whilst these tools are not in themselves "new", their application in asset management is yet to become routine, and steps will need to be taken to bring them within reach of all users. We highlight the key components of a programme that could help to deliver this.

Highway assessment tools for the 2020s

An efficient toolkit must deliver data that supports the needs of users, who may not be pavement engineers and are likely to be time and resource pressured. These users will benefit from advanced data, visualisation and decision tools that allow more efficient and accurate decision making. We have identified five key components in our toolkit. Four information gathering components each feed into the Decision Support Tools. We highlight here a few areas where, individually, they can/will improve asset management:

Asset surveys

- New survey technology can deliver higher levels of detail, accuracy and coverage – employing imaging and other sensing technologies covering both pavements and footways.
- Emerging systems will provide a step change in the ability to measure structural condition and subsurface structure at the network level.
- Advances in computing will deliver real time processing and transmission of data, improving the connectivity between asset surveys and data management systems.

Intelligent infrastructure (IoT)

- Rapid developments in low power, robust, MicroElectro-Mechanical Systems will offer widescale sensing options for all assets.
- Widescale distribution of Internet of Things (IoT) sensors will offer real-time information on asset status and environment that was previously unavailable.
- IoT enabled infrastructure will offer centralised control of active assets – e.g. tunnel environmental controls, traffic calming, signage etc.

Decision Support Tools (DST)

- Reduced constraints on data size and access, high speed computing, and AI will transform the assessment of condition and improve the prediction of future condition. Decisions will accommodate the emerging challenges of decarbonisation and Connected/Automated Vehicles (CAV).
- Integrated systems will remove the barriers to connected data, allowing newly-available datasets to support enhanced decision making.
- The ability to represent large volumes of data in environments such as Augmented Reality and Digital Twins will improve real-world visualisation, which is no longer restricted to GIS or tabular representations.

Crowd sourcing

- Road users have become data providers by providing direct feedback on issues encountered.
- Vehicles will act as data providers via direct delivery of telematics, video, environmental data.
- Mobile devices can provide autonomous feedback on journeys, travel times, routes taken, and vehicle flow rates, telemetry and imagery.

Remote sensing

- Satellite and drone observations will improve the practicality and safety of monitoring remote assets.
- Aircraft and satellite imagery will facilitate more efficient planning and prioritisation of rural networks.

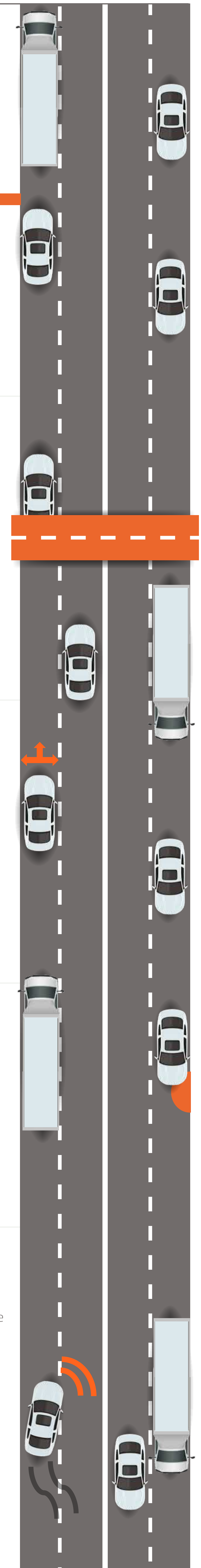
Challenges to overcome

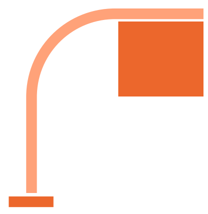
The toolkit will bring together these essential tools to provide combined outcomes that exceed the benefits that can be gained by treating them individually. However, this will require the development of an integrated strategy to overcome a number of challenges which we summarise below.

Challenges	An integrated toolkit	Benefits
The approach to the collection of condition information on highway assets is often siloed by asset type (pavement, sign). Combining data sources is still novel.		A joined up whole system approach for all highway assets (pavements, drainage, lighting, VRS etc.) will provide a holistic understanding of assets.
A lack of understanding of the data collected (or ability to access/use it) leads to the same data being collected multiple times for different needs (e.g. for network level assessment then for project level assessment). Inefficient techniques, such as walked inspections, are used when better tools could have delivered the same data.		The information needs across all highway assets will be better understood. The right data will be collected at the right time using the right tools. Data will be collected once and used for many needs. Data will have high value for operational maintenance and will support national and local assessment. Data will be available on demand to those that need it, even on site, and will be easy to associate with the location of the asset.
Asset surveys can be held back by fixed/ageing specifications. The take up of new technologies can be sporadic with infrequent amendments to standards.		Data specifications will be based on need, rather than the limitations of technology. This will encourage the take-up of new technologies and reduce the need to amend standards.
Strategic drive is needed to overcome the commercial, technical, legislative, and social challenges that are delaying the achievement of secure, robust, crowd sourced data streams. Intelligence is common for technology assets (e.g. health monitoring of lighting), but not for infrastructure assets (pavements, drains).		Low cost, pervasive systems will replace bespoke technologies wherever this offers an advantage. Crowd sourced data will be robust, safe, and supported by industry and government. New technologies will become an integral component of the asset management process.
A bottom-up approach leads to technology providers driving development. This is inefficient, with lessons being learnt multiple times. Lack of collaboration between data providers (tech) and information system providers (GIS/AMS) can prevent or delay the exploitation of new tools.		A well understood and developed route for new data will be introduced. Management systems and Decision Support Tools will work hand in hand with technology, delivering advanced and easy to use visualisation

What could it look like?

The data from the integrated toolkit can be applied in many ways to support operational and strategic needs. Here are a few examples.





Road markings, road studs, and signage:

- Long term monitoring of supporting posts (IoT)
- Quality of night-time visibility (asset surveys)
- Clarity / visibility to users (crowd sourced imagery)
- Operational performance (IoT – e.g. lighting)

DST combines and determines need for:

- Structural maintenance
- Cleaning and repair
- Cutting back vegetation

Bridges, tunnels, and embankments:

- Condition of inaccessible infrastructure (remote sensing)
- Structural and surface condition of decks (IOT, asset surveys)
- Health of bridge components (parapets, hinges etc.) (IoT)
- Traffic volume and density (IoT, crowd sourcing)
- Environmental performance (pollution) of tunnels (IoT, crowd sourcing).

DST combines and determines need for:

- Planned maintenance
- Control of traffic speed and density
- Improvements in safety

Network assurance, journeys, and routing:

- Mapping of remote networks (remote sensing)
- Assessment of network accessibility (remote sensing, crowd sourcing)
- Inefficient network design/use (remote sensing, crowd sourcing)
- 3D mapping of condition and risks (e.g. flooding) (asset surveys, remote sensing)

DST combines and determines need for:

- Strategic planning/design for conventional and automated vehicles
- Routing/traffic control to maximise asset lifetimes/reduce exposure to extreme conditions
- Improvements to accessibility

Pavement condition:

- User experience (roughness / bumps, noise) (crowd sourcing)
- Detailed surface condition in 3D (asset surveys)
- Ageing and deterioration of asphalt (asset surveys)
- Deteriorating structural condition (asset surveys, IoT)

DST combines and determines need for:

- Local improvements (structural repair, noise reduction)
- Immediate interventions (e.g. potholes)
- Long term strategic plan (upgrade, redesign/layout)

Safety

- Skidding risk from ABS, traction control events (crowd sourcing)
- Friction and surface texture data (asset surveys)
- Prevailing weather and extreme weather events (IoT, remote sensing)
- Accident occurrence (crowd sourcing)
- Environment – extent of salt present, pollution, noise (IoT, asset surveys)

DST combines and determines need for:

- Immediate traffic management to reduce accidents and pollution
- Deployment of winter maintenance (gritter) including quantity of salt to deploy
- Intervention to reduce accident risk

Asset Surveys

Asset surveys support the key needs of network operators for up to date and accurate knowledge of their asset inventory, its condition and operational status. Typically commissioned for specific purposes, they come in various forms.

Trends

Although well established, asset survey deployment is influenced by the changing needs of users:

- Bespoke traffic-speed survey systems are expected to continue to provide high resolution data on pavement condition, using lasers and high-resolution 3D imaging. These are expanding the capability of asset surveys and reducing the need for inspectors to walk the highway. The depth of content is such that the same data can be used for project level assessment and maintenance design (a requirement on trunk roads[4]).
- Compact video surveying systems with low-cost high-definition imaging are widening the scope and coverage of asset surveys[5], especially when linked to AI processing tools and advanced data visualization[6].
- New technologies are being continually implemented. E.g. Traffic-speed measurement of structural condition is now achievable[7], and the technology is transferable to other assets[8]. and tools are in development with the potential to test the chemical composition of pavements and predict deterioration[9].
- The assessment of non-pavement assets (e.g. markings, signs, bridges and verges) can now be integrated into routine asset surveys[10].

Vision

Our future asset survey toolkit should:

- Apply the policy of survey once, achieve many goals – a joined up approach that optimises the design of surveys to meet user needs
- Employ non-intrusive (traffic-speed) surveys that can provide the information required to understand condition, identify, prioritise and design maintenance treatments.
- Be provided by a flexible and capable pool of service providers bringing the relevant, capable technologies across the network.
- Bring data handing and visualisation that is simple, quick and effective.
- Provide the ability for easy sharing of detailed data across stakeholders, to reduce replication and improve efficiency.
- Be applied by a knowledgeable group of end users, who bring an awareness and understanding of the data and its range of applications.

Challenges

There are a number of challenges to the continued development, application and improvement of asset surveys:

- The data complexity and manual handling of high data volumes deters use by the non-expert.
- On local roads, network survey specifications have remained static, failing to address improvements in technology, and placing barriers to improvement and adoption[11].
- Asset surveys are usually carried out relatively infrequently, covering the network a few times a year at best, making them appear low value if the data is not fully exploited.
- A piecemeal approach where specific surveys are used for specific applications (signs, pavements) adds to the perception of inefficiency.
- Take-up of new developments can be slow – e.g. although routine assessment of structural condition at traffic speed has been achieved on strategic roads, transfer to the local road network has not commenced.
- Surveys remain focussed on pavements. They are perceived to have limited ability for assessing other assets, although this has not been widely investigated.

Enablers

Actions which could support the improved use and deployment of asset surveys:

- The adoption of a more open, technology focused approach to asset data collection.
- The dissemination of knowledge and awareness of survey capability (strengths and weaknesses) to help stakeholders select the right survey tools.
- Standardization or assurance, where appropriate, to provide reassurance to end users when selecting survey systems.
- Bringing together technologies (combining with other tools in the toolkit) to optimise efficiency and fill the gaps that asset surveys cannot fill (e.g. the PREMiUM project[12])
- Develop wider and more advanced uses of the data using using new emerging methods for interpretation (e.g. to better understand the relationship between measurements and vehicle safety, noise, user experience[13])

Intelligent infrastructure (IoT)

The Internet of Things (IoT) describes a network of physical objects ("things") that are embedded with sensors, software, and other technologies, that can be connected to the internet to exchange and share data. IoT will make highways smarter and more responsive.

Trends

Technological advances in IoT have triggered an evolution that have boosted its ability to a new level, including:

- The application of ultra-low & low-energy sensors that deploy battery-free solutions. e.g. Narrow Band IoT (NB-IoT) has reduced the energy consumption in sensor nodes to enable maintenance-free asset monitoring[14] and boost the potential for wider deployment.
- The deployment of Edge Computing in IoT devices - IoT can now be equipped with powerful embedded processors for advanced AI computing at the device.
- 5G communication and IoT technology is unleashing a powerful combination of increased speed, expanded bandwidth, low latency, and increased power efficiency that delivers networks with many more connections.
- Big Data and IoT can be integrated to provide more informed insights on asset status.
- Blockchain has been introduced to enhance the security of IoT networks, although a level of cyber security risk remains as sensor deployment increases[15].

Vision

IoT could transform the collection and use of data for roadway asset management, bringing significant benefits to asset operators and users:

- Increased safety - Sensors will track (e.g.) vehicle speed, pavement temperatures, the presence of vehicles at high risk locations (e.g. intersections, around a blind bend) to provide a safer environment for road users.
- Better operational performance - Realtime monitoring of critical infrastructure will track changes in asset condition - improving maintenance planning, reducing operating costs and boosting capacity[16].
- Reduced congestion and energy consumption - Realtime data will enable asset owners to optimise asset behaviour to meet current demands. IoT will trigger rapid responses to evolving traffic, asset or environmental conditions so actions can be taken to minimise adverse impact, assist drivers, improve safety, ease congestion and reduce pollution[17].
- Improved user experience - with improved asset reliability customer service levels will improve. Users will use the information to support route selection, time of travel etc. and network operators will plan based activities on the network based on user needs.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Challenges

Although much of the sensor technology is mature, IoT is still evolving and challenges to its implementation on highways include:

- Scaling up of solutions - with a huge number of devices requiring simultaneous connectivity, scalability in IoT systems has become a concern. IoT nodes will have to provide increasing capability, such as functional scalability, access control, data storage, fault tolerance etc., to deal with increased complexity.
- Power – IoT networks must be energy efficient, requiring energy-efficient routing protocols, the deployment of renewable energy sources and wireless charging.
- Bandwidth – the demands of hundreds of thousands of IoT devices sending request/response signals to the server on cellular network are challenging and costly.
- Cybersecurity and privacy – both the IoT data connections and everything connected to the hardware is vulnerable.
- Reliability - When the power goes out, or the ISP experiences an outage, entire systems go offline.
- Network infrastructure - Organisations will need to manage more IP addresses, work with larger data volumes, and manage more complex IT infrastructure.

Enablers

There are a number of actions that could support improved use and deployment of IoT:

- The use of modular systems will offer users more flexibility and a less expensive alternative to redundancy. Building in power, cooling and computation as building blocks will improve flexibility and reduce cost.
- Standardisation of IoT is key. It reduces the gaps between IoT protocols (and the associated security issues) and leads to a reduction in the overall cost (of the data and manufacturing the components).
- A powerful cloud will be crucial for reliable data delivery.
- Automated device integration will allow IoT platforms to recognise new devices and allocate them to the appropriate network – simplifying deployment.

Crowd sourcing

Crowd sourcing is the practice of sourcing information from large groups of users via (e.g.). vehicles, smartphones, and direct user input. Due to the frequency and volume of data provided, this is sometimes called a "Big Data" technique.

Trends

Crowd sourcing draws on a range of technologies that are becoming pervasive:

- Connected and Automated Vehicle (CAV) vision sensors e.g. digital images, RADAR, LiDAR and intelligent data processing techniques have become the backbone of CAVs[18]. The data collected is easily adopted to support asset inventory or condition assessment, offering rapid, early detection of defects[19].
- Location (e.g. GPS, Origin-Destination), speed and flow data crowd sourced from vehicles and smartphones are currently used for traffic management, rerouting, and navigation, but there is an increasing appetite to expand its application to asset management[20].
- Steps are being taken to apply crowd sourced data to support infrastructure condition monitoring and to fill the gaps left by traditional asset surveys. E.g., the use of wheel sensor and ABS data to detect poor skid resistance[21]; user perception data to assess ride quality[22]; use of GPS and accelerometer and other vehicle sensor data to measure geometry and road surface condition[23].
- Smartphone Apps and websites[24] are being deployed to enable users to feedback on traffic, incidents (e.g. WAZE[25] or google maps[26]) or ride quality.

Vision

Crowd sourced data could support a step change in the availability, timeliness and content of data to support routine asset management:

- Increased safety – Real time identification of safety defects (locations with reduced grip, water spray) or defects that develop in a short time (e.g. potholes, obscured signs) will improve the targeting of maintenance and response times.
- Improved functionality – Continuous monitoring will provide improved trends in asset condition and support predictive maintenance planning.
- Improved sustainability – Implementation of real time traffic control systems will help minimise the effects of loading on infrastructure (e.g. exposure to heavy traffic in hot conditions) to improve durability.
- Improved efficiency – Crowd sourcing will increasingly provide the data previously provided by asset surveys, reducing their application to focussed surveys for project design
- Real-time data will be used to maintain live digital twins that track assets over their lifetimes and support new uses such as the provision of information for Automated Vehicles

Challenges

The key challenges to applying crowd sourced data solutions are associated with the technical, social and commercial barriers to obtaining data:

- The quality of information from smartphone sources is inconsistent, and poorly regulated.
- Inertial data is becoming more common for the assessment of ride quality (e.g. RoadBounce[27]) but more advanced uses requires greater data content and better understanding of its capability. There will need to be agreement on which types of data are worth collecting for asset management purposes.
- Providing real time data requires stable, high speed connectivity, which is unavailable on many areas of the network and may be costly to establish[28].
- Although there is great potential to employ the measurements from Automated Driving systems (ADAS[29]) agreements on the routine exchange data between OEMs, users and public authorities are still in their infancy and implemented on a focussed basis[30]. This is limiting accessibility.
- Crowd sourced data must be securely processed (incl. anonymisation) and shared between stakeholders.

Enablers

Some of the key actions to support the implementation of crowd sourcing in highway asset management will include:

- Legal and commercial questions over ownership, privacy and value will need to be resolved.
- Open data standards and APIs to connect data from different sources will support sharing of data.
- A standardised approach for a cloud hub to deliver and process crowd sourced data from CAVs, smartphones and other sources would improve access to the data.
- Advanced models and algorithms that combine AI and machine learning techniques will help in the conversion of "Big Data" into "Smart Data" and could also be applied in data validation and quality control.
- Real time data delivery on the highway network will require robust and affordable communications networks.
- A greater buy in from all stakeholders (government agencies, road owners, vehicle manufacturers, tech companies, end users etc...) will drive accessibility.

Example apps

Remote sensing

Remote sensing offers increased access to road networks and assets, especially those in remote, inaccessible, or dangerous locations. Imagery and sensing from satellites and manned aerial vehicles is used in the identification of assets, and detailed assessments of asset condition is achieved using Unmanned Aerial Vehicles (UAVs).

Trends

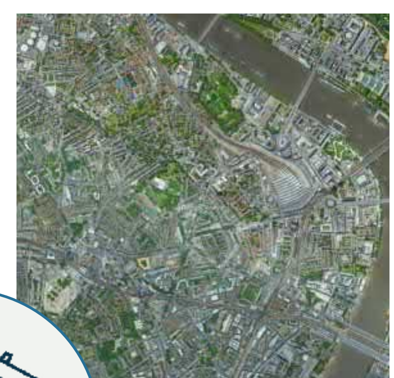
Remote sensing technologies continue to develop allowing a greater accessibility and usability of this technology:

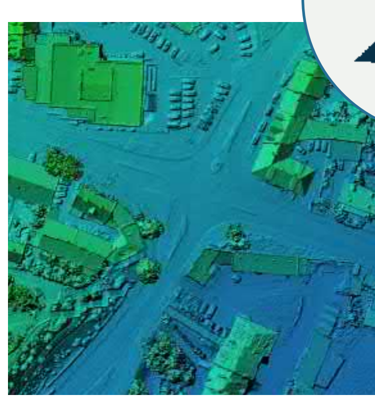
- Satellite Earth Observation (EO) is being used for engineering applications such as section alignment[31], landslide monitoring[32], and network establishment[33], and has progressed to monitoring of aspects such as rural accessibility[34] and progress of road construction.
- Satellite imagery is steadily improving in spatial and temporal resolution and provides the potential for the rapid monitoring of road networks over large areas.
- Small scale UAVs are becoming more capable in terms of their operational envelope, stability, manoeuvrability and payload capacity.
- UAVs are now deploying a wider array of sensors and tools with improving resolution, e.g. LIDAR, Synthetic Aperture Radar (SAR) and photogrammetry[35]. UAVs are being employed to carry out surveys in areas that would be difficult or dangerous to access, e.g. bridges and unstable slopes.
- Satellite imagery is being used extensively to support Rural Access Index (RAI) measurement worldwide, underpinning the key layers of population, road networks and all-season accessibility[36].

Vision

Remote sensing could transform how highway data is collected and used, especially in countries where funding and logistics for data collection can be challenging. In future this could:

- Provide routine objective, sustainable and robust data collection and analysis in remote or inaccessible areas, increasing the available knowledge[37].
- Employ AI for efficient, objective, accurate processing. This will also combine information from other data sources in the toolkit to produce holistic datasets.
- Support monitoring of the resilience of infrastructure to climate change, e.g. flood mapping[38].
- Facilitate better planning and prioritisation of rural networks, and hence improved accessibility to the world's poorest communities.
- Provide data for calculating the UN Sustainable Development Goals (SDG), especially around road network locations and population distribution[39].
- Provide opportunities for 'leapfrogging' technology in low and middle income countries.





Challenges

At present the mainstreaming of Satellite, manned aircraft, and UAV remote sensing is constrained by the following challenges:

- Roads are linear features, which are not readily suited for assessment with satellites and UAVs which have a geographically broad working range.
- Satellite imagery has minimum tasking proportions, which can make it appear costly. However, providers are willing to negotiate on large orders.
- Commercial image quality is limited by international agreements and, as yet, not as detailed as traditional surveys. This is likely to improve over time.
- Optical satellite imagery has to undergo specific processing to be representative, and radar satellite data needs specialist analysis.
- UAV imagery typically comes in small tiles that need to be georeferenced, normalised and merged to form useable images, which can be a challenging and onerous task.
- UAVs are subject to legislation that varies greatly between countries. Some restrict flights over live traffic and residential areas, whereas others have very few restrictions, which can hinder the use of UAV technology on a global scale.
- Practitioners are yet to be fully convinced of the value of this method; a change in mindset is required, backed by evidence.

Enablers

Some of the key actions to support the implementation of remote sensing will include:

- Research and innovation to support better understanding of how to use existing data. This could include how lower resolution, cheaper, satellite imagery might produce similar results to asset surveys, deploying machine learning.
- Better exploitation and development of existing sources of software that support remote sensing data, e.g.:
  - Machine learning; open source labelling and processing sites[40 41].
  - UN Global Platform; a cloud-based platform where countries can work collaboratively and use Big Data to measure SDGs[42].
  - ORFEO Toolbox; a library for remote sensing image processing, to provide users of satellite images with all the tools necessary to use these images[43].
  - Regional Data Cubes; provide satellite imagery for users in LMICs[44].
- Combining aerospace and UAV data with other established technologies to improve the power of the method.
- Clear and consistent legislation regarding the use of UAVs. This will require intra and inter-governmental agreement and legislation.
- Clearer demonstration of the benefits of remote sensing in practical applications.

Decision Support Tools (DST)

DST transform data into information to support decision-making, and can range from a simple spreadsheet to a virtual reality visualisation. In roadway management DSTs are used at all organisational levels: strategic (investment, policy, new construction), tactical (maintenance, scheme design) and operational (works scheduling, traffic control).

Trends

The trends in Decision Support Tools reflect those of the market, especially in the so-called "digital revolution":

- Systems are becoming more able to use a wider range and greater volumes of data
- The trend for software to be more open and interoperable is influencing DST design. Open-source solutions are also increasing in quality (especially in GIS).
- There is a drive to combine 'traditional' targeted data (commissioned, i.e. Asset Surveys) with 'new' distributed data (crowd sourced from private vehicles) within the systems.
- Increasing maturity of asset management organisations and greater societal expectations mean that analyses must consider an ever-widening set of goals and parameters (e.g. environmental goals, automated vehicles). Demand is also increasing for transparency around decision-making on public infrastructure.
- AI is being explored for its use in supporting in long-term condition projection and image analysis[45].

Vision

As DST evolve, their ability could transform highway asset management:

- AI-driven predictive models will rapidly improve, and play a much greater role in DST, leading to more robust long-term decision-making.
- Decision-making will become increasingly 'holistic', accounting for a wider range of desired outcomes, stakeholder requirements, and cross-asset interdependencies. It will be 'premeditated', with fewer decisions requiring truly reactive human judgement.
- Users will be able to switch seamlessly to the visualisation best-suited to the task: from abstract representations to high-fidelity realism. Augmented/Virtual Reality will provide the tools to deliver outcomes in a highly interactive environment supporting design, planning, simulation, what-if analyses.
- DST will become more closely linked with operation/control systems, closing the gap between the digital and the physical. This will drive ever more efficient and effective decision-making, making users more likely to achieve their objectives, and allowing broader and more ambitious objectives to be set.

Challenges

Perhaps the main challenge for all DST is the need to work with the ever-increasing volume, variety and frequency of available data:

- This is a particular challenge for roads – spatial data comes in large data volumes. When considering the data related to thousands of kilometres of road the challenge is significant.
- The linear nature of road assets adds a further complication as location referencing systems have a tendency to be non-standardised and situation specific.
- Road assets have a large number and diversity of stakeholders, with the general public alone representing a broad set of opinions and needs relating to roads. DST used in roadway management will need to find ways of capturing and accounting for a broader range of stakeholder requirements than they do currently.
- The continually increasing sophistication of the decision-making 'space' requires DST to encompass a widening set of data, objectives, and processes. This inevitably brings challenges around the need for better integration of systems, data and working practices.
- The increasing complexity of algorithms used in DST, in particular those associated with AI and machine learning, have the potential to lead to ineffective or biased decision making if not properly quality assured and verified.

Enablers

Some of the key actions to support the development and implementation of advanced Decision Support Tools include:

- Standards, schema, and tools to aid in structuring and linking data will be essential to allow data to be used in DST with minimal friction, and for disparate datasets to be combined to create new insights. Many such efforts are already underway – see for example the IFC standards, or projects such as CEDR's CoDEC[46].
- For visualisation, it will be important to better link the 'worlds' of GIS and BIM, allowing rich visual data to be used directly in a spatial analysis environment.
- The full suite of decision support systems (such as summarised by the University of Cambridge's IfM[47]) will need to be integrated into DST analytics in a more systematic way to allow more complex analyses to be undertaken.
- Subject matter experts and software developers will need to work very closely together –training and experience will be needed to ensure they work efficiently as a team, and speak each other's 'language'. Strong coordination of all these elements will be required.

Our Roadmap

The sun diagram shows how each of the themes discussed in this document could progress to deliver an integrated toolkit to understand the performance of highway assets. The roadmap has four phases. The timescale to achieve each phase will depend on the scope of the implementation, which may be different for Strategic and Local Roads. Delivery should be achievable within two RIS cyles on the English Strategic Road Network.

Phase 1 – Establishment

Central initiatives will define the goals for each phase and establish plans to achieve these goals. Collect once, use many times will become the norm for the majority of data collection methodologies – data which will support both strategic and local assessment.

Phase 2 – Standardisation and initial implementation

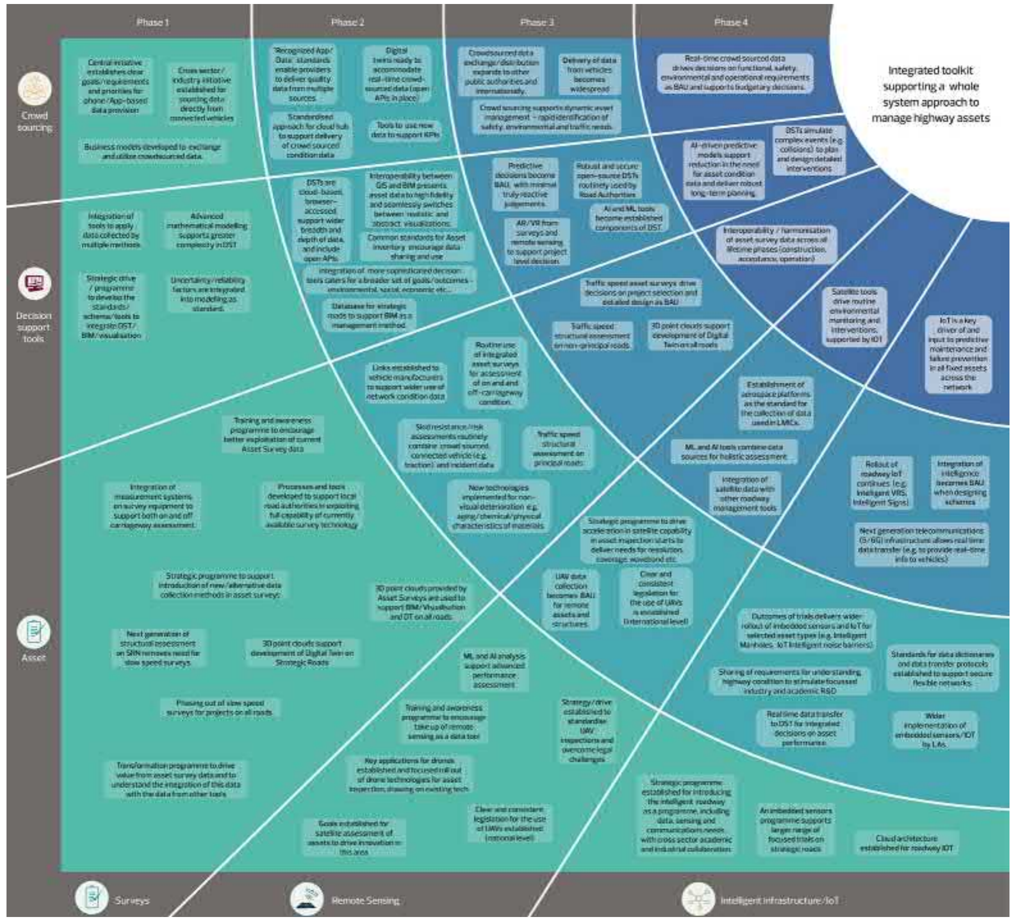
Standards supporting the development of new technologies and the evolution of existing technologies will be produced. Technologies will be developed, trialed and implemented. Low cost, pervasive systems will replace bespoke technologies wherever this offers an advantage.

Phase 3 – Roll out and integration

Wider rollout is achieved as technologies evolve and standards are established. These technologies will become pervasive and start to replace defunct systems. Data provided in real time will become the expected norm. Introduction of new technologies will be straightforward, with established routes for integrating new data streams.

Phase 4 – Full system capability

Technologies developed in the previous phases will reach full deployment, integration and regulation. Modelling and prediction tools will have the capability to replace frequent, bespoke surveys. Data will drive decisions based on AI technologies related to pavement design, maintenance and strategic planning.



The full size roadmap is available here

Key Milestones

The roadmap will feature several milestones that each mark a step change in capability delivered through the integrated Asset Management (AM) toolkit. We highlight a few of these here. The Milestones will be achieved through a joined up, collaborative, approach between asset owners, governments, data providers, technologists and researchers.

Decision support tools

Phase 1

Requirements for crowd sourced, remote sensing and IOT data established to support AM across a wide range of sources and applications

Crowd sourcing	Asset Surveys	Remote Sensing	Intelligent Infrastructure / IoT
Cross sector/industry initiatives established for sourcing data from vehicles.	Strategic programme to drive better value from asset surveys and deliver alternatives using new technologies	Strategic programme to accelerate drone and satellite capability for asset inspection	Comprehensive roadmap for IOT to transform AM

Phase 2

Crowd sourcing	Asset Surveys	Remote Sensing	Intelligent Infrastructure / IoT
Data standards enable providers to deliver secure, quality assured data from multiple sources direct to DST.	Network survey data applied routinely for project design	Clear and consistent facilitating standards/legislation established	IoT data and communication needs for AM defined
	Wider rollout/rapid uptake of new technologies (e.g. traffic speed structural assessment) on all roads	Assured and standardized asset drone inspection processes in place	Trials of IoT across projects accelerates development and use in AM

Phase 3

Crowd sourcing	Asset Surveys	Remote Sensing	Intelligent Infrastructure / IoT
"App" collection tools for AM widely used across the network			

Data Sources brought together in a whole system approach. Robust decisions routinely draw on traditional and AI analyses within DST. Enhancements to handling and visualisation tools opens the asset toolkit for a wider range of users

Crowd sourcing	Asset Surveys	Remote Sensing	Intelligent Infrastructure / IoT
Standardised central hub for hosting of crowd sourced data stimulates further take up	Asset Survey data drives decisions on projects and their design (for minimum carbon)	Assured and standardized satellite and drone inspection process established	Standards in place for the safe and secure use of IoT technologies in AM

Phase 4

Crowd sourcing	Asset Surveys	Remote Sensing	Intelligent Infrastructure / IoT
CAV (vehicle as a sensor) collection for AM becomes routine	3D data routinely supports Digital Twins, BIM and AR visualisation tools– inside and outside the asset	Integration of remote sensing data with other tools	Fully regulated, integrated IoT established for AM, deployable across assets and integrated with other tools
		Phased replacement of Asset inspections with remote sensing where appropriate	

Fully integrated toolkit for asset management with standardised, efficient data handling supporting robust decisions, real-world visualization (digital twins "inside and outside" the asset) and accurate condition prediction

Closing remarks

Whilst traditional highway asset management has drawn on well-established tools to manage the condition of networks, new technologies are now increasing the options available to asset managers. In this paper we have discussed these as a toolkit that includes asset surveys, internet of things, crowd sourcing and remote sensing, and we have considered how the data provided can be visualised and applied in decision support tools.

The objective of this paper has been to highlight the emerging capabilities of these tools, bring awareness to highway asset managers, and encourage their take up. Increased application will inevitably lead to further development in capability and, importantly, accessibility.

To get full value from these technologies within an integrated toolkit there are a number of challenges to overcome. Whilst some of these are technical, there are commercial and social barriers which will influence development and accessibility. We have therefore also discussed actions that may be needed to overcome these, within the context of a roadmap to the implementation of an integrated toolkit for understanding the performance of highway assets. Our roadmap is not definitive – it aims stimulate further thinking, debate and discussion.

The effective management of infrastructure assets is essential to deliver a clean, efficient, safe, reliable and accessible network. A joined up and collaborative approach will help the community achieve the benefits of the integrated toolkit that will help asset managers achieve this.

Our Team

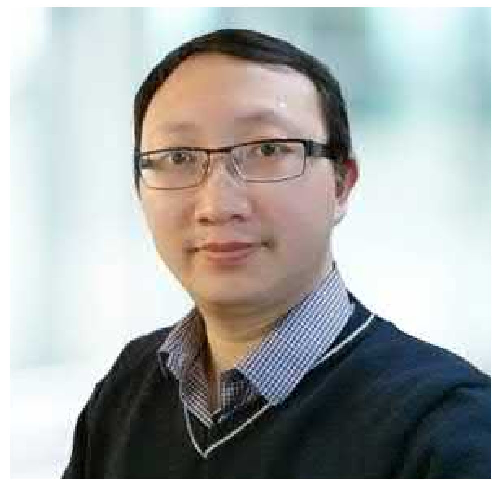
Dr. Alex Wright – is TRL's chief technologist and leads the delivery of new approaches to the application of technology in asset management.

Peter Sanders –is a senior researcher focusing on road/tyre interaction and is writing a doctoral thesis on using crowd sourced data to manage vehicle safety.

John Proust – is the Product Owner for iROADS, TRL's Highways Asset Management solution.

Robin Workman – is a principal consultant with international experience and is writing a doctoral thesis on road condition from satellite imagery.

Tadas Andriejauskas – is a senior researcher specialising in road surface characteristics, road infrastructure condition monitoring and asset management.



Dr. Hao Ye – is a senior consultant specialising in geospatial engineering and lead research on applying digital technologies for future road infrastructure.

About TRL

Our mission: Creating clean, efficient transport that is safe reliable, and accessible for everyone

TRL is a team of expert scientists, engineers and specialists working together with our clients and partners to create the future of transport.

We publish software that helps the world's largest cities, and many smaller towns too, reduce pollution, carbon footprint and congestion with advanced traffic management, better road design and good asset management.

We conduct leading edge research into infrastructure, vehicles and human behaviours which enables safer, cleaner, more efficient transport.

We deliver detailed incident investigation, structural survey and other high value field services to help clients to improve the service they give their customers.

We work with universities and other partners to invest in basic and applied research that will underpin future needs.

We have built, with partners from government and industry, the Smart Mobility Living Lab: the world's first physical and virtual testbed in a global megacity (London) that lets companies test new mobility products and services safely on live public roads.

Established in 1933 as the UK government's Road Research Laboratory, the renamed TRL was privatised in 1996 and today has more than 1000 clients in many countries. Our headquarters are in Crowthorne House, near Bracknell, and we have offices in Birmingham, Edinburgh, London, Germany and India.

Transport Research Foundation (TRF)

The TRL group of companies is owned by the Transport Research Foundation: a non-profit distributing company that enables our experts to give independent advice without influence from shareholders or finance companies.

References

1 Committee on Highway Maintenance. (1970). The Marshall Report. Available at: https//discovery.nationalarchives.gov.uk/details/r/C3827438. London: Her Majesty's Stationary Office

2 Pynn, J., Wright, M., A., & Lodge, R. (1999) Automatic identification of cracks in road surfaces. Proceedings of 7th IEE international conference on image processing and its applications: University of Manchester.

3 TRL. (2021). TRL Software – iROADS. Available at: https://trlsoftware.com/products/digital-asset-management/iroads/.

4 Highways England, Transport Scotland Welsh Government, Department for Infrastructure. (2020). CS 229 Data for pavement assessment. London: Highways England.

5 https://www.gaist.co.uk

6 https://www.exeros-technologies.com

7 Ferne, B., W., Langdale, P., Wright, M., A., Fairclough, R., & Sinhal, R. (2012). Developing and implementing traffic-speed network level structural condition pavement surveys. Available at: www.ntnu.no/ojs/index.php/BCRRA/article/download/2621/2686/. Wokingham: TRL

8 Amoore, J., Richards, P., Wright, A., Langdale, P., & Iaquinta, J. (2011) Continuous assessment of the stiffness of tracks at line speed. 5th IET conference on Railway Condition Monitoring and Non-Destructive Testing: Derby.

9 Bowden, H., Bateman, D., Jeffery, R., Rweished, M., & McRobbie, S. (2018). Spectroscopic analysis of roads at traffic speed – Sarts Stage 1. Available at: https://trl.co.uk/publications/spectroscopic-assessment-roads-traffic-speed. Wokingham: TRL.

10 Retro Tek. (2021). Available at: https://www.reflective-systems.com/retrotek-m/.

11 Chartered Institute of Highways and Transportation. (2021). UK Roads Liaison Group - SCANNER. Available at: https://www.ciht.org.uk/ukrlg-home/guidance/road-condition-information/data-collection/scanner/.

12 Wright, A., Benbow, E., Spielhofer, R., Denitsa, O., Weninger-Vyucidil, A., Brozek, B., van Geem, C., Carey, C., & Sjögren, L. (2018) PREMiUM: Understanding network-level measurement and management of road equipment. Transport Research Arena: Vienna, Austria.

13 Sanders, P., D. (2021). PPR980 Characterising the measurements made by sideways-force skid resistance devices: An experimental study. Wokingham: TRL.

14 Heidemann, J. & Govindan, R. (2004). An overview of imbedded sensor networks. University of Southern California: California, USA.

15 Dawaliby, S., Aberkane, A., & Bradai, A. (2020). Blockchain-based IoT platform for autonomous drone operations management. The Second Workshop on DroneCom in Conjunction with ACMMobiCom: London, United Kingdom.

16 McKinsey Global Institute. (2015). The internet of things - mapping the value beyond the hype.

17 Microsoft. (2018). Microsoft's Approach to IoT Digital Transformation and The Internet of Things.

18 Bullas, J., Andriejauskas, T., Sanders, P., D., & Greene, M., J. (2020). PPR962 The relationship between connected and autonomous vehicles, and skidding resistance - A literature review. Wokingham: TRL.

19 Wright, D. (2018). PPR725 Investigation into the potential of LIDAR to support traffic speed asset measurement and assessment. Wokingham: TRL.

20 Autonomous Vehicle International. (2021). Audi to harness swarm data on wheel slip to enhance hazard warnings. Available at: www.autonomousvehicleinternational.com.

21 Hammond, J., Bell, M., Wallbank, C., & Sanders, P., D. (2021). PPR988 The relationship between vehicle data, collision risk and skid resistance. Wokingham: TRL

22 Thomas C, Dhillon N, Nesnas K, Wright A. (2020). A practical investigation to understand how road users experience ride quality on the SRN. TRL Client project Report CPR2767. Wokingham: TRL

23 LiRA project. (2021). Available at: https://lira-project.dk

24 Fix My Street. (2021). Available at: https://www.fixmystreet.com.

25 Waze. (2021). Available at: https://www.waze.com.

26 Google Maps. (2021). Available at https//maps.google.com.

27 Road Bounce. (2021). RoadBounce | Ride quality measurement. Available at: https://www.roadbounce.com/.

28 Vermaat, P., Hopkin, J., Lodge, C., & Oughton, E. (2018). PPR869 Digital connectivity demand and digital infrastructure requirements for connected and autonomous vehicles. Wokingham: TRL.

29 https://www.mobileye.com/

30 European Data Task Force. (2020). Data Task Force Final report and recommendations. Available at: https://www.dataforroadsafety.eu/.

31 Beaumont, T., E. & Beaven, P., J. (1977) TRRL Supplementary Report 279: The use of satellite imagery for highway engineering in overseas countries, United Kingdom: Ministry of Overseas Development, A Paper presented at the British Interplanetary Society Meeting "Advances in earth observation (space) techniques" London, 22-23 September.

32 Landslides @ NASA. (2021). Landslide Hazard Assessment for Situational Awareness (LHASA) Model. Available at: https://gpm.nasa.gov/landslides/projects.html#LHASA

33 Informed Infrastructure. (2021). Kampala Undertakes a Pavement Management Project for its 1700km road network. Available at: https://informedinfrastructure.com/10986/kampala-undertakes-a-pavement-management-project-for-its-1700-km-road-network/

34 Transport & ICT. (2016). Measuring rural access: Using new technologies. Washington DC: World Bank

35 Schnebele, E., Tanyu, B., F., Cervone, G., & Waters, N. (2015). Review of remote sensing methodologies for pavement management and assessment,European Transport Research Review, vol. 7 no. 7, pp. 1-19

36 The world bank. (2021). Rural Access Index (RAI). Available at: https://datacatalog.worldbank.org/dataset/rural-access-index-rai

37 Workman, R., A. (2014) Road Condition Assessment; Transport Infrastructure Monitoring Phase 2, Project Report for Satellite Applications Catapult, Didcot, UK.

38 Tanzania flying labs. (2021). Creating sustainable cities, one map at time using drones: Flood resilience mapping in Dar es Salaam. Available at: https://www.arcgis.com/apps/Cascade/index.html?appid=5bf5d5767fb84878840fd8fad85a3c42

39 United Nations. (2021). The 17 goals. Available at: https://sdgs.un.org/goals

40 Ground Work. (2021). GroundWork. Available at: https://groundwork.azavea.com/

41 Geospacial World. (2021). The tremendous potential of Machine Learning in satellite imagery. Available at: https://www.geospatialworld.net/blogs/machine-learning-in-satellite-imagery/

42 UN Big Data. (2021). UN Global Platform: Data for the world. Available at: https://unstats.un.org/bigdata/un-global-platform.cshtml

43 Orfeo ToolBox. (2021). Open source processing of remote sensing images. Available at: https://www.orfeo-toolbox.org/

44 Digital Earth Africa. (2021). African regional data cube. Available at: https://www.digitalearthafrica.org/african-regional-data-cube

THE FUTURE OF TRANSPORT

The application of consistent, reliable information is a key component of highway asset management. However, the tools to understand asset performance have developed rapidly over the last decade. These include asset surveys, intelligent infrastructure monitoring, crowd sourcing, remote sensing, data analytics and visualisation. However, their potential is not yet being fully exploited within the highway environment. By bringing these components of sensing and measurement together we could better understand highway assets and improve reactive and proactive decisions.

This paper discusses the tools now available to understand the performance of highway assets. It explores their current and future capabilities, the benefits they bring, and the possibilities that could be achieved through their application within an integrated toolkit.

Whilst these tools are not in themselves "new", a key objective of the paper has been to highlight their emerging capabilities, bring awareness to highway asset managers, and encourage their take up. Increased application will inevitably lead to further development in capability and, importantly, accessibility.

There are a number of challenges to overcome to draw full value from these technologies. These include the technical, commercial, and social barriers that influence development and accessibility. The paper discusses actions that could help overcome these, which are presented within the context of a roadmap to the implementation of an integrated toolkit. The roadmap is not definitive – it aims to stimulate further thinking, debate and discussion.

The effective management of infrastructure assets is essential to deliver a clean, efficient, safe, reliable and accessible network. A joined up and collaborative approach will help the community achieve the benefits of the integrated toolkit that will help asset managers achieve this.

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