Cloud-based Road Management System

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ABSTRACT

Traditional RMS has been a Desktop application running on a Windows machine. With Cloud Technology, the RMS administration and data storage is centralized and easily accessible by a web browser. Often, the collected valuable road asset data is not easily available for the stakeholders and wider public and sometimes the data is scattered in various computers. This is changed with the Cloud-based RMS, which offers several advantages that lead to cost savings and increased data security and quality.

1 BACKGROUND

Roads are among the most valuable assets of many countries (*1*), but preservation of the assets have been partly neglected due to constrained budgets and poor asset management. Still, road networks are vital for economic, cultural and social development of most of the countries facilitating communication and transfer of goods and people improving thus socio-economic living conditions especially in rural areas (*2*).

Road Asset Management improves the decision-making process, support consistent and sustainable operations, enhance management capabilities, and improve the ability to manage efficiently and cost-effectively all management and operation of the road assets. Road Asset Management enhances the capabilities by providing timely and asset-centric decision-making support, based on readily accessible, relevant and valid information on the road assets as well as improved set of analytical tools to optimize the operational functions. With the help of Road Asset Management, road organizations can prioritize the road projects and optimise funding for routine and periodic maintenance as well as for upgrading works of the existing road network.

1.1 **Definitions**

The main idea of a Road Management System (RMS) is to derive economically, environmentally and socially sound investment decisions on road maintenance in order to maximize return on investment. In practice, RMS can be much more. Optimal investment decisions require data collected from the road network. Especially road condition and traffic information are the most important. Road assets can be easily visualized with the RMS and valuable data can be shared with all the stakeholders for various purposes such as vehicle routing, logistics planning and private sector investment planning based on traffic volumes.

According to the Organization for Economic Co-operation and Development (OECD), "an asset management system (AMS) will include all the processes, tools, data and policies necessary for the effective management of all the assets for which the road administration has responsibility, including physical highway infrastructure such as pavements and bridges as well as human resources, equipment and materials and other items of financial and economic value". Road Asset Management System (RAMS), however, is dedicated to road –related assets, but the scope varies from a country to country. The main principle is that the RAMS supports Road Asset Management practices and therefore the information and functionality contents depend on the objectives and business processes.

A Road Management System (RMS) is often used as a synonym and the World Bank definition according to McPherson and Bennett is “any system that is used to store and process road and/or bridge inventory, condition, traffic and related data, for highway planning and programming. Associated with the RMS are appropriate business processes to use the RMS to execute the business needs of the highway agency.” (*3*).

Along with the development of computer networking, World Wide Web, computing and programming languages web-based software a new concept called Cloud Computing has emerged. Even though it resembles the past idea of a combination of a server computer, Internet connection, web server software and browser-based software the main difference is bundling hardware and software for easy access and consumption. National Institute of Standards and Technology (NIST) defines Cloud Computing as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.” (*4*).

1.2 Phases of development

Several phases can be identified in development of Road Management Systems along with advances in Information Technology. The emphasis since the 1960s was on the Pavement Management Systems and during those times the software was running on individual computers. Those systems were custom-made for Road Agencies as there was not any market for commercial off-the-shelf tools that came later after the change of the millennium. The first systems did not follow 3-tier approach, where the presentation of the information would have been separated from the business logic and the data itself. Several past RMS implementations resorted to Relational Database Management Systems (RDBMS) in such a way that besides the stored data, the user interfaces were created and running on the RDBMS.

The main shift towards Cloud-based RMS was taken in the 2010s when web-based systems started to become more common. The first initiatives were custom-made for Road Agencies providing mainly a restricted number of functionalities for larger number of public stakeholders. Road users could not only visualize the road network on GIS, but also see relevant information such as road works and traffic amounts on a map interface. However, the early implementations of web-based RMS did not include all the relevant functionalities of a full-scale Cloud-based Road Management Systems such as road maintenance planning, smartphone support and RMS as a service pricing model.

Figure 1 presents development of Road Management Systems in several phases, where custom-made systems prevailed in the past, while shared data among users, road networks and countries and a service business model through Cloud Technology as an enabler lead the way to the future.

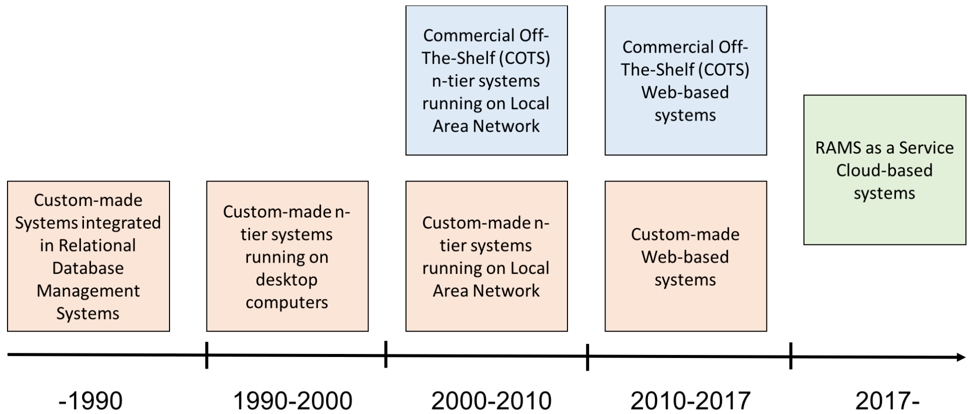

FIGURE 1 RAMS development phases

2 CLOUD TECHNOLOGY

There are three different service models and four deployment models for cloud services. The service models are Software as a Service, Platform as a Service and Infrastructure as a Service (*5*). The deployment models include Private Cloud, Community Cloud, Public Cloud and Hybrid Cloud (*6*).

2.1 Service models

In *Software as a Service (SaaS)* the users can use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through either a thin client interface, such as a web browser or a program interface. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings.

In *Platform as a Service (PaaS)* the user can deploy onto the cloud infrastructure user-created or acquired applications created using programming languages, libraries, services, and tools supported by the provider. The consumer does not manage the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly configuration settings for the application-hosting environment.

In *Infrastructure as a Service (IaaS)* the user can provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications; and possibly limited control of select networking components such as host firewalls.

2.2 Deployment Models

Cloud solutions can be deployed in different ways depending on the financial, technical and social requirements.

In *Private Cloud,* the infrastructure is provisioned for exclusive use by a single organization comprising multiple users. It may be owned, managed, and operated by the organization, a third party, or some combination of them, and it may exist on or off premises.

In *Community Cloud*, the infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns. It may be owned, managed, and operated by one or more of the organizations in the community, a third party, or some combination of them, and it may exist on or off premises.

In *Public Cloud*, the infrastructure is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or government organization, or some combination of them. It exists on the premises of the cloud provider.

In *Hybrid cloud*, the infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities, but are bound together by standardized or proprietary technology that enables data and application portability.

3 DIFFERENCES BETWEEN CLOUD-BASED AND TRADITIONAL RMS

The main difference between a Cloud-based and traditional system is related to data accessibility, data security and hardware and software needs. The advantages and disadvantages are presented below.

3.1 Advantages of the Cloud-based RMS

Overall, data management and data processing costs are significantly lower with successful Cloud implementation as server hardware with specific software need not to be purchased and improved accessibility reduces manual work related to data processing and transfers. The expected advantages are explained briefly.

3.1.1 Always-on and highly available infrastructure

Service levels are close to 100% with the major Cloud Service providers, which eliminates hardware related problems a road organization often phases once hosting is done in-house.

3.1.2 Data accessible from thin clients, such as desktops, tablets and smartphones

Web-based applications running on a Cloud server enable the RAMS to run on any of the main Operating Systems instead of being forced to use Microsoft Windows. The system can also run on thin clients including tablets and smartphones enabling the field access to the database.

3.1.3 Interoperability with other systems

The Cloud-based Road Asset Management System is based on standardized method of reading data from the central road asset database and writing to it using Application Programming Interfaces (API). Interoperability and integration with other systems is thus made easier since the source code and database connectivity would not need to be changed.

3.1.4 Data security

Cloud Service providers offer integrated data backup service, where the road asset database with any additional multimedia files are backed up and copies can be stored in the Cloud storage and if necessary, copied to a local file system. For increased data security, the backup files can be physically stored in different locations – data centres of the Cloud Service provider.

3.1.5 Data accessibility

Access to a web-based RAMS is not restricted to the same office and desktop or laptop computer with RAMS installation, but the system can be accessed from anywhere with an Internet connection. Accessibility to data reading can be granted to user groups beyond the main users minimizing manual interventions in provision of data for the stakeholders. Depending on the policy of the road agency, the data can be easily opened to anyone according to the recent philosophy of Open Data (*7*).

3.1.6 Faster implementation

Cloud-based RMS implementation can be done faster than traditional non-Cloud Commercial Off-the-Shelf systems since development, deployment and testing activities can run in parallel and remotely by the team.

3.2 Disadvantages of Cloud-based RMS

A downside with a Cloud-based RMS is limited customization options, which applies also to Commercial Off-The-Shelf software.

In case the Cloud solution is not deployed to a private Cloud control of the backend infrastructure is limited to the Cloud RAMS vendor. Even if the backend control was left with the Client there is a feeling of risk for losing the control over all the data as the data is not physically stored within the Client premises. Cloud solutions do not work if Internet connection is missing or if the bandwidth is too low for the given data.

When it comes to RAMS implementations the current Terms of Reference for implementation project do not take into consideration various Cloud-specific aspects such as Service Level Agreements, hosting and data security.

4 IMPLEMENTED CLOUD-BASED RMS

4.1 Architecture

The core Road Management System has been developed by SaaS Cloud model. Deployment can be done in any of the models. The public deployment is implemented in Amazon Web Services (AWS). Extended functionalities such as RMS-related document management can be implemented also as PaaS and IaaS Cloud models as shown in Figure 2.

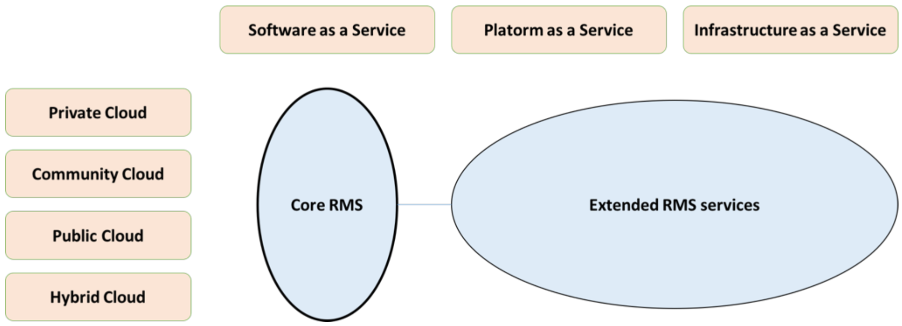

FIGURE 2 Cloud models in RMS

Figure 3 presents an overall architecture of the implemented Cloud-based Road Management System. The system can be divided into the Backend and Frontend. The Backend runs on the Cloud server, where the actual setup depends on the deployment model. However, the current implementation runs on Amazon Web Services. Master road data is stored in the Central Road Asset Database hosted in the Cloud Server consisting of the Relational Database Management System (RDBMS) software and the data model of the road data. Voluminous multimedia data is kept separate from the actual database in a file system with proper time- and location based synchronization with the road network. The file system can be either hosted in a private or public Cloud.

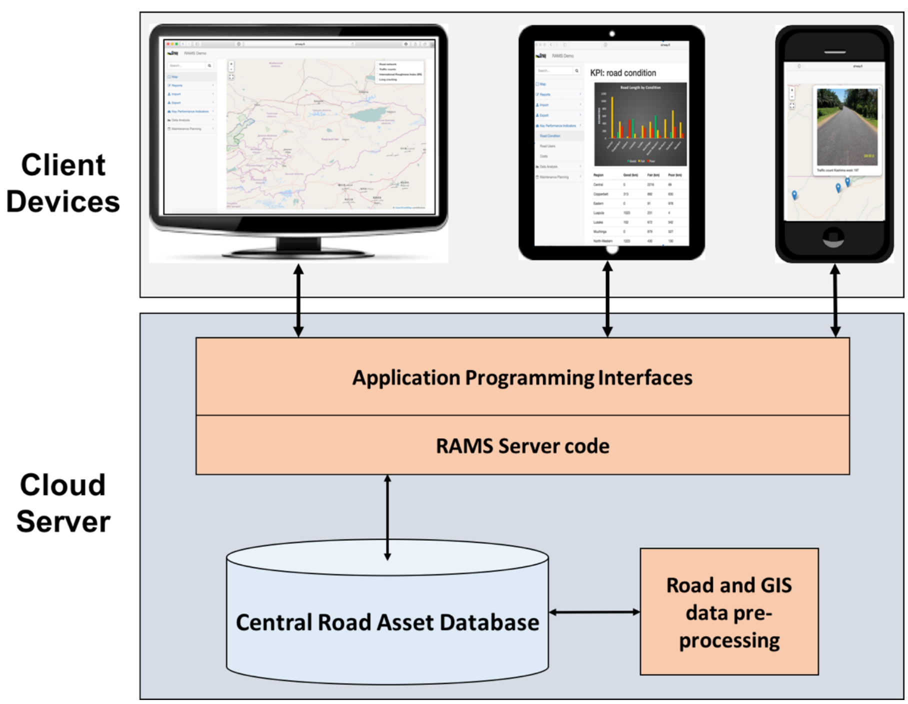

FIGURE 3 Architecture of Cloud RAMS

Most of the computations and data processing is done on the server-side to keep the Client code minimal for best performance. The server-side code is either in data pre-processing module or tied to and initiated by Application Programming Interfaces (API) that are accessed by the Client devices. The Client devices can be computers, tablets or smartphones running on any Operating System. A framework for APIs is presented in Figure 4.

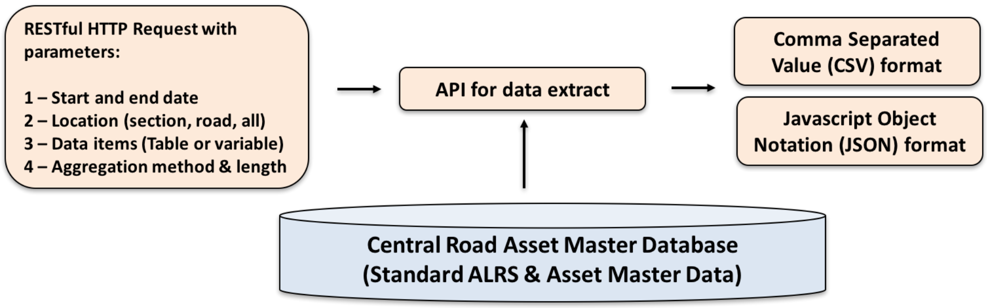

FIGURE 4 Application Programming Interfaces for data extraction from the RMS

APIs require parameters for data extraction from the central database. These parameters include variables that specify time and location. Besides these, it is important to specify the variables to be extracted and possible processing methods before serving the requesting system.

4.2 Data model

All the asset data of the Road Management System is location-based geographic information and therefore the information must be tied to the Location Referencing System. The asset database implements two Location Referencing Systems: 1) Coordinate Location Referencing System and 2) Linear Location Referencing System. Asset data can be tied directly to the both systems. In a simplest form the Linear Location Referencing System has roads separated to section by permanent structures, i.e. Location Referencing Points to smaller segments facilitating data management and finding asset locations in the field. A simplification of the data model is presented in Figure 5.

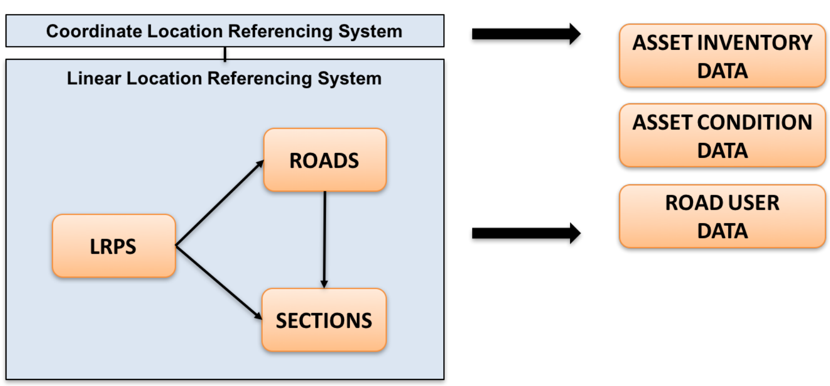

FIGURE 5 Simplification of the data model

Asset inventory and condition data is divided into separate tables in a logical way. A common logic is to divide by data collection so that for example road surface condition collected by profilometer is stored separately from bearing capacity collected by Falling Weight

Deflectometer. An important aspect of a Cloud implementation is a dynamic data model, where collected and stored variables can be changed without changes in the source code of the actual system.

4.3 Graphical User Interface

The Graphical User Interface (GUI) for the Road Management System is rendered on any modern web browser. The main driver in GUI design has been user-friendliness and therefore integrated Geographic Information and use of graphical elements is a focal point. Examples of the GUI are presented in Figure 6.

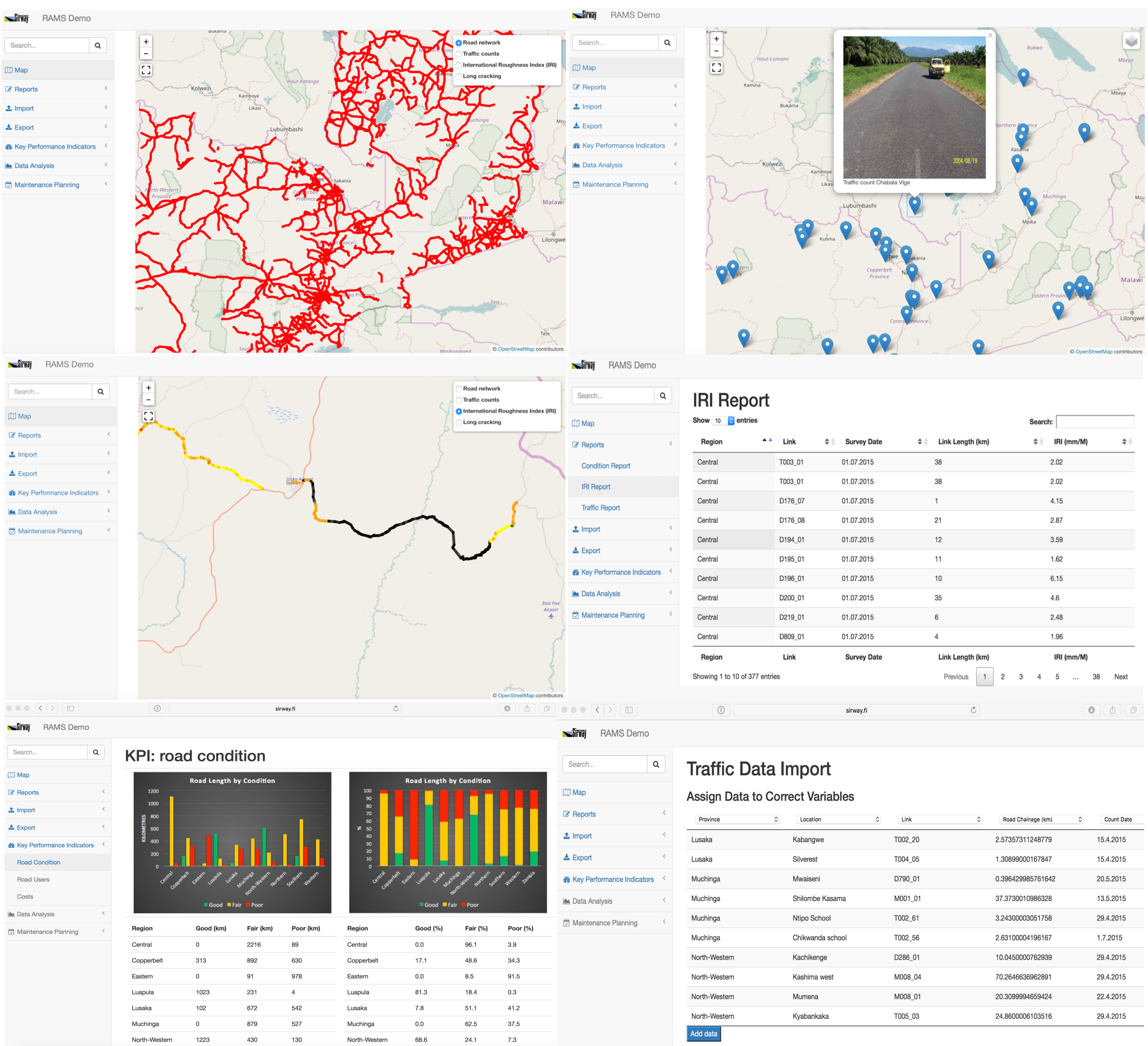

FIGURE 6 Examples of Graphical User Interface of the RMS

4.4 Main functionalities

Table 1 presents the main functionalities of the implemented Cloud RMS.

TABLE 1 Main functionalities

Functionality	Description
The RMS has a web-based GIS interface for visualizing: data stored in the database, outputs of analyses, and illustrating performance trends using pre-defined performance indicators.	The road asset database is separated from the RMS user interface and other applications. An integrated GIS module can connect to the road database for visualization on a web browser. An external GIS software connects to the database using APIs.
It is possible to import and export data from standard formats (e.g. CSV, excel, etc.) to and from the database.	Data can be imported from CSV (Excel) files. Data can be exported in the same formats as well as in JSON format using the database Application Programming Interfaces (APIs).
The database is able to record works / treatment history including the type of works, location in which it was carried out, the costs of the works and the extent of the works.	The central road asset database is predefined using the data model that accepts the maintenance work history and data import functionality allows import of work history. The system enables changing and visualizing the stored data and taking it into consideration in maintenance planning.
Data entered into the database is time-stamped and owner identified.	All the imported and changed data is stored with meta-data that includes date and time stamps as well as recorder.
The database incorporates functionality to automatically evaluate the performance of assets against defined thresholds on level of service and generate output reports.	The performance of assets can be classified by asset condition, importance, risk etc. with any given threshold values. These threshold values are also stored in the database so that they can be changed by an authorized user.
The database stores asset inventory, condition and usage data for all road assets including road pavement data, structures data, geotechnics data, lighting data, and data for all other ancillary assets found on the road network. Data types and attributes align with business needs.	Data structure, data model and attributes are modifiable any time without changing the source code. The database is predefined to the following data with a data model: 1. Culvert inventory and condition data 2. Road and section inventory with characteristics data 3. Road roughness and rutting data 4. Pavement Distress Inventory (PDI) data 5. Falling Weight Deflectometer (FWD) data 6. Pavement strength and geotechnics data 7. Traffic data 8. Road maintenance works data 9. Road user costs data
The database is able to record agreed annual work plan and allow users to package work into contracts and record contract details.	RONET maintenance planning models are used with the difference that the RONET models are made as a web application extracting the data from the road asset database and exporting the results in the same database.
The system allows for the definition of treatments based on intervention	These are implemented in a similar way to RONET, but as a web-based version.

thresholds, unit costs of treatment/works and works effects	
The system has built-in functionalities for asset degradation / deterioration modelling.	The deterioration models are derived from HDM-4, implemented in RONET and further to the web-based version. The models can be calibrated to environmental factors.
The system considers costs other than agency costs (e.g. Vehicle Operating Costs) and calculates Net Present Value and other economic indicators.	The total costs to the society will be used for the optimisation of the maintenance including Road User Costs and Agency Costs. The results can be examined as Net Present Value and Benefit-Cost Ratio.
The system is able to incorporate changing network/asset demand over the analysis period.	Traffic quantity is the principal demand factor. Changing traffic is incorporated by a traffic growth rate.
The model is able to carry out a full lifecycle analysis and prioritize schemes based on current condition and other suitable criteria using Multi-objective approach.	Full lifecycle analysis is created with the help of deterioration, works impact and optimisation models. The optimisation model takes multiple criteria into consideration.
The system allows users to optimize works/interventions to meet different constraints, such as budget, performance requirement, risk tolerance, etc.	Optimisation is based on minimization of the cost function to the whole society and other factors in multi-objective approach. The relevant constraints can be set and the problem is solved using evolutionary algorithms.
Inputs and outputs to the predictive model are saved within the model or database to allow for later retrieval, and comparison.	As the data is separated in the central database from the actual system, all the input data is stored in the database. The output data with potential future use can be saved back in the central database.
Model outputs include forecast of asset health and/or condition	The implemented deterioration models are used with the current condition status of an asset to forecast the future conditions.
Outputs include list of prioritized schemes, including recommended treatment / work volumes, scheme cost and cumulative cost	Modelling outputs include all the relevant information that help to put the maintenance plan in action. These include treatment description, estimated cost, treatment, effect on road users, condition after treatment etc. By grouping the planned works, cumulative costs can be evaluated.
The system reports whole life costs in terms of annualized costs and NPV	The whole life costs can be calculated and analysed by each road and section. It is also possible to analyse the whole network with all the annual costs and NPV for all the investments.
Model outputs are expressed in terms of asset type or homogeneous asset group	Maintenance planning and reports are separated by asset groups such as bridges, railings, traffic signs and pavements.
The system reports Capital and Recurrent costs separately	The cost estimates of the maintenance treatments can be aggregated from various elements such as capital

	costs, labour costs, material costs and equipment costs. The costs can be analysed, visualized and reported separately.
The system allows users to visualize outputs as data, graphs and where applicable spatially on a GIS map	Any of the data stored in the database can be visualized on a web-based GIS showing different variables as separate layers and value ranges by different colours (or widths or symbols)
Data required is automatically transferred from database to decision making tool(s)	Application Programming Interfaces are provided to the database and the data is retrieved automatically to the RMS or any other decision-making tools such as HDM-4.
Data stored in the system is secured	Data security is achieved by restricted data modification rights that is controlled by a username and password. Data backups are made automatically in the Cloud service separated geographically.

5 FUTURE VISION FOR ROAD MANAGEMENT SYSTEMS

It has been proved that empirical, data-driven methods are more accurate and provide better means for cost-savings in road maintenance compared to mechanistic models in maintenance planning (*8*). This means that the ever-increasing amount of data to be collected on the road network can be put in real use by applying the right artificial intelligence methods that give better forecasts for road condition and better optimisation of the road maintenance works in the future. However, as it is the reality in many countries, road data has not been collected in a systematic and comprehensive way for long time and road maintenance planning with predictive maintenance planning is not applied. A major potential for cost savings in road management could be achieved by application of artificial intelligence to the road data collected during several years. Since data-driven empirical methods require data for learning, it would be beneficial to have data available from other countries, but similar conditions as well. This could be achieved by having a global Cloud-based Road Database and open to several countries to train the road maintenance models beyond the current state-of-the-art of HDM-4.

It is also envisaged that the current standard of IRI will no longer be collected in the future as the laser technology enables collection of more detailed information on the road surface and all the currently widely used condition variables can be derived from the micro texture. This information would enable better indicators and variables for planning of road maintenance, but would greatly benefit from larger data sets provided by a Cloud-based RMS.

Autonomous vehicles and drones with crowd-sourcing capability will be the future for road data collection for cost-effectiveness and increased accuracy. This would not be possible with the old school closed systems, but require the Cloud-based solution, where the collected data is transferred to the Cloud almost real-time or in case of mobile network deficiency in a batch once a data connection is available.

Since the importance of road maintenance is increasing, the efficiency of road maintenance should be increased as well, accuracy can be increased by empirical models that require data, which is increasingly collected from the road network, it is quite clear that the old fashioned closed Road Management Systems will be replaced by the new paradigm, where the data is utilised to its fullest and the data is shared openly.

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