CREATING AN INTEGRATED PROVINCIAL ROAD ASSET MANAGEMENT SYSTEM (RAMS) USING OPEN SOURCE TECHNOLOGY

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ABSTRACT

Although the Gauteng provincial road network encompasses only one percent of the entire South African road network, it serves the economic heartland of South Africa and carries around 66 million veh-km on a daily basis. In order to effectively manage and maintain the provincial road network the Gauteng Department of Roads and Transport (GPDRT) made the decision to use Geographic Information System (GIS) technology to create, view, review and maintain a digital representation of their operational road network, its road structures and associated information. Each element of the provincial road network is thus explicitly regarded as a vital record within an operational Road Asset Management System (RAMS).

This paper provides an overview of the province's RAMS ecosystem, describing each of the systems that form part of it and how advancements in open source technology are used to seamlessly integrate these geographic disparate databases and systems to ensure a single view of the latest information. It also examines how the RAMS ecosystem is laying the foundation for and positioning the Department to support Smart City initiatives in the province.

1. INTRODUCTION

Since Road Asset Management (RAM) is a systematic and permanent process aiming at cost effective maintenance, upgrading and operation of physical assets, it is essential to recognize the two key issues to this process is *maintenance* and *modernization* (European Union Road Federation, 2018). RAM combines engineering disciplines with solid business practices and financial theories and, in this manner, it helps the road authorities to achieve sustainable and effective management of a safe and efficient road network.

A Roads Asset Management System (RAMS) is a technical management information and geospatial information system that caters for the viewing, reporting and processing of technical data ranging from condition, trafficability, maintenance history through to utilisation and optimisation of these roads assets. Ultimately, this technical system is designed to support the storage of asset information and facilitate asset managers to make informed decisions on the lifecycle of the assets. RAMS is a relatively new concept in developing countries who are facing obstacles implementing it due to a lack of a systematic approach to road management (Sodikov, 2015). In general, what sets asset management from past approaches is the move to merge conventional single-asset management systems into an integrated system-of-systems.

Road network development in South Africa is constitutionally a concurrent function across the three spheres of government. The Road Infrastructure Strategic Framework for South Africa (RISFSA) and good practice procedures require that road asset management systems are implemented by roads authorities to better manage and consistently report on the management of these key assets. For example, the consequence of delaying road maintenance has been shown to increase vehicle-operating costs exponentially as the condition of the road deteriorates (SABITA, 2012).

2. RATIONALE

According to the European Union Road Federation (2018) the fundamental RAM requirements are:

- Establish a complete inventory of all road network with all its elements.
- Provide a clear picture of the current condition/performance of the road network.
- Estimate the value of the asset.
- Predict future demand of traffic and service needs.
- Estimate maintenance needs and costs.
- Prioritise objectives related to the desired quality and performance of the road network.
- Set up funding scenarios for the regular and timely maintenance and upgrade of the road asset.
- Define a strategy (RAM Plan).
- Implement the RAM Plan.

The overall landscape in which any such system is to be developed includes and must allow for people, funding, software, procedures and processes, data and hardware (Figure 1). Two of the key blocks in this landscape are software and funding. It is from these two blocks that we have re-evaluated the solutions on offer in the RAMS space, taking into account the total software lifecycle costs.

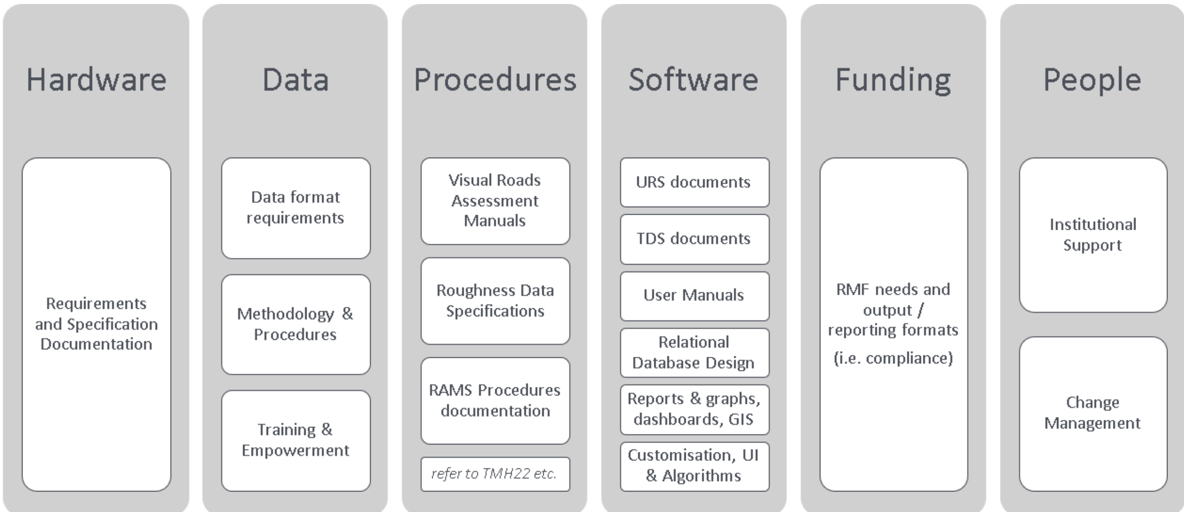

Figure 1: System Landscape

Free Open Source Software (FOSS) has progressed and advanced dramatically in the last five years and with the ease of installation and configuration now available, the options available within this framework can compete (and even out-compete) commercial applications. Knowing this, it is prudent to evaluate the current state of such technical systems and to align, where needed, with trends and advancements, to ensure that the user/ owner and, in fact, all stakeholders may reap the benefits thereof. It should be noted that all of the systems, as mentioned in this paper, have been developed or enhanced to cater for TMH (Technical Methods for Highways, as released under the Committee of Transport Officials - COTO) data requirements and as such is in line with South African data collection needs and specifications (COTO, 2013).

3. RAMS ECOSYSTEM OVERVIEW

The new RAMS ecosystem caters for road infrastructure, traffic information, and all pavement and bridge management processes by means of relational databases, GIS and web-based solutions. Three major applications designed and developed for RAM functionality and integrated into the current ecosystem are the RAMS, the STRUMAN Bridge Management System and RAMS Geospatial Decision Support System. These three systems are briefly described separately in the next three sections.

3.1 Road Asset Management System (RAMS)

During 2017 a new technical Roads Asset Management System (RAMS) was developed, focussing on using open source components. Following an investigation of pros and cons as well as the state-of-art in geospatial and database technology trends, it was concluded that the benefit and advances in the development of FOSS, within this particular technical market, would outweigh the cons and provide a lower total software lifecycle costs over ‘traditional’ fully licensed software products. In essence, the modular RAMS components involve RIAM (Road Infrastructure Asset Management), GIS (Geographic Information System), TIS (Traffic Information System, PMS & GrMS (Pavement Management System – Paved & Unpaved), and BMS (Bridge Management System) as illustrated in Figure 2.

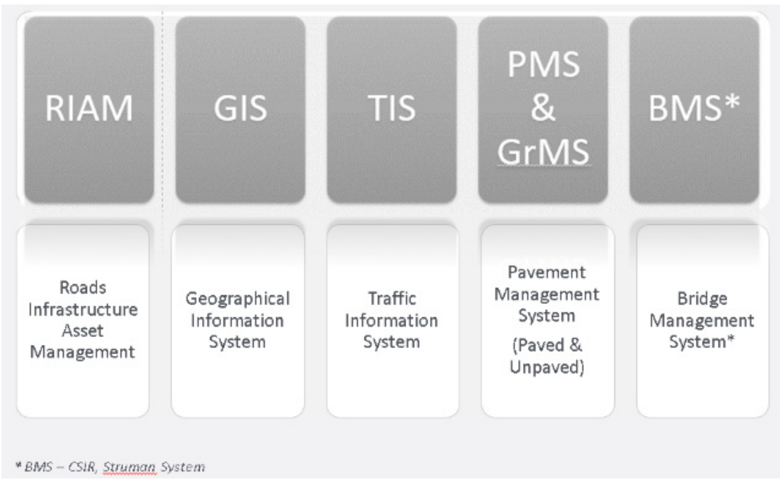

Figure 2: Overall RAMS Ecosystem

Technical information and data reports are accessed through the RAMS. It consists of a web-based application that provides the users the ability of viewing the data through a GIS Map, dashboards, reports, documents, data views and exports maps, and management sections (Figures 3 and 4). The dashboards and reports were created to be compliant with the TMH18 (Road asset data electronic exchange formats) reporting standards. RAMS users, responsible for maintaining and updating the data, can access the system through a spatial interface using QGIS, via database management studio or the web interface shown below.

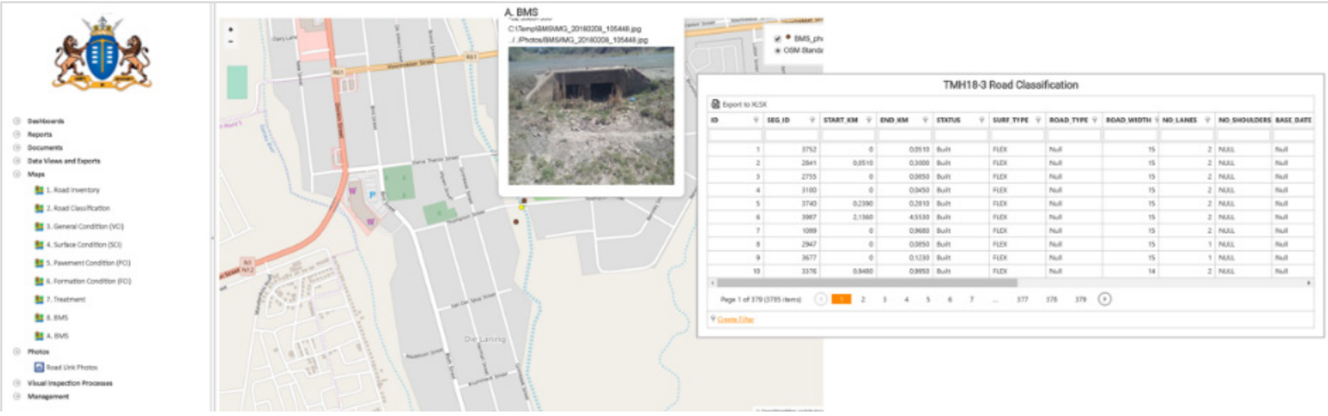

Figure 3: RAMS web-system interface and GIS data views

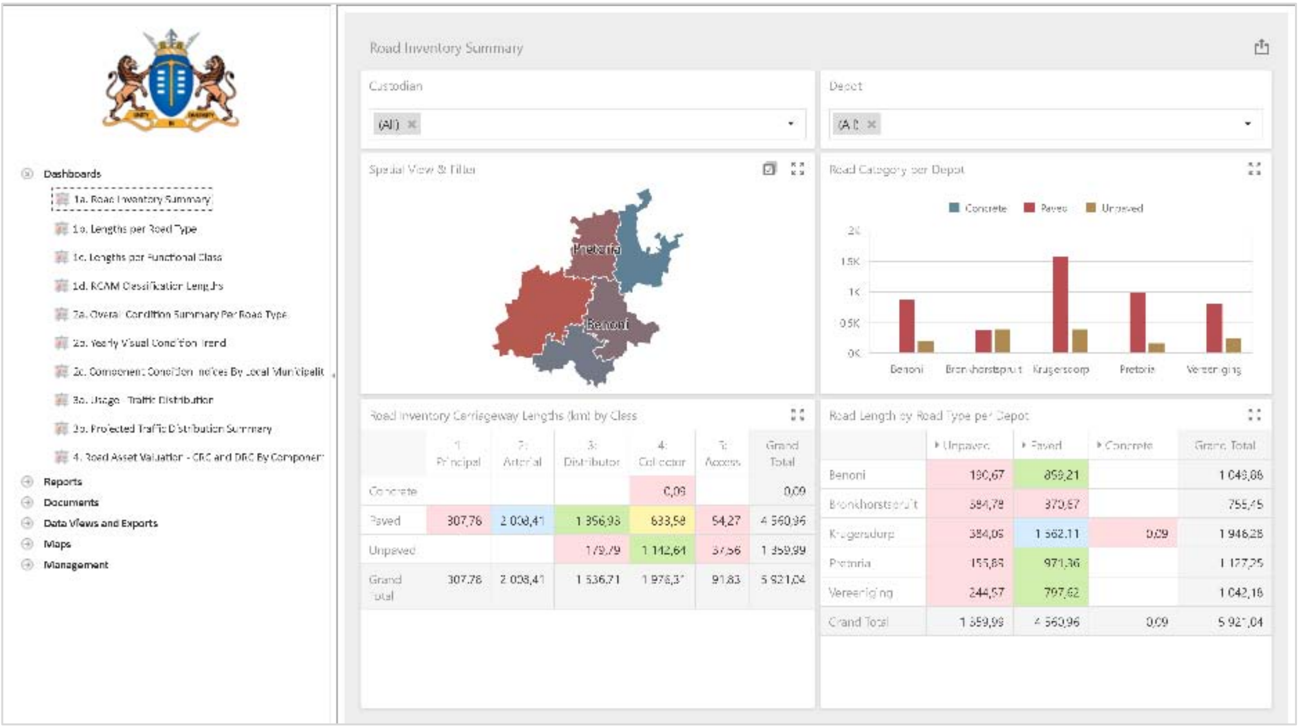

Figure 4: Reporting and management features on the RAMS web-system

One key (and very useful) function available is the spatial topology handling of road inventory, condition indices calculations and traffic projections or calculations. This is all achieved directly within the PostgreSQL database using a series of functions and triggers that were developed and became an integral part of the system and easily bundled with the database.

3.2 STRUMAN Bridge Management System

Bridges are valuable, costly and vulnerable elements of a national inventory of transportation infrastructure. Regardless of the number of bridges in the inventory, it appears that most have developed bridge management systems. These systems include bridge inspection, maintenance, rehabilitation and sometimes design (PIARC, 2011).

The development of STRUMAN started in 1995 and has been updating and improving the system on a regular basis. STRUMAN is a management system for road related structures and makes provision for the management of bridges; major culverts; lesser culverts; retaining walls; road tunnels; light masts and gantries. The system complies with TMH19

Manual for the Visual Assessment of Road Structures. STRUMAN is a defects based road structure management system that utilises the DER&U rating system for structures, where ‘D’ represents the *degree* of severity of the defect, ‘E’ the *extent* of the defect on the item inspected, ‘R’ the *relevancy* of the defect, and ‘U’ the *urgency* to carry out the remedial work to repair the defect (CSIR, 2017).

The STRUMAN system offers the following eight benefits to its users (CSIR, 2017):

1) It ensures the primary purpose that defects are identified timeously and repaired economically;
2) Structures are maintained at acceptable levels of service;
3) Remedial work is prioritised and expenditure is optimised;
4) funds are channelled to more serious defects;
5) expenditure is reduced on less serious defects;
6) control of expenditure by management is improved;
7) Knowledge on the current state of structures is obtained; and
8) Budget forecasting.

The STRUMAN system has four over-arching modules to deal with Inventory, Inspection, Condition, and Budget, as well as focused modules covering the GIS Viewer, Photo Viewer, Reports, and Graphs (Figure 5) (CSIR, 2017).

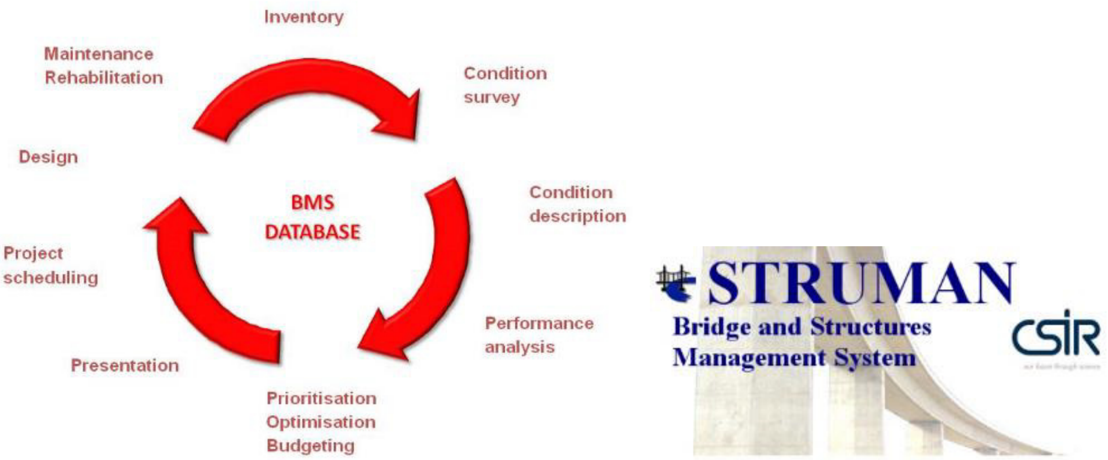

Figure 5: The systematic STRUMAN design for bridge and structure management

The ten structure types and number of inspection items accommodated in the system are listed in Table 1 (CSIR, 2017).

Table 1: STRUMAN structure types and number of inspections items

Structure	# Inspection Items
Bridge - General	21
Bridge - Arch	21
Bridge - Cable	21
Bridge - Cellular	14
Major Culvert	14
Lesser Culvert	5
Retaining Wall	7
Light Mast	8
Gantry	8
Road Tunnel	8

The STRUMAN system is currently widely used throughout South Africa and southern Africa by various road authorities.

3.3 RAMS Geospatial Decision Support System

The RAMS Geospatial Decision Support System (GDSS) was developed out of a need within the department to re-establish some spatial analysis capability. The GDSS also more commonly referred to as the "Viewer" was developed using a phased approach adding more functionality in each phase. Phase 1 started with the provision of basic mapping and querying capabilities to users. Phase 2 focused on the development of advanced search and query functionality, editing, analysis, data sharing and exporting tools.

The GDSS is built on propriety (ESRI) software and uses web-based GIS technology to provide users with the ability to view the latest RAMS data on any device that has an internet connection (Figure 6).

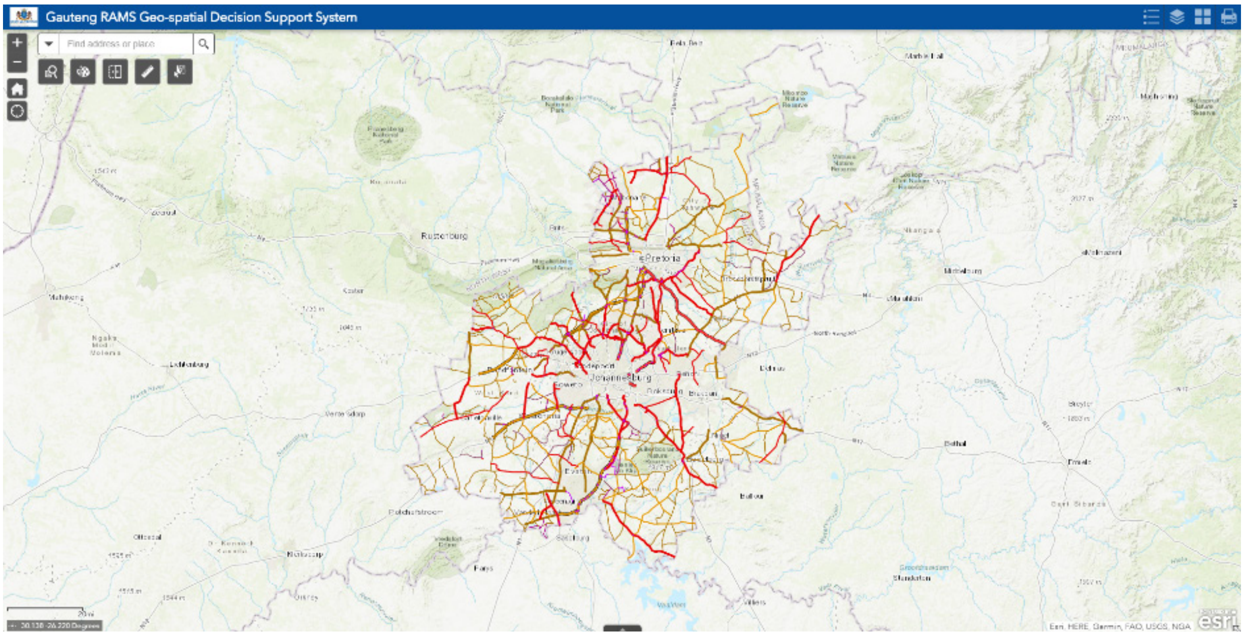

Figure 6: The web-based Gauteng RAMS GDSS interface

During 2019 a mobile phone application of the GDSS was also developed for devices using the Android operating system, allowing users to also access their data using mobile devices such as tablets or phones. The GDSS was designed with ease of use in mind, providing the user with an interface that is simplistic yet powerful. The design adheres to modern day web standards making use of infographics and tool tips to 'communicate' a button's function. Using buttons to access and expand a certain tool or function also allows for optimal use of the screen placing focus on the data rather than the tools contributing to better use of screen real estate.

The spatial-temporal nature of the RAMS data makes the GDSS the most suitable platform to access and view the various datasets required to maintain and manage the Gauteng provincial road network. Table 2 lists all the data currently displayed in the GDSS with a short description of each of the six principle layers. The GIS Viewer also allows a variety of background data (topographic maps, aerial or satellite imagery, etc.) that enhances the user experience significantly with regards to improving their orientation, interpretation, comparisons and more of the overlain RAMS data layers.

Table 2: RAMS GDSS spatial layers

Layer	Description
Road Network Inventory (RNI)	The Gauteng Provincial Road Network Inventory was developed and classified the roads according to the function served, as guided by the TRH26 (Veramootha and Breytenbach, 2017). Three thematic views of the RNI have been created and display it according to Class, Surface or Carriage Way type.
Bridges and Culverts	The bridges and culverts data are captured and maintained in the Struman Bridge Management System and the GDSS displays and consumes data directly from the Struman database.
Traffic Counts	Traffic count data are displayed for Manual, Secondary, Permanent, ORT, HSWIM and Temp-Electronic counting stations and various count (historic and latest) related attributes i.e. ADT or ADTT are accessible via the GDSS.
Road Condition	The Visual Condition Index (VCI) data for paved and Visual Gravel Index (VGI) data for gravel roads are used and is thematically displayed based on its condition ranging from Very Good to Very Poor.
K-routes and future planned or alternative routes	This layer displays the existing K-routes and future planned or alternative routes which is useful when doing planning on the RNI.
Road Reserves	This layer displays the official road reserves for the Gauteng Provincial road network.

The GDSS's software architecture uses Web Map Services (WMS) that were created for each spatial layer (dataset) and adheres to the Open Geospatial Consortium (OGC) standards. The OGC is driven to make geospatial information and services F.A.I.R – Findable, Accessible, Interoperable and Reusable and promotes royalty free, publicly available open geospatial data standards (opengeospatial.org).

4. TOWARDS A FULLY INTEGRATED RAMS

Each of the systems listed earlier provides critical data for the management and maintenance of the Gauteng road network and data sharing between them was a laborious task involving copying data onto an external hard drive after monthly meetings. This situation was not ideal and at times errors did occur and the process had to be repeated to ensure the correct datasets were copied onto the hard drives.

Part of the project plan for 2019 included a task to investigate how to integrate the data stored in each of the systems using best practices in data warehousing and storage. The GDSS and the RAMS already use PostgreSQL as its primary database and once the next upgrade of the STRUMAN system was due it was decided to also standardise on PostgreSQL.

PostgreSQL is a powerful, open source object-relational database system with over 30 years of active development that has earned it a strong reputation for reliability, feature robustness, and performance (postgresql.org). Standardising on PostgreSQL as the primary database for each of the systems created a unique opportunity to leverage a powerful core function built into standard PostgreSQL distributions called "Foreign Data Wrappers" (FDW). Creating a FDW enables a database to query and fetch data from remote data sources and return the results as if they were coming from a local table. Any update made in the remote data source is reflected immediately in the table created by the FDW connection, ensuring only the latest version of the data is used by and from each of the systems.

The RAMS technology stack includes PostgreSQL (with the addition of the PostGIS feature; enabling highly efficient processing and handling of database-stored spatial data), GeoServer and QGIS. This stack was chosen to largely leverage the spatial functionality that PostGIS has to offer and to promote the sharing of information more easily to different users. The overall RAMS system architecture and roles of each of these FOSS core systems are shown in Figure 7.

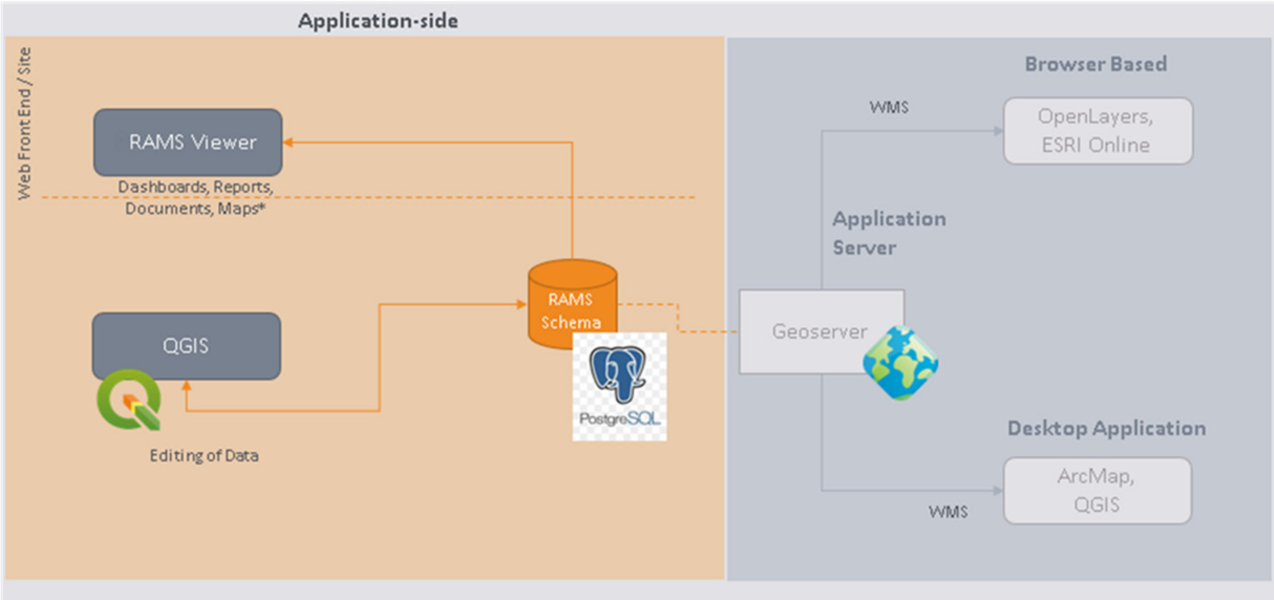

Figure 7: RAMS OSS components and architecture

All technical RAMS related data is stored in the PostgreSQL database that consists of road inventory, condition data, roughness and rutting, FWD and traffic data. The schematic in Figure 8 illustrates the overall network definition and schematic layout of the database, for the above referenced data tables.

As a simple example in a traditional RAMS systems the database inventory and the spatial information is maintained in disparate formats (such as shapefile or geodatabase) with unique identifier linkages between them, which is not the case in the current configuration – spatial information is simply another attribute in the database row or entry.

Even though the STRUMAN (desktop system) was not initially developed using open source technologies, its modularised nature enables a mix-and-match approach to integrating with open source technologies. Choice and cost are key drivers that inform the move to open source and STRUMAN is able to take advantage of these drivers where applicable. Server database costs can be significantly reduced when deploying an open source database as the database back-end for STRUMAN. The STRUMAN application was designed to be independent from the database back-end thus allowing for connectivity to a different database without requiring large amounts of code re-writes.

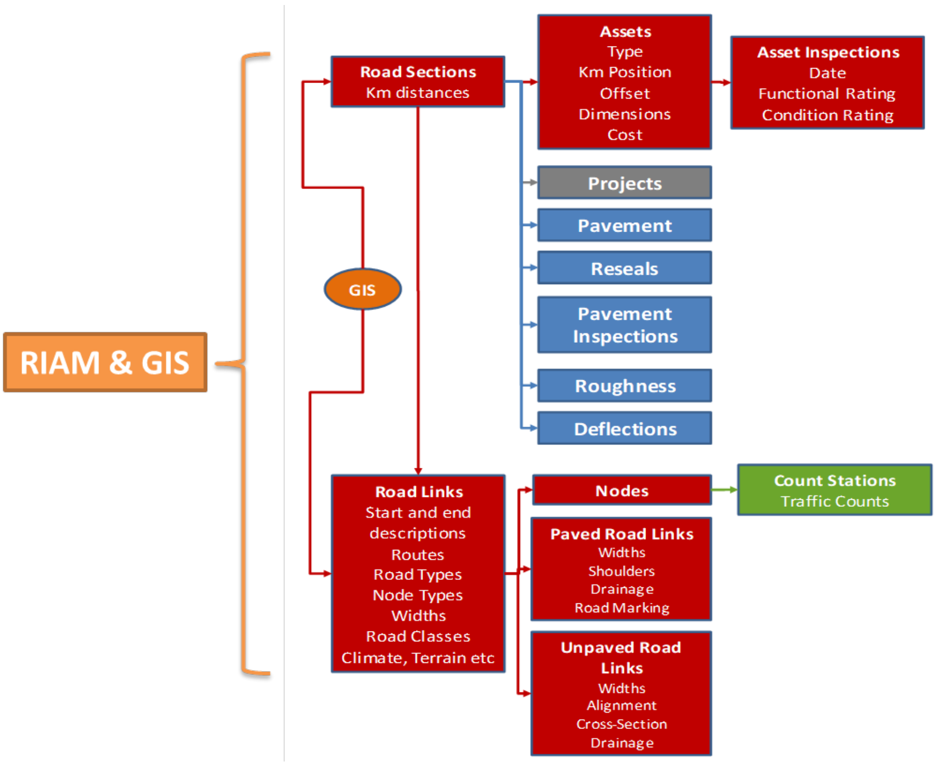

Figure 8: Road Network Definition Hierarchy

As the focus on more integrated solutions for systems becomes more prevalent, specialised applications need to be integration friendly. STRUMAN, as a specialised application, has since been enhanced to be flexible and modular to enable it to become part of a RAMS integrated application suite. The STRUMAN's methodology for visual inspection and calculation of road structures can form part of a RAMS system without the need for the re-development of a structures/bridge management sub-system.

The STRUMAN integrated functionality covers the following aspects:

- STRUMAN can store data in a PostgreSQL server database.
- A RAMS system that has an integrated web reporting interface can integrate with the STRUMAN database through a defined set of views to allow for a seamless interface across the various sub modules.
- PMS network data can be accessed in read-only format to prevent the need to duplicate this type of road data.
- RAMS tables can be populated with calculated results from STRUMAN.

Because the RAMS GDSS/ Viewer and the RAMS system makes use of the PostgreSQL/ PostGIS database, the STRUMAN was able to become integrated in a seamless manner by utilising the advanced PostgreSQL database functions. The stability, maturity, friendly licence and ongoing development of the PostgreSQL server database made it an ideal candidate for selection as an open source database. The PostGIS extension enabled it to also be a good candidate for storing the spatial data. The STRUMAN photo data typically requires at least 10GB and can be stored in a PostgreSQL database or on a Linux file server system. The planned web interface development will also be based on open source technology.

The RAMS ecosystem comprises three disparate systems hosted behind secure firewalls at the respective organisations. A secure cloud hosted server is used to store a replication of the RAMS PostgreSQL database and FDW's are accessing all the relevant data from it ensuring the integrity of each of the organisations data centres (Figure 9).

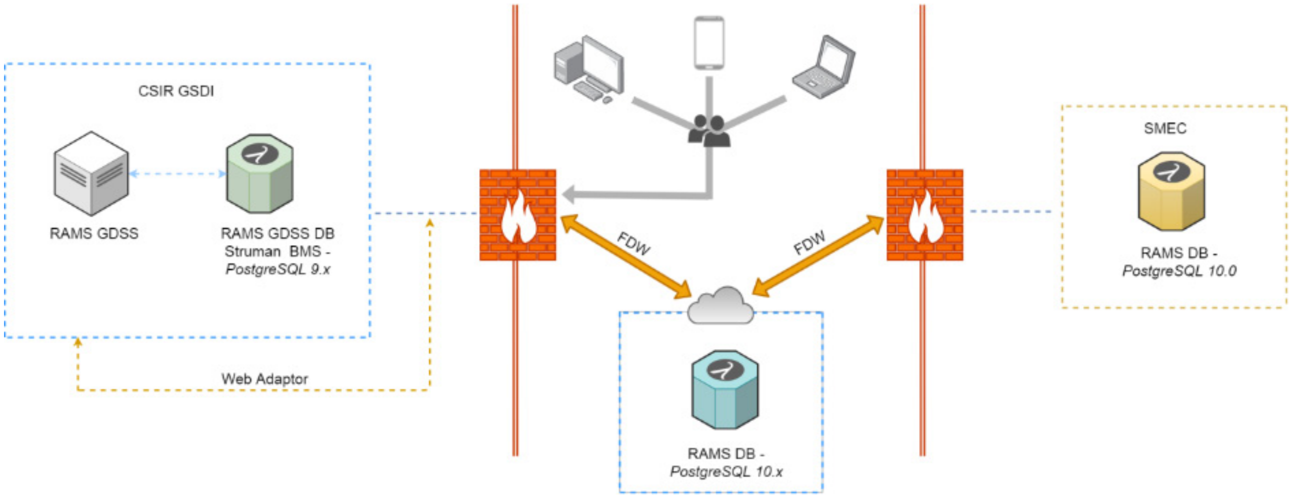

Figure 9: Overview of system integration architecture

Figure 9 illustrates the importance of open standards which are highlighted throughout the paper. The adherence to it by software developers for either open source or propriety applications is what makes it possible to seamlessly integrate and share data and are clearly illustrated in Figures 10 a, b & c.

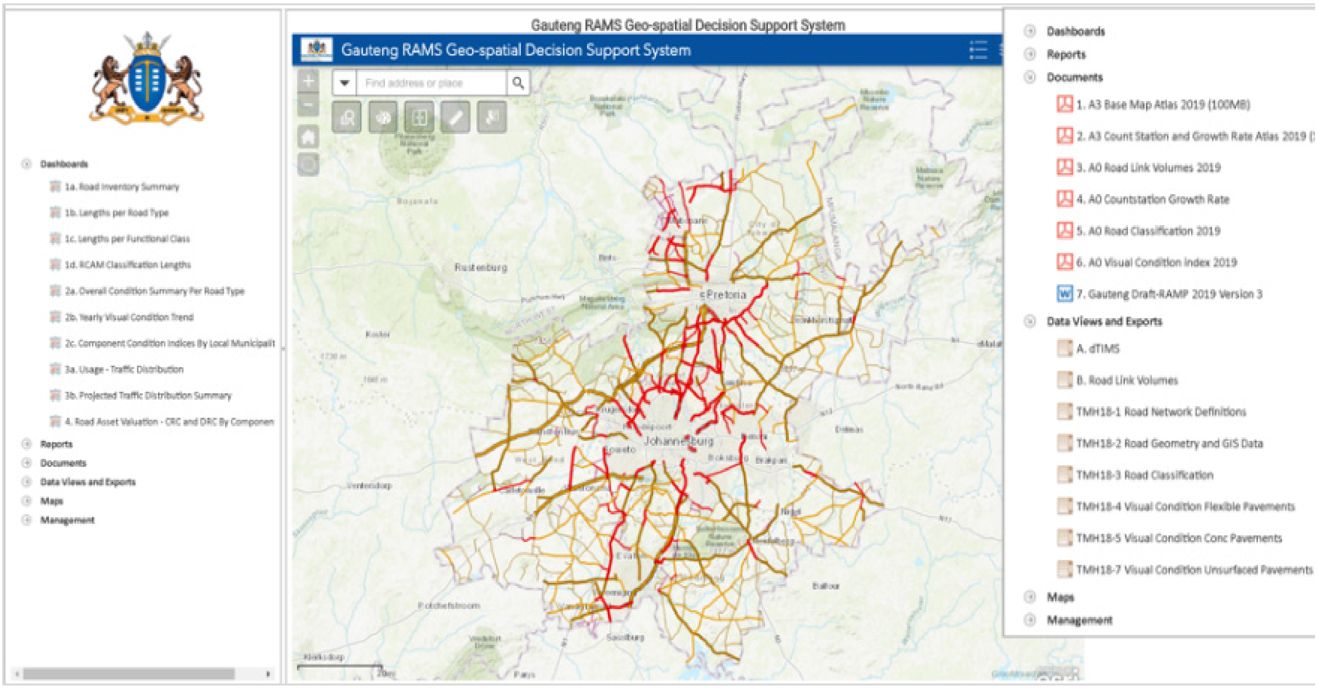

Figure 10(a): The web-based integrated RAMS interface and GDDS Viewer

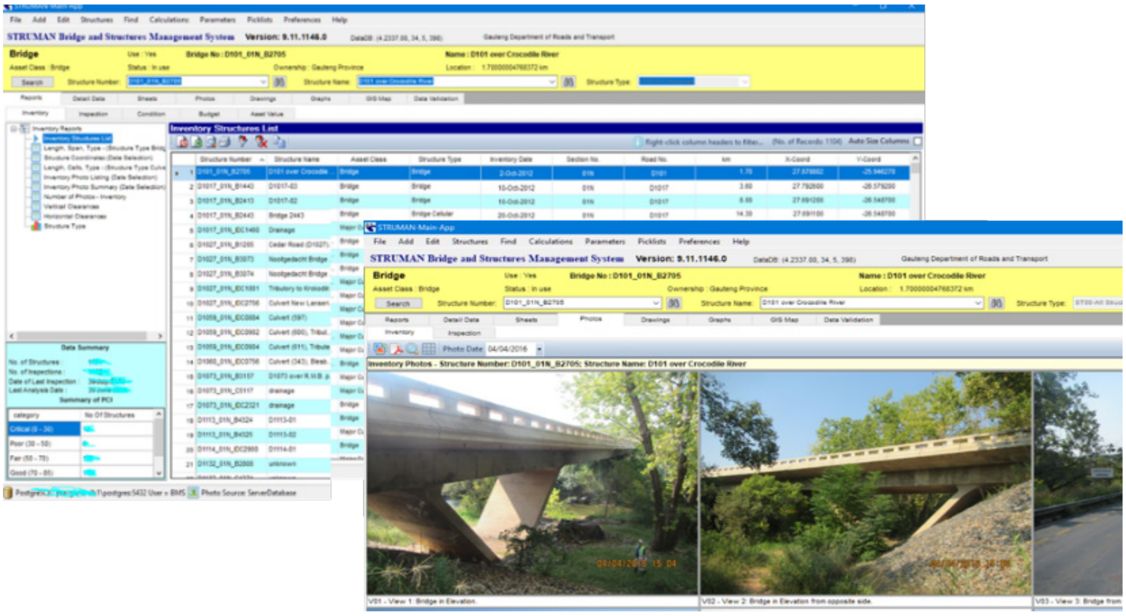

Figure 10(b): STRUMANS Bridge and Structure Management System interface

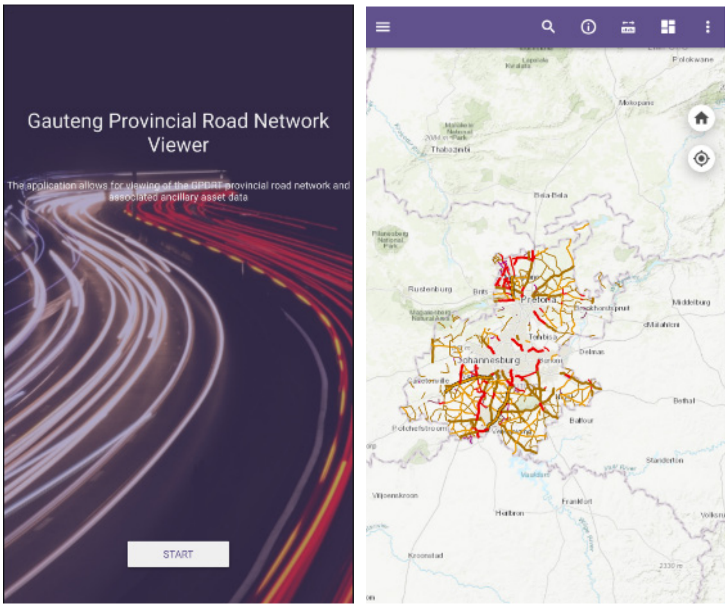

Figure 10(c): Android version of the RAMS GDSS

5. OPERATIONAL IMPACT

Since its inception in 2015 the RAMS GDSS user base has grown from 16 to more than 120 in 2019 (P van Heerden, 2020, personal communication, 10 January 2020). The GDSS enables the GPDRT to connect and view their data from anywhere provided there is internet connection, resulting in more productive meetings since the latest data is always available. It also strengthens the notion of ownership of their dataset(s) even though it is maintained outside. The open accessibility of the GDSS also reduced the number of queries received by the department since consultants now have access to the relevant data, impacting positively on turnaround times.

The Financial Asset Register (FAR) is linked to the data stored in the GDSS and has assisted the Department with Auditor General (AG) audits. For example, in 2015 the AG indicated they are planning to do physical inspections of 800 randomly selected assets from the register. Using the GDSS as part of the audit preparations the Department indicated to the AG that an inspection of 800 assets is unrealistic. The AG commented that by being able to view the FAR in the GDSS indicated to them that the Department have an up to date register and reduced the number of inspections to 200 assets (Z Dlamini, 2015, personal communication, 8 December 2015). Having access to up to date information also assists GPDRT with the preparation of their Road Asset Maintenance Plan (RAMP) which is a requirement of the Provincial Road Maintenance Grant (PRMG).

Annexure K – Intelligent Transport Systems (ITS) (2013) of the 25-year Integrated Transport Master Plan (ITMP25) of Gauteng describes the benefits and the need for utilising technology to improve the efficiency and safety of transportation systems and also reducing harmful effects on the environment. Improved traffic management, reliable travel information, improved incident management and response are all features of ITS. It is anticipated that in Smart Cities the integration of devices and disparate systems will allow for better management and maintenance opening the door for the GDSS to also share and consume this information, enhancing the management of the provincial road network.

6. CONCLUSION

The establishment of the updated RAMS GDSS and integrated systems, developed from propriety and FOSS stack, provides for a fully integrated and upgradable software solution. The systems benefit from the open source stack in that this can be opened up to any stakeholder and has been seen to increase the uptake of the system and promote greater awareness and knowledge of the state of the Gauteng Provinces' assets.

The authors construe that the total software lifecycle costs, reducing the need for expensive annual license fees and vast availability of documentation online, as well as the ability to in-source or outsource software developers who are actively developing skills in these open source solutions, far outweigh the traditional approach to the development of closed bespoke and fully commercialised systems.

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