Implementation of a GIS-based pilot application for roads management applied to the conservation and maintenance of unpaved low traffic roads

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Abstract. The lack of updating and unreliability of information has become one of the main problems that occur in the area of management of unpaved roads in developing countries as Colombia. Therefore, a GIS-based application was developed which allows keeping updated all the information at the structural and functional level of the road, and to control the premature pavement deterioration favouring the support for making decisions in management activities of the unpaved road network. In the municipality of Urrao (Antioquia), a research proposal on “La Encarnación” road was proposed. The Road Trial Section (RTS) is part of a bidirectional 3rd level road, which has 240 m-length and a 4 m-width. The RTS was divided into eight segments or cells (30 m-length), where each of them was stabilized with different conventional and unconventional materials (cement, hydrated lime, coal ash, brick dust, sulfonated oil, polymer and sugarcane sludge). Based on the results gathered in six pavement performance follow-up and evaluation campaigns, a geospatial database (GDB) was designed. This GDB is the core of the application “SGVVT Urrao v1.0” which is able to represent graphically the behaviour of the tests of functionality and the bearing capacity carried out (International Roughness Index, slip resistance, surface macro texture, lightweight deflectometer and visual inspection). The application is able to forecast the deterioration values allowing the prioritization of rehabilitation activities for the most affected sections in a given time period which is possible to extend the useful life of the roads, reduce the operation cost of the vehicles, and guarantee the road safety and the comfort of the unpaved road network users.

1. Introduction

At an international level, Colombia has a road infrastructure delay according to studies developed by the Economic and Social Research Centre of the Foundation for Higher Education and Development (Fedesarrollo) in 2013. It has been estimated that near the 67% of the existing road network in the country corresponds to the part of the road network that connects municipality cores and its rural zones (3rd level roads). This level generally has a superficial layer in granular material. Additionally, part of the 2nd level road network should be added to the aforementioned percentage due to its similar conditions. Both 2nd and 3rd level roads sum up 90% of the national network classified as unpaved roads.
It is evident the premature deterioration of unpaved national infrastructure. The reasons are the lack of resources in road conservation projects or an investment without the use of tools that permit establishing the technic prioritization of it, generating a detriment of the national patrimony. Hence, it can be affirmed that an increase on infrastructure investments can contribute to the reduction of the existing poverty gaps between regions and urban centres, as well as reducing the delay in the country’s competitiveness. This can be achieved using Road Management Systems (RMS) based on Geographic Information Systems (GIS) allowing prioritize technically the decision making in order to start the maintenance actions and/or the road rehabilitation based on deterioration models generated during the management process with the help of data collected in the field.

This paper proposes a pilot application for the integration of RMS and GIS. The collected data of a process performed on a Road Trial Section (RTS) built in the municipality of Urrao (Antioquia-Colombia) were conveniently organized with the aim to evaluate the performance and the deterioration of different stabilizers distributed in cells of 30m-length.

2. Road Management Systems (RMS)
RMS constitute a technological tool very useful capable of managing databases with road requirements, the inventory and diagnose of network, and its associated infrastructure. It has as primary objective to provide an overall assessment of the network’s condition [1] taking into account the systematization, coordinated planning and investments programming, design, construction and maintenance of the infrastructure. RMS allows reaching an acceptable service level of the infrastructure during its useful design life under the expected conditions.

Due to development of the fourth generation roads projects (4G) in Colombia, the road conservation activities become an important aspect that should be included in planning activities by the entities in charge of the road corridors maintenance. A proper management of the road network guarantees the adequate use of existing roads, especially unpaved roads, which are the main feeders of new highways, allowing the distribution of agricultural products throughout the country.

In spite of knowing the importance of 2nd and 3rd level roads at a national scale, most of these routes present a high grade of deterioration due to the different factors, such as intense rainy seasons that cause soil weakening, erosion, slopes instability, drag material, among others. Additionally, the constant use of the road, bumps or severe deterioration tends to affect the road surface. The aforementioned factors combined with the lack of maintenance or improvement activities, cause the deterioration and the inefficiency of the roads. As a consequence, the vehicle transit is interrupted affecting the normal development of the inhabitants, causing not only losses in familiar economies but a regional and national level.

The road patrimony conservation is paramount for the national economy, being land transportation the main method for communication between the regions. However, despite the last year’s investments in road construction have been made, currently is evident the premature deterioration of them because of the lack in the articulation of short, medium and large term plans for the national road network conservation. In general, all the road management activities in the country have been aimed at corrective rather than preventive maintenance.

3. Geographic Information Systems (GIS)
Currently, Geographic Information Systems (GIS) have become a solution to the difficulties that commonly appear in planning and management process of different transportation systems and their corresponding infrastructure.
The entities or institutions in charge of the activities associated to road networks, as their planning, construction, maintenance, rehabilitation and management, are exposed to the manipulation from a considerable information volume that needs to be processed and updated constantly. Therefore, the GIS have an important role as a facilitator on road network management processes. In the most general terms, the larger the road network, the more advantageous it will be to work with the mapping capacity provided by a GIS system [1].

Three main characteristics support the GIS applicability in road context. First, a GIS has a database management system which uses the geo-reference as the main method for data ordering according to a common criteria between them, making easier their analysis and consultation. Then, a GIS is capable of integrating spatial analyse functions that incorporate conceptual and statistic models, allowing the user to perform calculations or processes for sets of data. Finally, it is precise to consider GIS not only as a simple software, but as a part of a support system, since they must provide information in case it could be used in a decision making process as the road infrastructure management.

Taking into account the problems in road management, GIS are being articulated with the RMS collecting a diverse road information, among which it is necessary to mention the assessments of the condition of road surfaces, vehicle counting, road inventory and inspection of the infrastructure elements, as road signing, bridges, drainage works, and accident rates, among others.

4. Relationship between spatial analysis tools and road management
GIS are considered as a spatial analyse tool and a facilitator for the integration of information associated with roads regards their physical and mechanical properties, and their conservation grade. Using this type of tools, it is possible the manipulation, organization and operation of the information, through the use of spatial relationships between objects, represented graphically as geometric elements line type (routes) and their properties and associated events.

The assessment of road surface deterioration, pavement structure management, maintenance and/or rehabilitation programming, environmental level assessments, among others, constitute actions that can be carried out with this type of support systems. The relationship between the objects is involved and its spatial localization and associated events are represented. Therefore, the use of spatial technologies, constitute a very useful tool in analysing processes and road management, enabling timely decision making processes and maintenance and rehabilitation road plans support.

It is important to highlight that a road management system is a system with two main components, a spatial database with historical and current information of the conditions and characteristics of the road infrastructure elements, and a set of functional tools allowing the future assessment of road condition. The system is based in deterioration models established according to collected information of field follow-ups or by imported data of roads with similar conditions, allowing not only the identification and prioritization of maintenance and rehabilitation actions, but also the monetary value of the investment for carrying out those activities. For this reason, using a GIS platform is a key factor in making decisions support in everything related to road infrastructure.

At an international level, state entities have seen the need to implement spatial platforms in order to facilitate the manipulation and actualization of road inventory. Hence, they have also required the use of road management systems to make possible the updating of databases, with the possibility of displaying graphically the information (maps), using statistics and trend graphics through a friendly user graphic interface.
5. RMS-GIS integration and its evolution for decision-making

Among the activities developed in an RMS, investment plans destined for design, construction and maintenance (periodic and routine) are considered. This plan is intended to guarantee the adequate performance of a road network and facilitating the making decision process related to preventive and/or corrective actions.

In addition of the spatial platforms` qualities, it is worth to highlight the fact they not only facilitate the displaying of information in a graphical way, but also simplifies the process for the analysis and structuration of the information, giving the possibility of generating reports according to each user requirements.

The information structuring through the use of a GIS can be carried out with a high detail level including structural (or mechanical) characteristics, the physical condition of the road, the surface type, deterioration rate, among others. This information can be used for deterioration models development that allow the prediction of the road behaviour during a certain period, and take preventive measures to ensure the optimal performance of it. It is important to highlight that, the process success is based on periodic and updated information, which thanks to the technology that implies the use of GIS, can be made through surveys made directly on field by using mobile devices (tablets, palms, among others), or by the use of remote sensing equipment coupled to unmanned aerial vehicles (i.e. Drones). This GIS inclusion incorporates significant improvements to a road maintenance process in multiple aspects linked to an RMS. The RMS-GIS integration (Figure 1) offers the advantages listed below:

- Road network in a digital format with a high detail level.
- Graphic user interface friendly with system users.
- Maps graphic displaying and road state reports
- Making decision support about road maintenance programs, thanks to the possibility of prioritization according to the results of a performance and deterioration model coupled to the system.
- Programs optimization and road maintenance investments plans in a short and long term according to the budget in function of the different road deterioration levels.

![Figure 1. PMS/RMS-GIS integration](image-url)
In general, a road management system under a GIS environment contemplates two main components that allow adequate management and performance of the road. Initially, it is necessary to design and build the database according to the user requirements, including basic information about road inventory, as constitutive physical attributes of the infrastructure, its deterioration condition based on previous diagnostics, interventions and available resources to keep the adequate service level. Once the database is built, it is precise to link this information with the GIS platform interface in submodules, conformed by models and algorithms to calculate different parameters of the road, allowing the determination of surface deterioration and the prediction of its behaviour through the time.

Once the road management system works integrally with the GIS platform, it will serve as the Decision Support System (DSS) facilitating the analysis and managements of the geographic information associated with a road network. This integration allows the recognition of patterns, data logical comparison and the graphic curves modelling associated with deterioration (equation-based) of the road infrastructure. Subsequently, the intervention and prioritization stage is started, according to the deterioration state shown by the studied infrastructure. The use of GIS as a DSS tool for prioritisation has wider implications and scope, particularly since the factors adopted in the design of the integration model must be based on a general consensus amongst road managers and practitioners in local road authorities [2].

This stage allows the assignation and programming of the preventive and/or corrective maintenance, in the function of the available budget for these activities. This will offer the next advantages during the process:

- Optimization of the best reachable condition on the road network under a certain budget.
- Determination of the investment required to achieve certain serviceability level on the roads.
- Objective-based periodic and routine maintenance activities programming.
- Reduction of periodic surveys costs, about the pavement condition information, thanks to the use of deterioration prediction models.
- Applicability to roads with any type of road surface.
- Facilitate the graphic display of the thematic information about the road inventory, as the same as the generation of the statistical reports of the constitutive road network elements.

6. GIS-based pilot application case

According to the unacceptable physical conditions of the rural roads in the department, University of Antioquia, University of Medellín, Administrative Department of Science, Technology and Innovation (COLCIENCIAS), among others, developed research and innovation activities in road infrastructure, considering durability, sustainability and a high commitment in the responsible use of the environmental resources [3].

With the aforementioned considerations, the “INNOVIAL” project (network of researching and technological innovation in new materials and constructive processes for road infrastructure) was developed. This project was structured to research, test and develop new materials and construction techniques for more efficient and economic 3rd level roads infrastructure. One of the research study areas was adopted in the municipality of Urrao, localized in the southwest zone of Antioquia (Figure 2). This municipality has an approximate extension of 2556 km², where its municipal centre is
located at 1830 m above the sea level; its territory presents elevation variations between 100 m and 4080 m.

The municipality of Urrao has a 60% of the rural population distributed in 117 rural zones which based their economy in agricultural production. At the agricultural level, around 6500 hectares are destined for bean cultivation, tree tomato, coffee and cane.

In the municipality of Urrao was selected a Road Trial Section (RTS) in “La Encarnación” Road, located at the northwest zone of the urban centre, parallel to the local airport runway. According to the vehicle counting and classification study performed, this zone has an annual average daily traffic of 94 vehicles in the road corridor [3].

The RTS is part of a bidirectional 3rd level road, which has 240 m-length and a 4 m-width. The RTS was divided into eight segments or cells (30 m-length), where each of them were stabilized with different conventional and unconventional materials (cement, hydrated lime, coal ash, brick dust, sulfonated oil, polymer and sugarcane sludge). One reference cell without stabilizer was adopted, for comparison purpose between the other cells and the natural characteristics of the road.

In this process, performance and follow-up tests were carried out which the road functionality and its bearing capacity were related. The first ones were based on the International Roughness Index (IRI) measurement, slip resistance measurement, surface macro texture, and a visual auscultation. These tests were made to measure road superficial level deterioration, in order to estimate its evolution
through time and predicting the surface resistance to erosive processes caused by weather and vehicles, according to stabilizer type. The second ones were based in the assessment of the mechanical condition of each segment cell, where the resilient module was determined and the deflection produced by the application of a dynamic load through an impact lightweight deflectometer (LWD) [3].

Aware of the national need for reliable and updated resources for the prioritization and suitable decision making of road interventions, it was proposed a pilot trial for an application (under ArcGIS® environment) named as “SGVVT Urrao 1.0” in the municipality of Urrao, based on the tests performed to each test segment cell.

Initially, the ArcGIS® GUI is presented using the ‘Map Document (MXD)’ type that was created from the collected data on the field. This document could be modified according to the information that requires be represented graphically. It is precise to mention that the application has been developed in Spanish language and it has three main components, which can be executed clicking in the “Generar” (“Generate”) button, located in the tool bar at the superior left corner, as shown in Figure 3.

![Figure 3. Application execution](image)

As a starting point, the application has the module “Ensayos de Seguimiento” (“Performance Follow-up Tests”) module where all the collected information on the field is organized conveniently, including IRI tests, LWD, slip resistance, surface macro texture and visual inspection, for each assessed cells in a six (6) total campaigns follow-up (Figure 4). This module was designed for the user can display the information of any cell in the different tests performed, and if necessary, edit it conveniently and asses possible changes in the behaviour of the obtained results. The information is stored on an alphanumeric Excel® database of easy comprehension which can be read from any device.
The second module of the application is “Modelos de Deterioro” (“Deterioration Models”) which consists in the calculation and graphic representation of the created deterioration models from the shown information in the initial module. These models are based on trend lines associated with a unique equation for each possible combination that evidences the behaviour of the assessed parameters in each cell through time. The use of trend line equation allows the user to project values of the different tests performed and to propose preventive solutions to unacceptable values which are established thanks to acceptance and rejection ranges found in literature according to the analysed parameter (Figure 5).
Based on the two previous modules, the last module is “Prioridad de Intervención” (“Prioritization of road intervention”) for activities prioritization depending on the deterioration severity, guaranteeing a timely decision making with stronger arguments. This module operation is based on an Excel® macro, designed for the user to be able of updating the last test performed value, organizing immediately the values in descendent order, putting in the first place the cell that requires a priority intervention (Figure 6).

Figure 6. Module “Prioritization of road intervention”

Within the control and road tracing, keeping updated the information that describes the infrastructure elements conditions is very important. Some of those elements are vertical signing, horizontal signing, hydraulic works, electricity works, among others. “SGVVT Urrao 1.0” uses ArcGIS® tools to represent graphically and georeferenced those elements, creating a record about their existence and the pertinent maintenance attention of each one of them. This is possible thanks to “Información” (“Information”) button from the tool bar that let the user know the element characteristics, its location on the road and a linked image to the referenced element (Figure 7).

Figure 7. Road inventory
7. Conclusions

Tools and spatial technologies such as Geographic Information Systems (GIS) are appropriate for the integration of associated information to the road characteristics (physical and/or mechanical) in a georeferenced way. In general terms, an integrated management system for roads must be implemented under a GIS platform, as the key factor to the decision making systems support in everything related to the road infrastructure, such as its construction, maintenance and rehabilitation. The making decisions through this type of management systems based on computer platforms attempt to extend the road useful life, reduce vehicles operation costs, help to guarantee road safety and the comfort for the road network users.

GIS provide an effective tool for integration, management, storage, displaying, searching and spatial analysis of the information associated with a road network and its associated vehicles. This information can be associated with a PMS or RMS to conform an integrated management road system enriching a PMS with the aim to migrate it to a DSS. This integration incorporates an additional benefit that lies in the possibility of correlating georeferenced information and generating information that would not be analysed in a simple database.

Worldwide, there has been a great advance in the development of systems for road management by using technological geospatial tools, but in Colombia, the advance on this matter is very limited, excepting some efforts from state entities in the country’s big cities. These RMS initiatives under computer platforms have been proposed, but they have not necessarily become operatives and have been conceived for only paved roads, since 2nd and 3rd level roads have been left out.

The proposed application was focused on the road management problems solutions in rural zones under the commercial software. However, it raises the possibility that this application would be implemented under free software, to make it easily acquired and developed by low-resources municipalities. Further, the application can expand its functionality towards the evaluation of geological risks present in the road, taking as reference critical points with failure probability, sliding or any type of damages that represent a community risk.

References

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