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PAVEMENT MANAGEMENT SYSTEM FOR LOCAL GOVERNMENTS: CASE STUDY IN THE REPUBLIC OF SAN MARINO

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Abstract

Local governments manage large and heterogeneous road networks with limited budgets, human resources and often they cannot easily access or apply technology and methodologic innovations. For these reasons local governments need a tailored pavement management system (PMS) to plan activities, investments and to achieve efficient solution in a multi-year prospective. The PMS must identify a rational and cost-effective maintenance planning through a systematic process that considers technical, economical, social and environmental impacts. Tools and procedures have to be specifically determined taking into consideration the real potentialities of the local governments. The adopted PMS in the Republic of San Marino has been based on a tight coordination among national institutions and stakeholders operating in the territory. This paper shows the principles, procedures and tools developed and used in the Republic of San Marino.

Keywords: pavement management system (PMS), local road administration, geographic information system (GIS)

1 Introduction

The road maintenance is an activity of primary importance to preserve functional, safety and rideability characteristics of road pavements. Therefore, a systematic process of maintenance planning is essential for a cost-effective managing of road pavement network [1]. In the last decades, a large numbers of road administrations have applied the Pavement Management System (PMS) implementing Geographical Information System (GIS) tools, to streamlining the data collection, decisional processes and to identifying the optimal solution according to the annual budget limits [2]. Even if PMS concepts do not change moving among different contexts, local administrations need of customized tools that substantially differs from those adopted by highway or airfield administrations [3, 4]. Local road authority, generally, manage a wide variety of road data with limited budgets, human resources and technology tools. For these reasons the technical process and management methods must be created according to the specific potentialities, resources and needs of the public authority [5-7]. The management procedure in use in the Republic of San Marino relies on GIS tools to support survey activities, ranking maintenance priorities and selection of cost-effective strategies. Customized design documents and GIS-based routines were created to enhance and to standardize the data collection, analysis and planning of maintenance works, considering short and long-term perspectives [8]. Furthermore, the use of eco-sustainable techniques and materials, as alternative to the traditional materials and methods, were encouraged to reduce the environmental impact of the maintenance works [9, 10].

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2 Objectives

In order to obtain an effective and efficient planning of maintenance works in San Marino, the following objectives was defined:

- Identification of a rational, objective and sustainable planning method (customized PMS);
- Selection of data and implementation of GIS-based data management tools for the creation and management of road database. The main data are related to road network classification (network hierarchy, intersection hierarchy, road type, road function), segmentation of road network (homogeneous sections, unit samples), road inventory (geometrical data, pavement layers and materials, maintenance and rehabilitation history etc.) and survey data (pavement condition, roughness, accidents, traffic volume etc.);
- Standardization of the technical methods and documents;
- Implementation of GIS analysis and decision-making tools for ranking maintenance works priorities and identifying the cost-effectiveness maintenance strategies from a set of multi-annual investment scenarios;
- Standardization of technical method and quality control for road maintenance;
- Encouraging of the use of eco-sustainable materials and techniques.

3 Road management system for San Marino road network

The planning of road maintenance was studied considering the needs and resources of the San Marino administration. For a direct application of the process a sequence of functional phases was defined. The process was designed as a self-feeding succession of connected phases in which every activity outcome is the starting point for the following activity. In detail, each functional phase is associated to specific actions to be performed using tailored tools and reference documents [8]. As shown in Figure 1, the following functional phases and actions were identified:

- Information: road network hierarchy, road network functions, road type, the historical data, survey outcomes are collected and implemented in a GIS database. Information has to be showed by means of thematic mapping;
- Maintenance prioritization: priority index (PI) has to be calculated considering specific information and conditions;
- Type of maintenance: specific repair methods have to be selected based on distress type, condition level, service life, environmental issues, and cost;
- Multi-years planning: the technical and economical assessments have to be performed using projection multi-year models, through the use of custom GIS tools. Several solutions can be compared by means of a strategic index (SI);
- Application: maintenance has to be carried out following the design and specification. Quality control and reporting data have to be implemented on the GIS database.

The management process identifies two operative levels: network and project levels. The former is related to the monitoring of pavement conditions and the evolution over time of pavement distresses, on the entire road network. The sample units with low performance or conditions are ranked in a priority maintenance list according to technical thresholds. At the project level, maintenance repair methods of priority sample units are assessed considering distress types, environmental issues, budgets, service life, specifications and maintenance strategies.

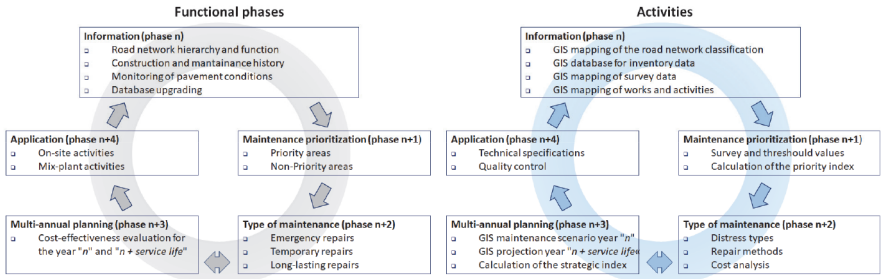

Figure 1 Functional phases and associated activities

4 Selection of data and implementation of GIS-based data management tools

An effective PMS requires the creation of road database in which collect and store different types of data. Generally, road inventory data are collected in a wide variety of formats (includes automated data acquisition, spreadsheet tables, pictures, video, hardcopy notes etc.) which are distributed on a large territorial extension. In this context, GIS is particularly useful to manage and to give spatial reference to a wide amount and heterogenous data to be included in a location referencing system [2]. For these reasons, GIS routines and services for recording, digitization and managing of road maintenance data were developed, organized and implemented through dynamic database for the San Marino Public Administration [11]. The San Marino road network was digitalized and divided into networks and road types, homogeneous sections and sample units. Road networks and intersections were distinguished and classified considering hierarchical, functional and traffic levels. Furthermore, the road types were classified according to the context (urban or extra-urban) and the previous road network level (Figure 2).

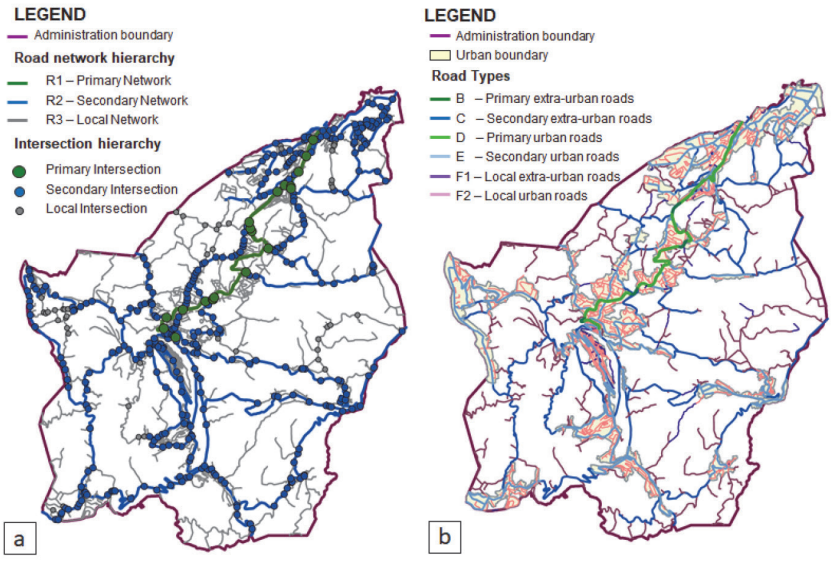

Figure 2 a) GIS map of the network and interconnections hierarchy; b) functional classification by road types

The road network was then divided into easily identifiable and homogeneous sections defined as specific portions of a road having constant characteristics in terms of: context, function, geometric characteristics, structural composition (courses and materials), construction date and traffic volume (average daily traffic, percentage of commercial vehicles etc.). Homogeneous sections were divided into sample units for delimiting the areas on which pavement information are gathered. Sample units are as width as the road lane and have a maximum length of 0.5 and 1 km for urban and extra-urban roads, respectively.
Each road sections and sample units were identified with a unique alphanumerical code to avoid misleading identifications and analysis in the GIS database. Road survey and monitoring of the pavement conditions were carried out periodically. A rating system was defined considering standardized visual inspection method. The pavement condition index (PCI) was calculated (ASTM D 6433-11) on several pavement segments to create a reference scale and address the classification of sample units by comparison [7, 12]. The International Roughness Index (IRI) was measured (ASTM E 1926-98) on specific routes using a selected application for smartphones.
Inventory, survey and monitoring data were systematically recorded in the shared database, with a standard format, using GIS tools (Figure 3 and Figure 4). A GIS-based service was created for mobile devices, for the real-time monitoring and reporting of road emergency on localized areas (Figure 5).

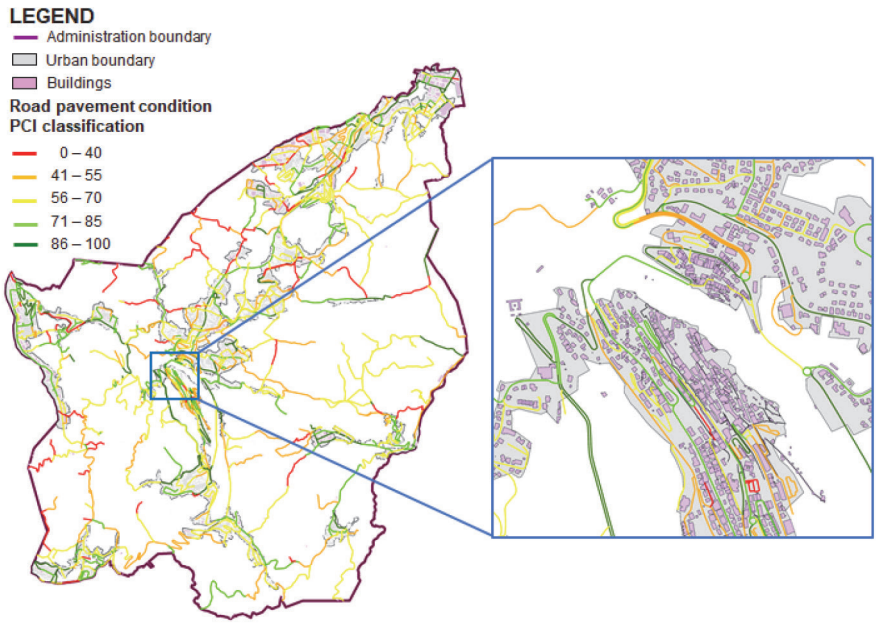

Figure 3 GIS map of the road pavement condition (PCI classification)

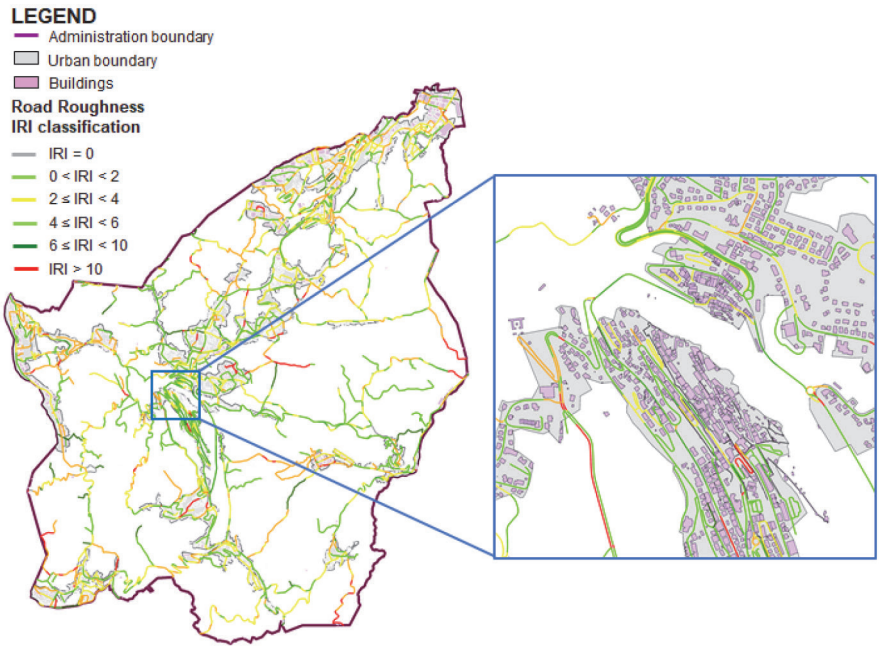

Figure 4 GIS map of road pavement roughness (IRI classification)

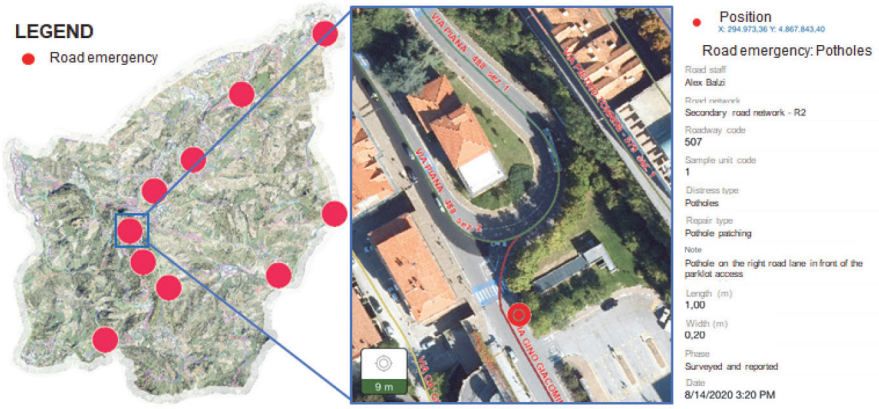

Figure 5 GIS-based mobile application for road pavement survey and monitoring

4.1 Implementation of GIS analysis and decision-making tools

The planning of maintenance according to the condition rating is essential for a cost-effective of the investments on a wide road network with significant constraints of resources. The prioritization of maintenance considers the following technical factors [4]:

- PCI values (estimated or calculated);
- Traffic level factor (TF) based on the average daily traffic values (ADT);
- Road network hierarchy and function classification factor (FF) based on type of network (Primary R1, Secondary R2, Local R3) and road functional classification;
- Strategic function factor (SF) based on commercial or tourist roadways, places of public interest, evacuation roadways, etc.;
- Historical maintenance and rehabilitation factor (MH) based on annual costs of previous maintenance carried out;
- Roughness condition factor (RF) based on IRI values.

Note that the ADT values, the network hierarchy, the strategic function, IRI values and the historical maintenance are parameterized according to a relative rating value ranging from 0 to 100. By applying appropriate weights to each parameter (Equation 1), the priority index (PI) was defined as a number ranging from 100 to 0, where 100 means the maximum priority while 0 means no repair or preventive maintenance. The PI is calculated if the PCI or IRI, or both, values exceed the respective safety threshold (PCI ‹55, IRI ≥ 6 for primary roads or IRI ≥ 10 for secondary with operating speed lower than 50 km/h and local roads).

$$PI = 100 - [0.65PCI + 0.TF + 0.05FF + 0.1SF + 0.05MH + 0.05RF] \quad (1)$$

The calculation of PI was performed on GIS database using a specific routine. All the priority sample units were displayed on the map (Figure 6). All the priority sample units, singularly and as a whole, have to be further investigated at project level to identify the specific maintenance strategy for the road network and, hence, for each area to be repaired.

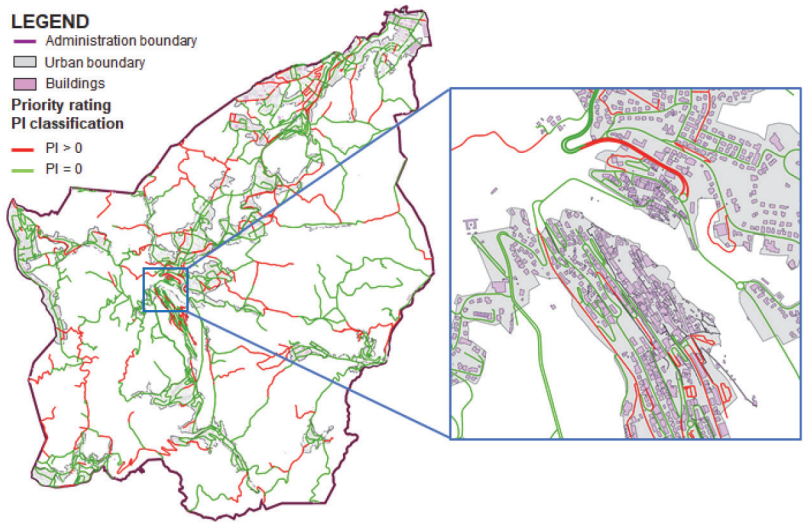

Figure 6 GIS map of the priority rating

5 Conclusions

This paper shows principles, procedures and tools developed for the implementation of PMS in the Republic of San Marino. The process was designed as a succession of connected phases, which each functional phase is associated to certain actions to be performed using specific tools and reference documents. The overall activity opened new perspectives for the road network management and pavement maintenance. Although the greatest benefits are gradually obtained over time, the application of PMS has already allowed to gather positive experiences, enhance quality standards and establish good practices, to support and motivate the decision making and maintenance strategies adopted. The use of GIS-based tools is particularly useful for the standardization and rationalization of the recording, digitization and managing of road maintenance data in a shared database. The graphical display of the information about road network hierarchy, road network functions, road type, the historical data, survey outcomes is performed with thematic maps. Priority set, repair methods and cost-effective analyze can be assessed using GIS-based analysis tools. Finally, the quality control and reporting data of the planned maintenance works are collected, ensuring the constant updating of the GIS database.

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