Preservation Management of Secondary Road Networks

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The pavement management systems developed tend to require human, technical and financial resources that are not affordable by the vast majority of the municipalities, in particular the smaller ones. Still, they are responsible for maintaining the road network. For these organizations it would be highly beneficial to have simple and inexpensive Pavement Management Tool, or equivalent, that could assist in deciding effectively when, how and where apply the resources to carry out the required maintenance.

This work aims to develop and implement a decision support tool similar to a pavement management system, but simpler and easy to use to assist the municipalities in the activities related to the maintenance of their road network. This tool will be applied to the road network in the municipality of Ourém and its main steps are: i) data collection; ii) organizing the database; iii) calculation of PCI; iv) forecast pavement condition; and v) maintenance costs and assessment of the maintenance strategies.

In the conclusion of this study it is explained a way to carry out surveys of the present condition of the pavement without invest huge resources and using a simple process. The results obtained using the decision support tool demonstrate that it is possible to organize the application of preventive maintenance measures to ensure the possibility of making a proper resources management avoiding unnecessary expenses.

Key words: Pavement Management System; Pavement condition index (PCI); Clusters analysis; Decision support tool.

INTRODUCTION

The dynamics of the modern communities are based on a set of infrastructures which provide essential services to its operation, namely the transportation of goods and people, the water supply and drainage, the energy supply and the communication. In this context, the communication routes are the infrastructures that provide the transportation of goods and people, playing a critical role in the socio-economic development of the communities and countries. Within the communication routes, the road network is the most extensive and dispersed segment, contributing to greater fairness on the possibility of developing economic activity at local, regional, national and international. Mindful of the importance of the road network it becomes necessary to carry for their preservation or rehabilitation to ensure a suitable service.

Given the extent of the road network in most countries, especially the most developed, there was a need to develop strategies and plan efficiently and effectively the interventions due to the financial burden they represent, thus giving rise to the Pavement Management Systems.
In relation to this problem there have already been made several investigations which lead to the development of pavement management systems [1–3].
The majority of these systems follow the structure of the pavement management system: i) data acquisition; ii) road network database; iii) quality evaluation tool; iv) pavement behavior models; v) M&R unit costs; and vi) decision-aid tool and M&R actions.

In each mentioned step can be chosen different models and parameters depending on available data or the desired degree of accuracy.

The secondary road networks are, usually, roads with low traffic volumes under the supervision of local authorities with considerably limited budget. Since most local authorities in Portugal do not have a Pavement Management System, this dissertation aims to develop and implement a Decision Support Tool to contribute to improve of the management of secondary road networks. The proposed Decision Support Tool is similar to a Pavement Management System but simpler and easy to use to assist the municipalities in the activities related to the maintenance of their road network.

DECISION SUPPOT TOOL

The proposed Decision Support Tool was developed and applied considering the specific context of the road network of the Municipality of Ourém with the aim of contributing to enhance the management of secondary road networks. The tool follows the methodology present in Figure 1, which is based on the structure of an SGP, and consists in: i) collecting data and creating a database; ii) determine the PCI and forecast pavement condition; and iii) estimate the cost of rehabilitation of each road section and assesses the intervention plan using different strategies.

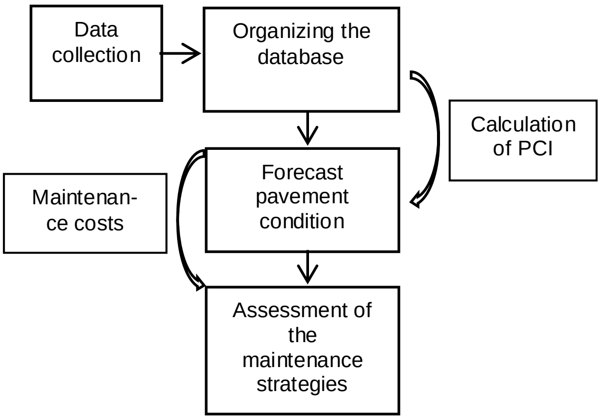

Figure 1- Diagram of the Decision Support Tool for secondary road networks

The development of the tool required information from the city of Ourém and Fremont. Data were collected from the town of Ourém which allowed characterizing its location, area, population and climate. Regarding the characteristics of Ourém roads it was analyzed a survey of the state of the condition of municipal roads 24 pavements conducted in 2006 and the type of existing pavement on each route. To characterize the rehabilitation costs and existing traffic analyzed, respectively, the unit costs of different types of rehabilitation and two noise studies conducted in different years. In order to update existing information pertaining to the surface condition of pavements we carried out a new survey on this year of 2015. This survey, similarly to what has been done in 2006, featured the existence of cracks, surface depression and potholes in each 100m on 24 routes analyzed and divided into 59 sections. Then each section is associated with a unique ID. This information is stored in a database with all the existing information about the sections.

Predict the evolution of the pavement condition requires the existence of an history of the pavement condition, in this case the historic value of PCI was unavailable in Ourém municipality, since there are only two years of surveys and a few sections of the network cataloged. In this context, and to avoid using a uniquely expert forecasting model, has admitted the possibility of extrapolating the trend PCI of a network of municipal type comparable to Ourém in terms of types of pavements, traffic and weather and which has a database with the history of several years for the condition of the pavement. Focusing research on US cities, specifically in the state of California, the city of Fremont was the one which provided all the required information and had more similarities with the city of Ourém. It was been possible to collect the climate, type of pavement, traffic class and PCI history of the City of Fremont.

The calculation of the PCI Ourém routes was based on the survey of the pavement condition conducted in 2006 [4]. In this survey it is characterized the roads analyzed in accordance with the overall condition of the road classified as good, reasonable, poor or very poor, to be associated with a training PCI value.

It was assumed that the pavements performance observed in Fremont can be adapted to Ourém. For forecast pavement condition the model that best fits the existing data and the size of these is the cluster analysis, specifically the Two-Step Cluster method [5] which is applied using the IBM SPSS Statistic software [6].

The Decision Support Tool is developed from the viewpoint of the public entity responsible for the maintenance of the roads. In this sense the cost model does not consider the cost to the user, in short, it will only consider the estimated cost to implement the maintenance measures to the existing sections. Maintenance costs are calculated considering the length and width of the section and the unit costs of different types of rehabilitation obtained for the town of Ourém.

To select routes with priority for rehabilitation, the most widely used method according to Zimmerman [7] was used. The method consists in ranking the priority based on the pavement condition and selecting the routes which should be actually rehabilitated considering existing constraints (e.g., budget). As such, the first step is to determine an organized list roads prioritized according to the PCI. The second step consists in selecting the routes which should be actually rehabilitated. To determine the list of roads that really should be rehabilitated are considered several hypotheses: i) most degraded road sections; ii) increased rehabilitation cost; iii) lowest rehabilitation cost; and iv) capacity below a threshold value.

To ensure a user friendly framework for the technicians of the municipalities, all the elements of the Decision Support Tool were developed and operationalized in Microsoft Excel. The spreadsheet has a graphical interface that guides the user in data entry and query results, thereby ensuring the consistency of the calculations and macros.

RESULTS AND DISCUSSION

INITIAL CONSIDERATIONS

To develop the Decision Support Tool , and after the data collection and organization, it is required to define a method allowing the computation of the PCI from the data collected in the survey carried out. We also need to predict the behavior of Ourém pavements that is supported by the evolution of class C pavements Fremont, using the cluster analysis. Then is described how to define the cost of maintenance of each section. Getting the results it is possible to complete the macros mentioned above and thus resorting to created menus to obtain and analyze the results of different evaluations considered. Finally, discusses the results by comparing with the decisions taken by the municipality of Ourém.

CALCULATION OF PCI

The the first step in the PCI calculation is to associate the overall state of the pavement with the training PCI value, where good state corresponds to a training PCI 95, reasonable with 85, poor with 70 and very poor with 50. The same survey also characterizes every 100m where there are cracks, surface depression and potholes. Thus calculating the percentage of the road section on which there is every type of deformation and considering the training PCI because when the value of PCI is of all sections regardless of the overall state of the roadwas held a polynomial regression using RapidMiner[8]. The obtained equation must be corrected, because when the value of PCI is 100 the pavement doesn’t show any degradation, thus yielding the equation 1.

PCI= 100 - 0,262* Surface Depression- 0,409 * Potholes - 0,222 * Cracks (1)

FORCAST PAVEMENT CONDITION

To apply cluster analysis it is necessary to choose the criteria of distance, which is the Log-Likelihood, set the number of clusters, in this case we opted for 3 and considering the Outlier Treatment to exclude all cases which are not similar to the remaining.

Then we consider the history concerning the progress of the PCI of each route of Fremont and are characterized variables that the model will have to evaluate: the PCI of the initial year and the annual degradation. The degradation corresponds to an annual change of a PCI per year ,wich corresponds to the PCI decreasing rate per year. This analysis considers only the data set associated with the class C of Fremont floor. This database contains 577 pairs of PCI initial / annual degradation, which are continuous variables. The results of this analysis can be seen in Table 1, where it can be seen the constitution of each of the three clusters resulting. Within each cluster obtained, each variable is characterized by a distribution described by a mean and standard deviation.

Taking into account the average value of the initial PCI obtained for each cluster we define three ranges, corresponding to the first 80 to 100, the second 80 to 50 and third 50 to 0. In the case of the initial value PCI be comprised between 80 and 50 it appears that the average annual degradation shows a large discrepancy with respect to other values. This means factors such as the quality of construction, construction methods and materials used influence the degradation of pavements.

Hence it is considered that for this cluster distribution of annual degradation corresponds to an percentile of 95% for the case of good quality construction; the percentile 85% in case of medium quality construction and the percentile of 75% for poor quality construction. Table 2 relates to PCI intervals with Annual degradation. So it is possible to calculate the evolution of degradation of Ourém pavements to an analytical period of 3 years.

Table 1- Constitution and characteristics of clusters

Cluster distribution					Characteristics of clusters			
		N	% of combined	% of Total	Initial PCI		Annual degradation	
					Average	Standard deviation	Average	Standard deviation
Cluster	1	261	45,2	45,2	83,35	8,55	-2,2	1,2
	2	223	38,6	38,6	39,9	16,19	-3,36	2,12
	3	92	15,9	15,9	74,95	13,15	-7,98	2,85
	outlier (-1)	1	0,2	0,2	86	.	-26	.
	Combined	577	100	100	65,22	23,97	-3,61	2,92
Total		577		100%				

Table 2- Rehabilitation type associated with the range

Initial PCI	Annual degradation	
PCI > 80	-2,2	
50 < PCI < 80	Good quality construction	-4,8
	Medium quality construction	-5,4
	Poor quality construction	-6,1
PCI < 50	-3,4	

MAINTENANCE COSTS

To calculate the maintenance cost for each section must be taken into account the table 3, which associates the type of rehabilitation required according to the PCI interval. Thus the cost of maintenance is equal to the product of unit costs of rehabilitation and the existing of annual degradation of the area section. As the survey does not cover areas or lengths of degradation is considered the length of the section and its width to calculate the area to be rehabilitated. However knowing that the rehabilitation of type 1 is applied when the section has cracks and dispersed surface depression, considering that only 10% of the pavement area needs rehabilitation. Regarding the rehabilitation of type 2 described by the section have cracks, potholes and potholes with some frequency, it is considered that 60% of the pavement area needs rehabilitation. The rehabilitation of type 3 should be applied on pavements with surface depression, cracks and potholes too often, in this case due to the severity and scale of the work is considered that the entire pavement area needs rehabilitation.

Table 3- Rehabilitation type related to the PCI range

Type of rehabilitation	PCI	Unit price (€/m^2)
1	PCI > 80	8,00
2	50 < PCI < 80	15,00
3	PCI < 50	22,00

ASSESSMENT OF THE MAINTENANCE STRATEGIES

In all assessments it is considered that the budget available for the rehabilitation of the analyzed sections is 1,291,792 €. The evaluation A aims to select the most degraded sections to reach the available budget. By definition the most degraded sections are those with the lowest PCI. In order to achieve this it is estimated the cost of rehabilitation of each section according to the PCI and order up a list of sections in ascending order in relation to PCI. Scrolling through the list we select the sections to be rehabilitated and the costs of rehabilitation are added for each section until we reach the available budget. This analysis indicated that we should rehabilitate six sections (corresponding to the ID's 56, 52, 41, 55, 42, 36) of the total 59 sections where the necessary budget is 1,291,050 €.

The evaluation B takes into account that when a pavement is too degraded its rehabilitation cost is higher than when it displays good condition, in this sense, it selects the sections in which the degradation presenting along three years results in an increase the rehabilitation cost to reach the available budget. The results (Table 4) indicate that should be rehabilitated 16 sections using 1,219,810 € and guaranteeing savings over the analysis period of 2,823,280 €.

Table 4- Sections to be rehabilitated each year according to the annual budget as assessed B

Year rehabilitation	Number of Section	Budget needed (€)	Savings (€)
2015	6	206.318	1.066.282
2016	2	90.608	231.332
2017	8	922.884	1.525.666
	Total	1.219.810	2.823.280

The evaluation C selects the sections with lower cost of rehabilitation in order to rehabilitate as many sections with the available budget. This analysis focuses on sections with high PCI, as these have low cost of rehabilitation because it is preventive measures. This review selected 24 sections to be rehabilitated, most of this sections present a PCI over 70, using 1,249,566 €.

The evaluation D selects the sections which have a poorer quality than the threshold value, ensuring that at the end of three years of analysis all sections have a higher quality than this threshold value. This analysis results in the selection of 10 sections (corresponding to the ID 56, 52, 41, 8, 9, 55, 38, 49, 27 and 10) investing 1,268,400 €.

DISCUSSION OF RESULTS TAKING INTO ACCOUNT DECISIONS OF THE MUNICIPALITY OF OURÉM

As a first analysis, taking into account the sections to rehabilitate obtained in each of the described evaluation, it was intended to compare with the decisions that the municipality of Ourém have chosen to the year 2015. It is noteworthy that only the year 2015 will be compared since by time constraints is not possible define those sections that the municipality will really rehabilitate 2018.

Thereby observing the list of routes which really were picked and rehabilitated by Ourém municipality in the year 2015, it appears that the only route coincident with those analyzed in this project is the route EM360, which is represented by two sections, ID 8 and 9, which are sections that have a PCI in 2015 less than 45, it demonstrates the low existing state in these pavements. In this sense it appears that the existing degradation on the pavements is for sure an important factor and considered by the municipality, as justification for the decision of the choice of pavements to rehabilitate and therefore this is always reactive about the state of the pavement.

The evaluations A and D foresee the rehabilitation of at least one of the two mentioned sections. In these evaluations, the sections are selected according to the quality of the surface pavement. This justifies the selection of sections ID 8 and 9 that are highly degraded.
There are grounds related to the database that can justify the low compatibility between the obtained results and the decisions taken by the municipality. In fact it was not possible to survey the entire road network of the city despite of the 59 sections considered. However, it was clear that one of the greatest weight in the decision to rehabilitate the pavements by the municipality was the public opinion of users after verifying that pavement condition was really degraded.

CONCLUSION

The aim of this study was to develop a Decision Support Tool on how to invest in the maintenance of secondary road networks, easy to use, reliable and cost-effective implementation with regard to obtaining the information used to justify decisions. This work was applied to the road network of the Municipality of Ourém.

The process developed initially allows the characterization of the state of the the pavement surface of each road without using mechanical equipment and without requiring specialized technicians. Then there were developed a behavior prediction model specifically for this problem by comparison with a similar situation detected for Fremont, state California city in the US. Finally we set different application strategies of financial resources that can be implemented for conserving the road network.

Briefly, the simplified identification pavement state for the year of departure (2015) through a global indicator (PCI), the evolution of pavement performance obtained by application of cluster analysis technique to the reality of the city of Fremont, and the definition maintenance strategies taking into account the costs and the evolution of pavement condition based on the evolution of their behavior resembled the city of Fremont, are the essential components of Decision Support Tool developed to Ourém. It is thought that this way was achieved the main goal of this work.

Of this study was concluded that it is possible for municipalities with reduced budgets to carry out the survey of the current state of the pavements in a simple, inexpensive and functionalizing an instrument similar to that developed for Ourém given the opportunity to apply with a criterion of preventive maintenance measures to their road networks, thus ensuring better management of financial resources available to them to do so.
There are of course improvements that can be made to the Decision Support Tool in response to future improvements:

- Making more accurate PCI calculation which will also entails greater allocation of human resources and therefore higher costs. However it helps with regard to the reliability of the characterization;
- Find references such as Fremont to perform a behavior prediction modeling and cover a larger number of structures and situations;
- Include this project with SIG existing network so it can be possible to see all the information over an existing platform.

REFERENCES

1. Haas RC, Hudson WR, Zaniewski JP. *Modern Pavement Management*. (Malabar F, ed.). Krieger Pub. Co.; 1994. Available at: http://books.google.com/books?id=TstQAAAAYAAJ.

2. Picado Santos L, Ferreira A, Antunes A, et al. Pavement management system for Lisbon. *Proc. ICE - Munic. Eng. 157* 2004;157(3):157-165. doi:10.1680/muen.2004.157.3.157.

3. Kirbas U, Gursoy M. *Developing the Basics of Pavement Management System in Besiktas District and Evaluation of the Selected Sections*. Istanbul; 2010.

4. Divisão de Obras Municipais. *Ficha de Inspecção de Vias Municipais- EM/CM*. Ourém; 2006.

5. Norušis MJ. Cluster Analysis. In: *IBM SPSS Statistics 19 Statistical Procedures Companion*. Prentice H.; 2011:361-391. Available at: http://www.norusis.com/pdf/SPC_v13.pdf.

6. IBM@. IBM Knowledge Center. 2015. Available at: http://www-01.ibm.com/support/knowledgecenter/SSLVMB_21.0.0/com.ibm.spss.statistics.help/twostep_notation.htm. Accessed July 3, 2015.

7. Zimmerman KA. Pavement Management Methodologies to Select Projects and Recommend Preservation Treatments. *Transp. Res. Board - NCHRP Synth. Highw. Pract. 222* 1995:46.

8. RapidMiner. Manual Rapidminer Studio. 2014:116. Available at: https://rapidminer.com/.