Identifying Urban Road Segments whose Pavement Surfaces Are the Most in Need of Maintenance Works - An approach using Geographical Information Systems

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Synopsis

Within the urban road pavement management arena, the Town Councils find themselves, with an increasing frequency, before the task of identifying the road segments which present the most critical conditions as far as safety, comfort and vehicle operating costs are concerned. Regarding the condition of the pavement surface, its maintenance is viewed here as a mere intervention to restore its traffic condition, that is to eliminate or mitigate the impact of its defects. This can be justified in a situation where there is an acute budget restriction on pavement maintenance investments and the resources are only enough to keep the road pavement network in acceptable traffic conditions, without further indepth consideration on the pavement structure as a whole.

Initially the paper presents an approach of using a Geographical Information System - GIS for identifying and visualizing the segments of an urban paved road network, whose surfaces are most in need of maintenance works. The road segments surface conditions are assessed by means of a pavement functional index – PFI, which takes into account a set of three types of surface defects thougth to be important to the road users in urban areas, namely : surface depression, potholes and surface cracks. A series of defect weighs has been used to calculate the PFI for each road segment. The Brazilian National Department of Roads - DNER standard procedure for the PFI determination has been adapted to generate IFP values so as to take into account the total number of defects for each category of surveyed defects. Concerning the potholes, their level of severity has been broken down into three subclasses depending on their sizes. Such finer detail description in measuring this defect is justified by its great influence on the road conditions with regard to comfort, safety and vehicle operating costs.

Apart from the surface defects, it is also taken into account the surface degree of rugosity, here given in terms of its macrotexture, measured by the sand patch test as specified by the American Society for Testing and Materials standard procedure. The road segments macrotextures and their functionalities within the urban network, are then compared to their corresponding legal speed limits in order to check for possible surface inadequacies in terms of skid resistance (safety condition). Last, traffic volumes per lane in each road segment are taken as an indication for the speed of surface deterioration and thus used as a complementary indication of need for a short term maintenance intervention.

A practical application of the pavement surface assessment approach to the City of Joinville – Brazil – is then reported. Using a loose-coupling procedure, the surfaces conditions are determined outside a GIS and inserted into it afterwards as themes for thematic mapping. Maps have been generated for visualization purposes and queries have been made in order to identify the most critical road segments in the study area. The feasibility of carrying out a multicriterial analysis in a rather simple way has been shown, so highlighting the usefulness of the approach for both developed and developing countries.

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As the development of new methods and techniques for collecting and processing spatial data continues to progress in a fast pace, it seems clear that the strategic urban road planning and the urban road (street) management systems tend to become even closer to each other. Such trend has important implications on the way the strategies for urban infrastructure management, and its future expansion, should be devised. This is so, because the ever increasing speed in performing tasks such as collecting, organizing and retrieving spatial information, as well as carrying out spatial analyses, will induce the replacement of the traditional long-term system planning view by a short to medium-term view based upon these new emerging paradigms of data collection, processing and analysis. In such scenario the local authorities tend to feel pressed by the need for updating the way in which urban infraestructure planning and management are carried out.

Concerning the establishent of an urban road network surface maintenance policy, one has to consider that a proper strategy should be set. In fact, the road surfaces are constantly being subjected to cyclical loads by the freight as well as passenger vehicles with specific intensities and specific patterns in urban areas and the surface defects caused by the traffic are, in many instances, managed by means of random and/or hasty interventions. Another important point to be noticed is that the overall majority of methods for road pavement surface maintenance do not take into account the deteriorating effects caused by cars on the road surface.

Disregarding the effects of passenger cars in an urban road management scheme is clearly an underestimation of the effects these vehicles cause upon the road surface conditions and this needs to be addressed. Therefore, concerning the alternative urban road network management strategies, there is an increasing necessity of fast, more precise and cheaper methods of road surface conditions assessment with the aim of developing better road maintenance schemes. It is here that comes into play the new geographical information technologies such as the remote sensing technologies, the digital cartography, the computer aided design softwares and the powerful relational data base systems. The fact is that these methods and technologies are now present in most commercial Geographical Information Systems – GIS, and can no longer be ignored. This is what makes the GIS tool a key stone to the improvement of present road maintenance management systems and the conception of new ones.

In the following sections the paper presents an approach to identify the urban road segments conditions, as determined by their surface defects patterns, to assess their relative degrees of importance within the road network system (rating) and to spot the segments with a greater necessity of superficial short-term maintenance works. The approach has been conceived for being used in a GIS environment, requiring thus the availability of a digital map of the urban road network as a basic prerequisite.

A STREET SURFACE CONDITION EVALUATION APPROACH

A street surface condition evaluation approach has been conceived so as to take into account::
a) the main types of surface defects, important enough to compose a pavement functionality index which represents the surface conditions in a realistic way;
b) a surface macrotexture measurement which can be used to characterize safety conditions (skid resistance), and
c) the traffic volume per lane which includes in it the number of passenger cars, and that can be used as an indicatior of the expected speed of surface deterioration over time.

With respect to road users comfort and safety and to vehicle operating costs, the three road surface defects thought to be the most important in urban areas were the potholes, the surface depressions (due to plastic deformation) and the severe surface cracks more than 1.0 millimeter wide and with edge erosion (FC3). Although the surface defects are usually associated with the pavement structural conditions as a whole, the analysis of such relationships is outside the scope of this work. Rather, the streets surface condition maintenance will be considered as a short term objective per se and that its attainment does not depend on going into deep considerations on the pavement structure (usually associated with pavement rehabilitation).

Therefore, the approach presented here can be viewed as part of a short term mitigation strategy for street surface conditions maintenance and its conception is directed towards the needs for technical guidelines, which are mostly present in the Road Departments of the City Councils.

The Pavement Surface Functional Index - PFI

The overall effect of the defects on the surface condition of a street segment is measured by a pavement functional index – PFI, given by the extent of the area or the number of defects of each type which are present on the segment, with regard to its length (distance between two neighbour intersections). The street segment s are considered homogeneous in terms of their surface conditions.

Each type of defect is weighted by a factor to characterize its relative importance (Freitas, 2002). In determining the pavement surface condition, such factors have to be determined by an appropriate calibration procedure that, in turn, should involve the judgement of road experts and road users. As far as the defects inventory procedure is concerned, the inventory method DNIT 006/2003-PRO from the Brazilian National Roads Department (DNIT, 2003) has been adapted to take into account the total number of defects on the road segments, instead of a sample of them. Such adaptation follows the inventory procedure proposed by Freitas (2002) and published by Trichês et al. (2003).

The pavement surface functional index for a street segment has been determined by the following equation:

$$PFI = \left\{ \left[\frac{(AFC3)\cdot(P1)}{(W)\cdot(SegL)} \right] + \left[\frac{(DepL)\cdot(P2)}{SegL} \right] + \left[\frac{(NP)\cdot(P3)}{SegL} \right] \cdot 100 \right\} \qquad (1)$$

PFI = pavement surface functional index;
AFC3 = area of the surface with cracks FC3 on the street segment (between intersections) (m^2);
P = defect weight (P1 for cracks, P2 for depressions, P3 for potholes);
W = street segment width (m);
DepL = depression lenght (m);
NP = number of potholes for 100 meters of street extension;
SegL = segment lenght (m).

The adopted defects weights, given in Table 1, are the ones specified by the Brazilian National Roads Department in its road surface defects assessment procedure DNIT 006/2003-PRO.

Table 1: Adopted defects weights as given in DNIT 006/2003-PRO

Surface Defects	DNIT 006/2003-PRO Weights
Cracking (FC3)	0,8
Surface Depressions	0,9
Potholes	1,0

The Street Pavement Surface Macrotexture

In this paper the macrotexture of the pavement surface is taken as its macroscopic roughness, characterized by the protrusion of the aggregate surfaces (USACE, 1999). The surface macrotexture is highlighted here because it is considered the main responsible for the decrease in skid resistance with speed. Such a decrease is very considerable even when the microtexture is good. This is due to the fact that the macrotexture allows the water on the surface to be drained rapidly and, therefore it becomes important at vehicle speeds greater than 50 Km/h (USACE, 1999).

In urban areas it is usual to find roads with speed limits superior to this threshold and this confirms the importance of the surface macrotextures in the urban context too. In Brazil, for instance, the road speed limits in urban areas are established by law as follows: freeways 80 Km/h, arterial streets 60 Km/h, collector streets 40 Km/h and local streets 30 Km/h. So, as far as the surface macrotexture is concerned, the main worry is directed to the urban freeways and arterial streets, notwithstanding the usual disrespect of the legal speed limits by drivers in the two other types of urban roads.

If on one hand, low values of macrotexture lead to low levels of skid resistance and to a decrease in vehicle safety conditions, too high values of macrotexture, on the other hand, are undesirable because they lead to a higher rubber tyre abrasion and fuel consumption. Although the measurement of the surface macrotexture can be made via a series of different tests (USACE, 1999) in this work the sand patch test will be adopted. According to USACE (1999), values of macrotexture depth greater than 0.80 millimeters are considered excellent, providing safe skid resistances, whereas values inferior to 0.60 millimeters are considered as inadequate, leading to a slippery surface. On the other hand, macrotexture depths greater than 1.20 millimeters, although recommended in special cases (Pasquet, 1968), cause an excessive increase of tyre-rubber abrasion, more discomfort to road users and higher noise levels and are, thus, considered undesirable.

From this, two disfavourable situations regarding extreme values of macrotexture depth can be pinpointed. The first situation is the one in which a local street, designed for low vehicle speeds, presents high macrotexture depth (above 1.20 mm). In this case it could be desirable to reduce such depth to a more suitable level by means of a resurfacing. The other situation is the one in which a freeway or an arterial street, designed for speeds superior to 60 Km/h, shows low macrotexture depth, inferior to 0.40 mm, characterizing a 'closed' surface texture (see LCPC, 1971). Here the problem is related to safety since the skid resistance falls below the recommended inferior threshold and it would be necessary to proceed a skid resistant surface covering or a grooving operation to correct the surface macrotexture.

APPLICATION TO A STUDY AREA

In order to test the approach just described above, its application to na study area made up of two borroughs of the City of Joinville in Southern Brazil, has been performed.

The Study Area

The City of Joinville is situated in the Northest of Santa Catarina State (South of Brazil). Figure 1 shows the municipality location within Brazil.

Figure 1: Location of the Municipality of Joinville
Source: http://www.joinville.sc.gov.br

The municipality of Joinville has a population of 429,004 inhabitants and is a predominantly industrial area with a total road network of 1,485 kilometers. Out of these, there are 443 kilometers of paved roads with bituminous (asphalt) surface (IPPUJ, 2004). (Relatório de Joinville 2001/2002). The regions topography is characterized mainly by flat plains with wet lands nearby the Babitonga Bay.

The human settlements have occurred in these flat areas where the altitudes are 20 meters, at most, and the predominant soil in the region has properties of a silt-clay type, being sensitive to rain and prone to erosion. Presenting an air relative humidity of 76.4% and a high rainfall index of 1,909 millimeters/year, the area is a good experimental ground for testing road maintenance strategies.

Such physical and environmental conditions requires from the City Council a great effort to maintain the road network in a satisfactory condition. Such efforts, however, are partially hindered by the velocity with which the roads deteriorate over time and the shortage of financial resources to cover the costs of an intensive road maintenance program. In such circumstances the City Council is obliged to spot the road segments which are in worse conditions and that demand a quicker maintenance intervention, in order to maximize the effectiveness of the road maintenance investments. The road maintenance strategy usually adopted is the one in which the need for intervention is based upon an evaluation of the road surface condition, that is by means of a defects surveying program, followed by a surface condition assessment.

As far as the conception of a road maintenance program, it is clear that a systematic approach for collecting information on the road surface defects and using such information to develop a surface condition assessment, is the best way to identify the intervention priorities and to achieve the desired level of effectiveness.

Determining the Road Surfaces Conditions

Using equation (1) and the set of defects inventoried by Freitas (2002) for the study area, the PFI for each of the street segments has been determined. Table 2 shows a sample of the defects inventoried on the street segments of the Santo Antônio Borough. Each street segment is identified by its identification (ID) code.

Table 2: Sample of street segments characteristics, inventoried defects and the IFP

Street Name	ID Code	Pavement Type	Traffic Volumes (annual)	SegL	AFC3	DepL	NP	PFI
Gerkes S. Rocha	3-B	Asphalt	710,000	190.52	0	0	0	0
Gerkes S. Rocha	3-C	Asphalt	710,000	70.04	0	0	0	0
Gerkes S. Rocha	3-D	Asphalt	710,000	70.04	0	0	0	0
Gerkes S. Rocha	3-E	Asphalt	710,000	60.00	0	0	1	1.67
Gerkes S. Rocha	3-F	Asphalt	710,000	50.00	0	0	2	4.00
V.P. Luiz C. Garcia	4-A	Asphalt	885,000	70.04	15	17.510	4	5.98
V.P. Luiz C. Garcia	4-B	Asphalt	1,100,000	207.68	45	64.381	9	4.66
Iguaçu	5	Asphalt	885,000	877.21	160	263.163	29	3.61
Sem Denominação 1	6	Asphalt	1,200,000	87.89	20	27.2459	4	4.88
Gercy R. Alvez	7	Asphalt	1,100,000	75.06	0	7.506	3	4.09
Alexandre Humboldt	8	Asphalt	589,000	586.37	12	0	2	0.35
Beatriz S. Wetzel	9	Asphalt	695,000	106.81	0	0	3	2.81

The same street surface conditions classification used by Freitas (2002), i.e. good, regular and bad, has been adopted in our study. These conditions were obtained via a consultation to road maintenance experts from the local City Council, who have driven over the street segments to assess them. Such surface conditions, were then used to establish the PFI interval which characterizes each condition. Such calibration has led to the PFI intervals showed in Table 3. With the aim of differentiating the segments conditions in a thematic map, within a Geographical Information System, a representational code has been assigned to each functional surface condition.

Table 3: Road surface condition classification according to the PFI index

Indices	Functional Condition	Representation
PFI ≤ 1,0	Good	White
1,0 < PFI < 4,0	Regular	Striped
PFI ≥ 4,0	Bad	Black

Using a GIS for Mapping the Road Surface Conditions

After constructing a relational data base for the street segments, similar to Table 2, and determining the segments surface conditions as explained above, a loose-coupling procedure has been used to insert the segments information into a Geographical Information System (Ulysséa-Neto, 2000). The GIS has the task of associating the street segments data table with a digital map of the study area street network (created as polygons objects).

The GIS provides us with automatic calculations of segments widths, lengths and areas, apart from the construction of thematic maps and thus the possibility of ‘visualizing’ the street surface conditions. Such a visualization, in particular, facilitates the spotting of the critical segments and their relative spatial positions on the network. This is important mainly for defining the ‘logistics’ of the intervention schemes, for optimizing the displacement and deployment of maintenance work force and equipment fleets and for achieving gains in scale and productivity. As a result, it is expected a reduction on the overall maintenance costs and time.

The GIS preparation

The first issue involved in analysing the possibility of using a GIS system for street surface maintenance purposes is the need of a digital map of the study area street network, in a scale suitable for measuring and representing distances (e.g. street segments lengths and widths) with enough precision. A digital map of the study area in a scale of 1 : 2,000 has been inserted into the GIS and used to create a workable WIEW of the study area street network.

Each street segment is represented in the VIEW by a closed polyline (polygon), allowing thus the determination of its width, length and area by means of the conventional GIS tools. This is specially important to the adopted surface condition evaluation approach since that the influence of a segments set of defects on its surface condition, is related to its length and area.

The street segments characteristics, defects and conditions were processed in a spreadsheet and ‘linked’ afterwards to the VIEW via a JOIN procedure. This procedure has made the street segments data table a part of the theme attributes table in the VIEW, making it possible to use those data for map drawing and querying in the VIEW.

Mapping the street surface conditions

A map of the street surface conditions has then been drawn with the representational codes established in Table 3 as the street segments attributes. This map for the Santo Antônio Borough is shown in Figure 2.

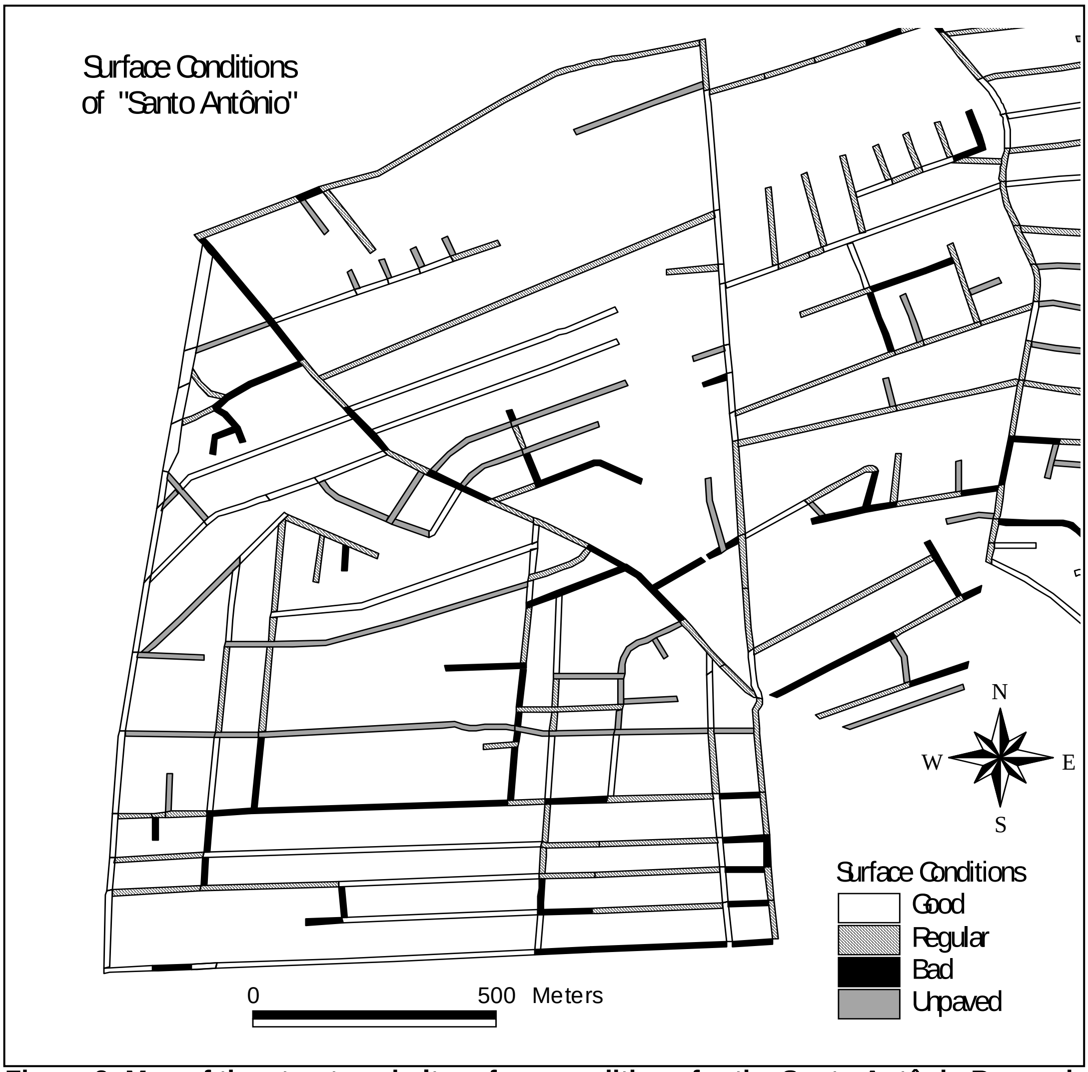

Figure 2: Map of the street asphalt surface conditions for the Santo Antônio Borough.

With such a map, the street segments in bad condition can be easily spotted. The GIS has given the total number of segments in each of the three surface conditions. In the study area there have been identified 63 segments in good conditions (32.1%), 40 segments in regular conditions (20.4%) and 93 segments in bad conditions (47.5%).

Also, it is possible to identify segments in bad conditions that are clustered in specific areas, serving thus as an indication on the best sequency of segments to be targeted for maintenance work. From this, it follows the possibility to estimate the amount of work force and equipments needed, to decide where these should be deployed and to find out the best plan for displacing them from one site to another.

CONSIDERING THE SURFACE MACROTEXTURE EXTREME VALUES

As explained at the outset, the main concern with macrotexture is due to its relationship with skid resistance and safety at medium to high speeds and to the unecessarily high roughnes at low speeds. Two elements have been considered: the surface macrotexture and the street functionality. Sand Patch Tests have been carried out to measure the surface macrotexture depth on 13 streets (63 segments) of the study area.

Figure 3 shows a map of the streets functionality for this set of segments.

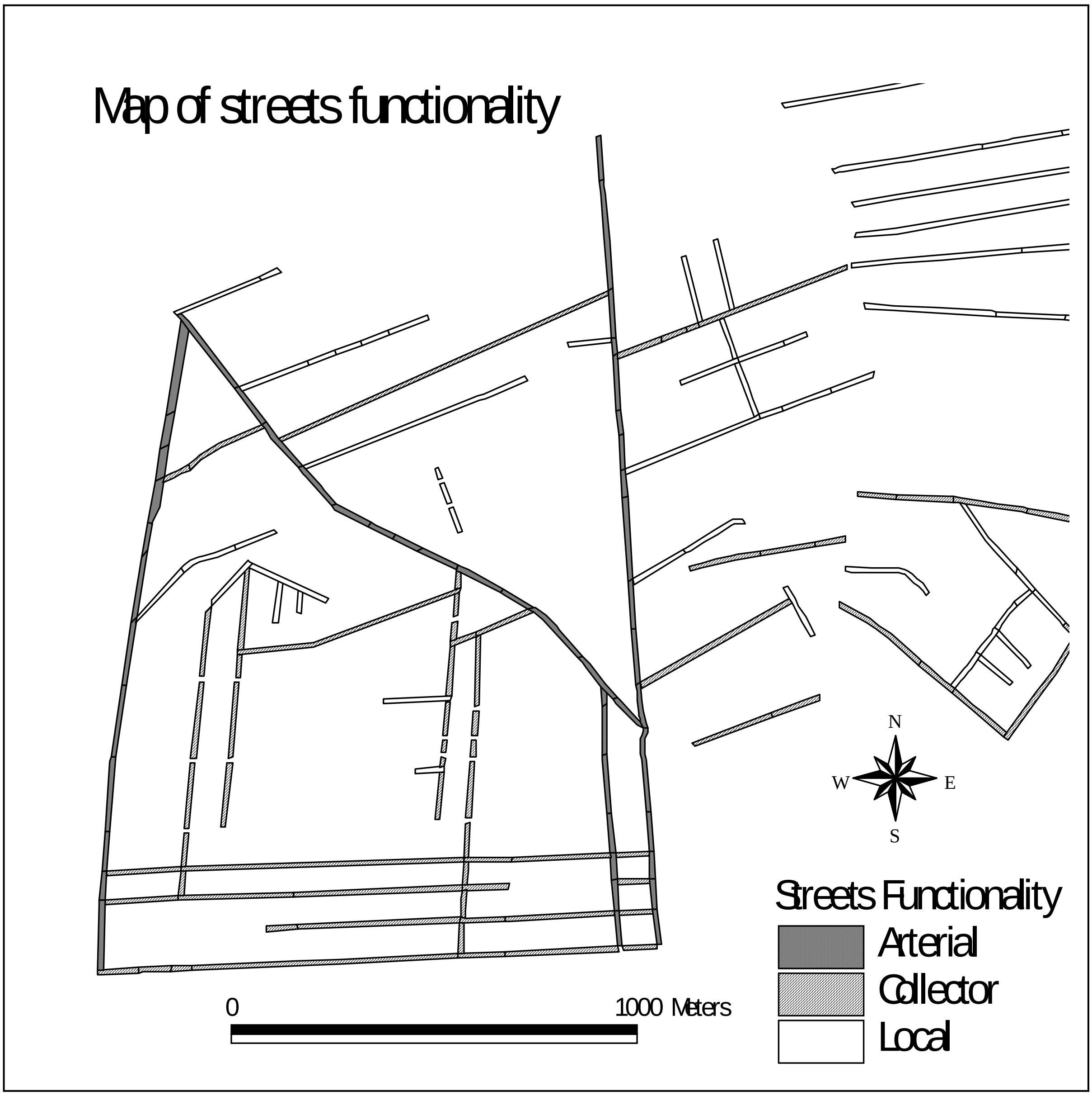

Figure3: Map showing a sample of street segments and their functionalities.

A map of the surface macrotextures of the same set street segments is shown in Figure 4. With such a map one can easily spot the street segments whose macrotextures depths fall outside the acceptable values, that is outside the range 0.40 to 1.20 millimeters.

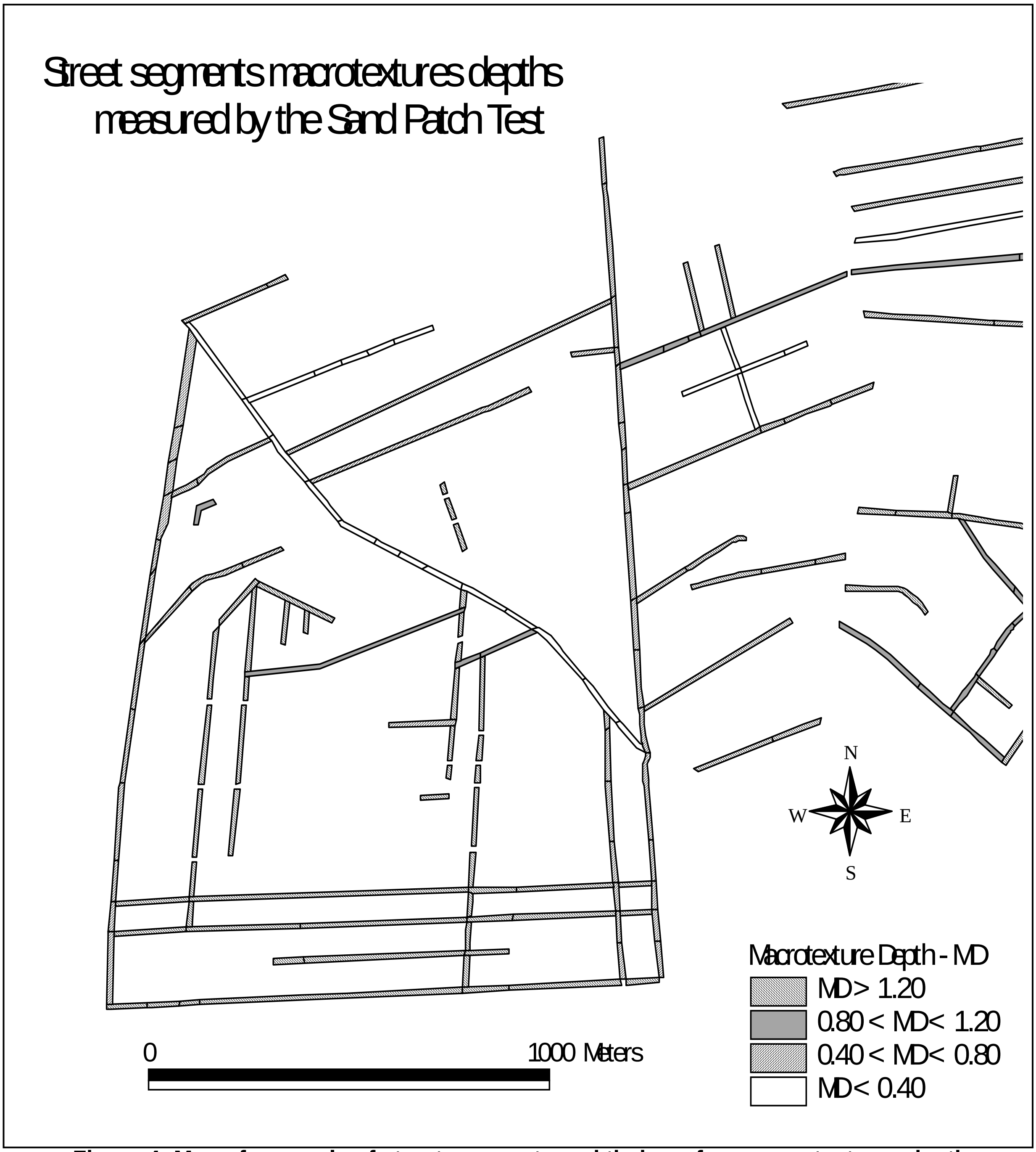

Figure 4: Map of a sample of street segments and their surface macrotextures depth

A sensitivity analysis involving the street functionality and macrotexture was made. The visualization of the streets segments which are in the two extreme situations, i.e. when an arterial street presents macrotexture depth inferior to 0.40 millimeters and when a local street presents a macrotexture superior to 1.20 millimeters, has been attained by means of two queries.

The first query is shown in Figure 5. As the arterial streets allow speeds greater than 60 Km/h and for these speed levels it is necessary have a macrotexture depth superior to 0.60 millimeters in order to comply with the safety standard conditions, these segments have to be spotted as potentially dangerous since their macrotexture depth is inferior to 0.40 millimeters.

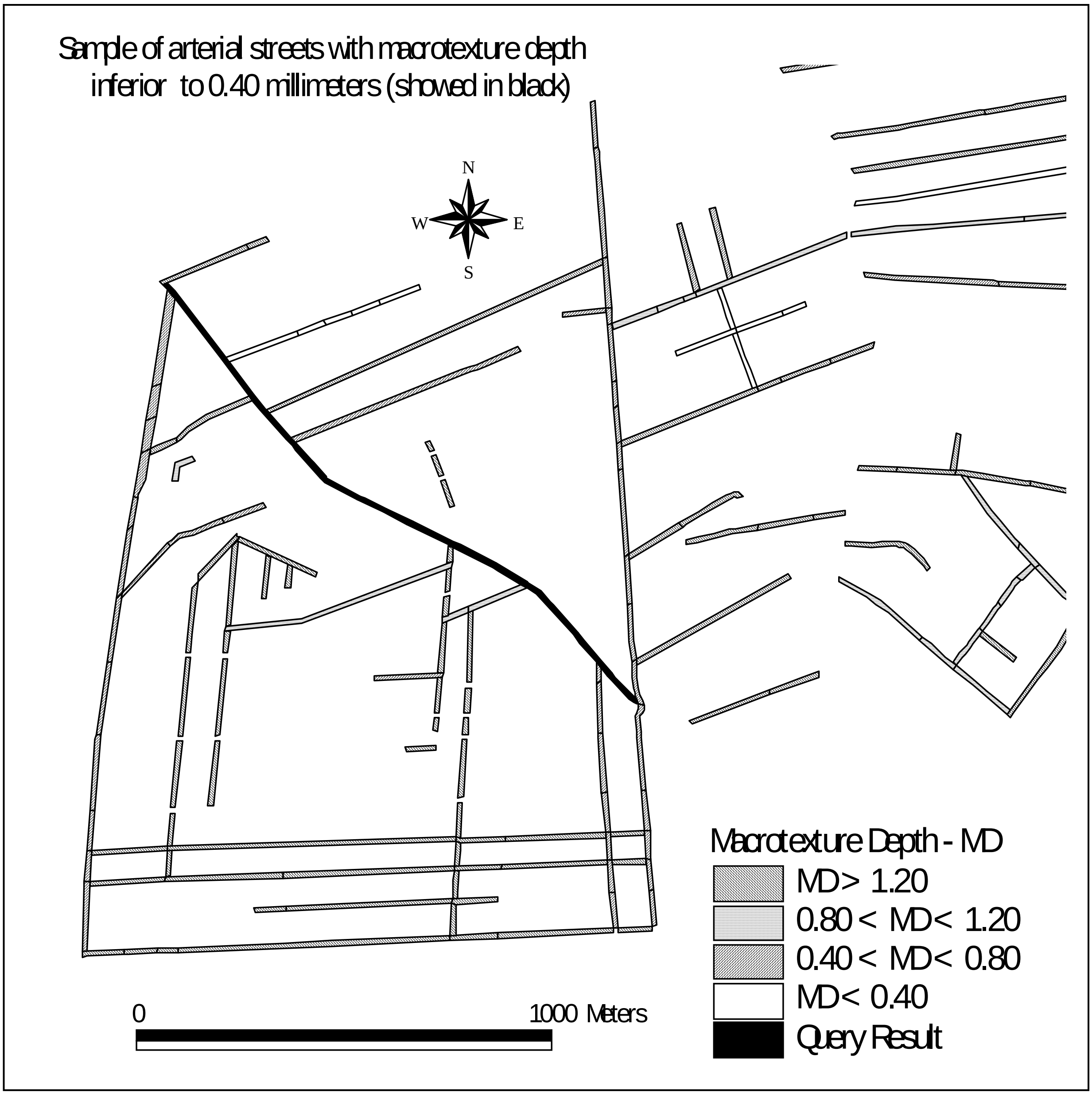

Figure 5: Query showing the arterial street segments (in black) with surface macrotexture inferior to 0.40 millimeters.

As seen in the map of Figure 5, there is a whole street selected in this query. Such street happens to be an important arterial street in the Santo Antônio Borough, with many segments presenting bad surface conditions (look at the surface conditions map in Figure 2 above). Therefore it is clear that this street is a strong candidate to receive a high priority rating for a maintenance intervention. In this case, apart from looking at the surface defects inventory it will be necessary to plan for increasing the surface macrotexture depth by means of a grooving operation or a skid resistant resurfacing.

If one is mainly interested in taking into account the street safety conditions, these two criteria (i.e. surface conditions and macrotexture) should receive a high weight in a multicriterial priority evaluation and rating. Such criteria should, thus, suffice. However, a compromise with others criteria should be sought in order to contemplate important issues such as vehicle operating costs and environmental impacts.

The second query is presented in Figure 6 where the street segments highlighted in black are the ones with a too open surface macrotexture (superior to 1.20 millimeters). Such segments, although not being dangerous, have surfaces exceedingly rough, are uncomfortable to vehicle riders, cause an increase in vehicle operating costs and become an important source of traffic noise.

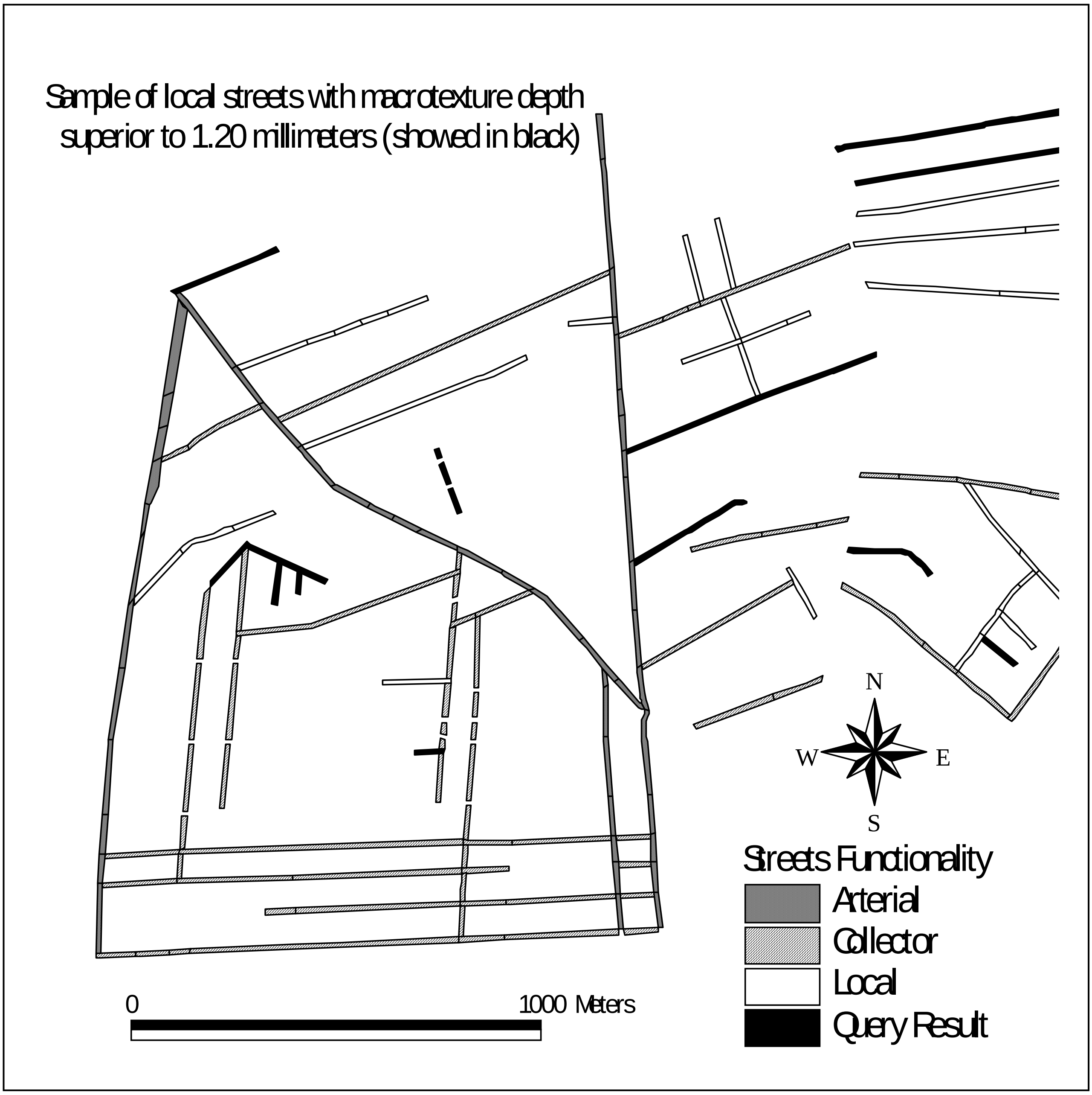

Figure 6: Query showing a sample of local street segments whose surfaces present a macrotexture depth superior to 1.20 millimeters (too rough).

Looking at the map of Figure 6, it is possible to spot many local street segments which are excessively rough for a street where the vehicle speeds should not exceed 30 Km/h. Here the main worry is with the increase in vehicle operating costs, tyre-rubber abrasion and noise levels. In terms of a plan for maintenance intervention, a proper resurfacing can solve both the problems of bad conditions and excessive roughness.

TAKING THE TOTAL TRAFFIC VOLUME INTO ACCOUNT

As said before, the surface conditions evaluation and rating approach here presented is fundamentally based upon the pavement surface functionality index, the surface macrotexture and the street functionality. However, one cannot disconsider the fact that the street segments which are subject to more intense traffic volumes will present a higher probability of experiencing a faster surface deterioration process than the ones subject to lower volumes. As the effects of traffic volumes vary according to the number of traffic lanes, the total traffic per lane should be considered.

Moreover, in urban streets the effects of the automobile traffic volumes on the street surfaces conditions cannot be ignored. Therefore, the total annual traffic per lane on the street segments (including automobiles) has been used as an extra criterion for further defining intervention priority. This is specially meaningful when two segments present similar structural and functional conditions but undergo very dissimilar traffic volumes and profiles. Therefore, the traffic volumes can be considered as a 'tie breaker' for rating street segments, whenever they present similar characteristics and surface conditions.

The Geographical Information System has been used to find out the the most critical street segment in the study area, considering also the expected deleterious effect of the total traffic volume per lane, on the segment surface condition. The GIS came out with the same critical segment showed in Figure 5, since it also supported a high total annual traffic volume per lane (3,475,000 vehicles/lane/year).

Although the consideration of the total traffic volumes per lane is a logical step, one cannot forget that each pavement has its own stage with regard to its life cycle. Despite the fact that two segments may present similar surface conditions, they can differ significantly with respect to the traffic pattern that each one will have to undergo in the coming years. The traffic volumes and their growth rate, as well as the percentage of heavy vehicles may have a decisive influence on the street surface condition degradation speed. This is specially important to the streets nerby commercial and industrial areas and thus subjected to significant heavy vehicles traffic. Such issues, however, are being investigated by the authors and no full conclusions on them have been reached, for the time being.

CONCLUSION

This paper has presented a street surface condition evaluation and rating approach to be used in a Geographical Information System environment. The simplified approach is based essentialy upon a surface condition index which is related to the pavement traffic functionality and does not take into account the pavement structural problems. The pavement surface condition is determined by a pavement functional index – PFI that has been defined so as to weight the surface defects with regard to the street segments lenghts and areas.

It has been shown that when the street surface conditions are maped, it is easy to visualize the segments with highest PFI, i.e. whose surfaces are in bad conditions. This same mapping procedure is useful for visualizing the other characteristics which are to be used as surface evaluation and rating criteria. In this paper maps of two of these characteristics namely the street functionality and macrotexture depth have been shown.

When such information are 'superimposed' to one another, say the information on the surface condition and macrotexture depth, by means of a query procedure, it is possible to identify the critical street segments regarding to suitable safety, economical and environmental standards. Other information such as the total traffic volumes on the street segments and percentages of heavy vehicles can be fast and easily manipulated, analysed and used as complementary rating criteria with a GIS.

It is recommended that further research steps be taken to better consider the information on the pavement s life cycle and the future traffic volumes which are expected on the street segments, with the purpose of establishing an appropriate maintenance priority rating.

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