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EVOLUTION STUDY OF THE PAVEMENT STRUCTURAL INDICATOR BASED ON EVENNESS AND DEFLECTION RESULTS USING A GIS TOOL MAPPING

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ABSTRACT: The pavement structural condition analysis is an essential parameter for evaluating the comfort, quality, durability, and preventing future road maintenance scenarios. It must be based on the analysis, collection, and abstraction of a road database related to inspections and studies performed. From this perspective, road monitoring network has always been a complex process. The present paper proposes a GIS approach for the visualization and the interpretation of different pavement structural deteriorations based on the analysis of the road inspection results using LACROIX Deflectograph and longitudinal profile analyzer measurements. The study location is at (439617, 099607; 358252, 3626787) to (478570, 08923; 364436, 6971297) covers a 50 km length of the Moroccan National Road number 06 connecting Meknes and Khemisset cities. The data is represented in four deterioration levels using a matrix fixed by the Moroccan method to classify the equi-quality sections, one hand, on the other, to quantify the pavement structural indicator (STI), to model them in the form of georeferenced thematic maps using a Geographic Information System (GIS) tool. The present study aims to establish a cartographic representation of the pavement structural indicator too making needs, optimization, and predict the maintenance costs.

Keywords: Road deterioration, GIS, Pavement Structural Indicator, Deflection, Evenness.

1. INTRODUCTION

The current and future needs for road data manipulation and geographic information applications are enormous. Road network management and its optimization are very difficult to manage with the usual sup support such as plans, maps, or photography. The road management system is based on the information system currently represented in the geographic database, also called spatial reference, and its form requires a diversified, adequate and thoughtful integration process. The present study does not seek to distinguish itself from the studies already carried out, but rather, to address another aspect of structural deterioration analysis modeling for the flexible pavements using computer tools in general and Geographic Information Systems (GIS) [1]. The results are represented in a thematic maps their importance comes from the fact that they allow to evaluate with great precision, comfort level, deterioration state, heir evolution.

Geographic information systems [1-2] are characterized by the exchange of spatial data and spatial information flow between the actors operating on a territory. These exchanges must face the process among all the infrastructural supports that intervene in a territorial development policy.

There exists a category that transcends all the others by its strategic character in contemporary development, which is the road infrastructures. This strategic character has been recognized at all times and in all places. Activities such as pavement condition assessment, maintenance, rehabilitation activities, and treatment prioritization are all components of pavement management [3-4].

Several methods can be applied to collect and measure the road pathology characteristics, including manual, automated, and semi-auto, and methods [5].

Selection and prioritization of maintenance actions, pavement condition prediction, and optimization of budget allocation are performed using structural performance indicators. The most common indicators in this regard are the International Roughness Index (IRI) [6], Pavement Serviceability Index (PSI), Structural Index (STI), Pavement Condition Index (PCI), Ride Comfort Index (RCI), and Distress Manifestation Index (DCI) [7].

Road inspections are required to quantify, measure and, evaluate the pavement structural indicators. These characteristics can be expressed in terms of the deterioration level.

Most research has focused exclusively on the extent and severity resulting from the road pathology distribution measurements.

In addition, it is possible to address issues such as the creation of indexed thematic models representing all structural distresses in all or a part of a pavement section's deterioration, maintenance problems, and safety problems. This paper is a preliminary attempt to propose a geographic information system (GIS) approach to the pavement structural index representation by a spatial model (deterioration level) at the project level. In this regard, the inspection results performed (deflection and evenness) between 2008 and 2018, textual data of deterioration matrix, topographic maps, and image processing approach will be used. The structural index level (STI) will be performed.

Many studies have been conducted on pavement management. The focus has been on structural performance indicators or distresses. Most studies are based on the use of traffic speed deflectometer (TSD) and falling weight deflectometer (FWD) measurements at the road network level [8]. In addition, the incorporation of pavement structural conditions into the decision matrix of the pavement management system was investigated [9]. A study proposal for the Geographic Information System (GIS) and PAVER integration was carried out to establish a permanent distress classification and maintenance priorities [10]. In another aspect, the structural indicator was used as an indicator of pavement capacity to determine the structure influence, traffic demand, and, climatic factors on the urban flexible pavement condition over time [11].

The new proposal for a GIS-enhanced pavement management system (PMS) is to enhance maintenance strategies and decision-making regarding pavement preservation [12].

The geographical distribution of deterioration levels and graphical representation were not considered. The expert system and HDM-4 software were used to prioritize urban road maintenance [13]. Using severity and extent measurements, a simple ranking method was developed to prioritize the maintenance of pavement distresses such as cracks, patches, and, roughness [14]. The pavement deterioration process at two airports based on PCI and IRI measurements was performed [15], and the effect of structural distress severity on pavement performance was studied. Several other studies have been conducted on pavement condition evaluation using performance indices or structural distresses. These studies have only examined the severity and extent of distresses, without considering the deflection distribution aboutness.

2. RESEARCH SIGNIFICANCE

The main objective of this work is to study the Geographic Information System (GIS) potential and establish a more flexible pavement distress classification for maintenance priorities. The classification process includes distress category and distress level through a matrix. Two different outputs are used to determine the Structural Indicator (STI), Deflection and Evenness. They are represented as four distress levels: A (good), B (fair), C (poor), and D (very poor). The system used data collected during inspections on the study road.

The ArcGIS software is used to display, analyze the data, validate the model and perform a planar representation of structural distresses under the georeferenced topographic maps. Pavement distresses are assigned based on calculated pavement structural condition index (PCI) values.

This technique has proven to be cost-effective and appropriate for sound decision-making for various maintenance activities and programs. The study developed structural condition analyses that can provide a maintenance scenario for the entire pavement or specific sections based on the inspection results. The potential of this procedure is demonstrated by bypassing the ability to develop scenarios, which allows the development of maintenance programs for this road network. The data is represented in a Geographic Information System (GIS) and is processed by Python scripts [16].

3. MOROCCAN CONTEXT:

As in all countries in the world, investing in the Moroccan road network maintenance requires a considerable sum [1]. As soon as they are brought into service, the pavements are subject to more or less rapid evolution. They deteriorate under the traffic effect and climatic conditions. In order to manage this important heritage, estimated at 150 billion dirhams, it is essential to determine the evolution and behavior of pavement structures to an optimal maintenance strategy for the road network. Considering the strategic importance of their mission and its constant urgency, road network managers can certainly not afford the luxury of waiting a decade to have an answer to their concern.

The Moroccan context [17] is characterized by the use of somewhat diversified pavement maintenance techniques, based on untreated gravel or treated with hydrocarbon binders in the base course and surface dressings or bituminous mixes in the wearing course. Cement concrete pavements are still underdeveloped. To a large extent, the method used is based on the normal aging and one Moroccan pavement scale [17], the principle of which consists in replacing the factor of time or loading duration with pavement age factors.

The basic assumption of this cross-sectional approach is as follows: "sections with the same residual structure, the same traffic, the same supporting soil, and the same climate must have the same characteristics over time". Thus, by considering each type of structure family, sections having the same parameters: traffic, soil, and climate but different ages. It is possible to draw curves representative of the pavement deterioration evolution as a function of time, simply by measuring the deterioration of all the sections in the same year.

Despite these operations, the pavement has suffered structural damage [18], which is mainly reflected in deformations related to pavement comfort and evenness, which implies the managerial mandate to improve the durability and safety criteria that are increasingly difficult to meet.

Good knowledge of the pavement components behavior, as well as the road databases processing, are essential to fulfill this mandate. This paper is organized as follows, an analysis of the studied section, the methodological presentation and the materials used, the road data reduction related to the deflection [19] and evenness results obtained [18-22], and the thematic maps presentation of the structural indicators from the year 2008 to 2018 and finally some conclusions and directions for future work.

3.1 Study context:

With more than 26,000 km in length [2], Morocco has one of the largest road networks in Africa, including highways, and national, provincial, and regional roads. This network is heavily used, especially with heavy vehicles, which is one of the main factors governing road maintenance operations. This policy aims, on the one hand, to provide users with a satisfactory level of comfort and safety, in particular through the satisfactory maintenance of road facilities, signage and safety equipment, and, on the other hand, to ensure the road network's preservation (pavements, bridges, tunnels and retaining walls). All these parameters are taken into account by the Moroccan National Center for Road Studies and Research, which is the main public body in charge of monitoring roads, applying control techniques and defining preventive actions for problems, directly and indirectly, affecting road rigidity and quality.

3.1.1 Case of study

With a length of 10255 km, the Moroccan National Roads represent 38.90% of the total Moroccan road network. Despite maintenance interventions, road managers have not always had the means to diagnose their networks. Therefore, it is useful to assess the pavement condition, especially for flexible pavements [20] which constitute 90% of the Moroccan road network.

The pavement structure damage [6] is mainly expressed by deterioration in the form of cracks and rutting. In this respect, we propose in this article an in-depth analysis of the structural deterioration evolution on the section most solicited by the traffic belonging to the national road number 06, connecting Khemisset and Meknes cities.

This section has experienced a strong increase in traffic and several maintenance interventions carried out by the Moroccan Roads Directorate under the Ministry of Equipment, Transport, and Logistics [17]. The following table presents the study section location in (X, Y) coordinates, depending on the kilometer points of departure and arrival:

Table 1 location of study section

Kilometer point (KP)	Coordinates	
	X	Y
KP-origin	439617,099607	358252,3626787
KP-fin	478570,08923	364436,6971297

The roadway link is permanently open (24 / 24) to traffic on all sides of the roadway and provides for the traffic's comfort and safety. The pavement and paved shoulders are conditioned by their service levels as shown in the following table

Table 2 Moroccan roads safety conditions

Deteriorations	Maximum cumulative extent tolerated
Obstacles on the road of any nature	prohibited
Penetration testing	600 ml
Crackling pavement	Prohibited
Settlement amplitude >5cm	Prohibited
Repping-off (Spalling, peeling, and potholes)	Prohibited

The traffic increase and the aging of the wearing course have led the Moroccan Road Directorate to plan periodic maintenance works which generally correspond to pavement strengthening, resurfacing, and reprofiling.

3.1.2 Study section history

Since 2008, the pavement reinforcements carried out to date on the study area generally consist of laying an untreated gravel structure 15 to 30 cm thick on the existing pavement, generally topped with a two-layer surface dressing, and applying an asphalt structure 8 to 12 cm thick or an asphalt gravel structure topped with an asphalt mix. The shoulders are treated with selected materials of the same thickness. Reprofiling consists of applying a 3 to 5 cm thick asphalt layer or a 4 to 6 cm thick emulsion gravel layer on the degraded parts, or a generalized wearing course of surface dressings.

4. MATERIALS AND METHOD

The proposed method is based on the road inspection results carried out in this section from 2008 to 2018, reducing the data according to their deterioration level through the matrix developed by the Moroccan National Center for Road Studies and Research [1]. This operation allows to facilitate the pavement structural indicator (STI) reading on the one hand and to prepare the input data necessary for the modeling using GIS software on the other hand.

4.1 Road Inspection Network in Morocco:

The National Center for Road Studies and Research is the organization that monitors the structural condition of Moroccan roads using the Lacroix reflectography for pavement bearing capacity measurement and the longitudinal profile analyzer (APL) for the longitudinal evenness evaluation [22]. The road network inspection is the major component of a road maintenance schedule.

It provides essential information to determine the deterioration types, their location, and remedies to be considered.

4.2 Structural Indicators Condition (STI)

The structural indicators condition reflects the road's bearing capacity. It includes both deflection and evenness.

4.2.1 Deflection

The deflection indicates the bearing capacity and pavement stiffness. It is a decision’s criteria for reinforcement thickness choice and pavement quality evaluation. This test is carried out by the Benkelman bead with a comparator by the requirements of standard NF P 98 200-2.

It consists in measuring at a given point on the roadway the deflection caused by a rolling load by taking the value of deflection indicated on the comparator [19].

The measurements are performed under a load of 13 tons using a Lacroix Deflectograph machine (Fig.1) according to the LCPC n39 test methods and the NFP 98.200.1 to 98.200.7 standards. Lacroix Deflectograph stresses the structure in such a way that it generates a greater amplitude of deflection that varies more slowly. This loading mode is compatible with an inductive sensor measuring the displacement at V100 mm. The deflection measurements provided by Lacroix are used as a basis for an evaluation of the load-bearing capacity of the tested structure and thus the verification of pavement structural condition.

Fig.1 Lacroix Deflectograph measurement

The Deflectrograph characteristics used, are shown in the following table:

Table 3 Deflectograph characteristics

Characteristics	Lacroix Deflectograph
Load application method	Rolling load
Speed of load application	10 km/h (5Hz)
Performance (routine measurements)	2 to 3 Km/h (Classic Lacroix)
the measuring step	4 to 6 m (Lacroix Flash)
Resolution of the measuring sensor	1/100 mm
Location of measurements	Wheel track Left and right
Deflection basin measurement	Real basin for flexible pavements /65 points
Loading level applied for a measurement	Single (50 KN or 65 KN - axle 10 t or 13 t)
Type of superstructures inspected	Flexible pavements [9]

4.2.2 Evenness

Longitudinal Profile Analyzer system [7-8] allows the longitudinal evenness measurement of road pavements, aeronautical runways, and more generally, of any lane that can be travelled by motor vehicles regardless of its pavement structure and its hardness. The measurement is based on the pavement longitudinal profile measurements. Then, a mathematical model is used to calculate the IRI (International Roughness Index). The APL operation (Fig.2) is independent of carrying out and operating profile measurements using the APL
Are defined in LCPC test method No [23].

Fig .2 Longitudinal Profile Analyzer

4.3 Moroccan Method

The Moroccan National Center for Road Studies and Research has developed an experimental matrix series [17] to facilitate road inspection data reading. The evenness method, and the traffic class (T) it is determined from the following table.

Table 4 Evenness repartition matrix

International Roughness Indicator IRI: mm/Km				
	T0	T1	T2	T3-T4
A	<2000	<2300	<3000	<3200
B	[2000, 2500[	[2300, 2800[	[3000, 3500[	[3200, 3700[
C	[2500,300 00[	[2800,33 00[	[3500,4000[	[3700,42 00[
D	>=3000	>=3300	>=4000	>=4200

The deflection class is determined from the deflection value and the traffic class, according to the following table:

Table 5 Deflection repartition matrix

Deflection in 1/100 mm				
Class	T0	T1	T2	T3-T4
A	<80	<100	<120	<140
B	[80,120[	[100,140[	[120,160[	[140,180[
C	>=120	>=140	>=160	>=180

The cracking and deflection indicators are determined from the following matrix:

Table 6 Cracking and Deflection matrix

Cracking and Deflection	Deflection class		
Class of cracks	A	B	C
A	A	B	C
B	B	B	C
C	B	C	C
D	B	C	D

Finally, the STI is determined according to the matrix below:

Table 7 STI matrix

STI	Evenness class			
Cracks class	A	B	C	D
A	A	B	B	C
B	B	B	B	C
C	B	C	C	D
D	C	C	D	D

The observations are integrated trought the total scores attributed to each distress (evenness and deflection) on a section of 1 km. These indicators characterize 1 km of road and can be assigned four condition values: A (good), B (acceptable), C (poor), and D (very poor).

4.3.1 Data reduction

To reduce the road data inspection related to the deflection and evenness results, firstly, the study section was divided into 1 km sections, secondly, the deterioration matrices mentioned in the previous tables were applied to deduce the structural indicators in each subset (STI).

4.4 GIS approach

A spatial database was prepared, including the pavement surface index based on the matrix presented in Table 8. The transformation of the obtained qualitative variables into other quantitative values became essential for the import of the collected data stored in a spreadsheet on ArcGIS software (Table 9). Since collected data concern pathologies located along the road, the georeferencing was performed with geographic locations using relative positions along a linear feature measured from a linear datum measured from a defined starting point. Fifty linear reference points were recorded in all databases so that the structural index could be mapped, and the data could be analyzed more easily. With this integration, ArcGIS improves data integration and access, accuracy, minimizes redundancy in the databases, and allows visualization of the four deterioration levels: A, B, C, and D.

Table 8 Variables presentation

Structural indicators classes	Reading in ArcGIS
A	1
B	2
C	3
D	4

Table 9 GIS Data inputs

Km point		Structural Indicators/year					
Origin-Fin		STI 2008	STI 2010	STI 2012	STI 2014	STI 2016	STI 2018
80	81	1	1	1	2	2	2
81	82	1	1	1	2	2	2
82	83	1	1	1	1	1	1
83	84	1	1	1	1	1	1
84	85	1	1	1	2	2	1
85	86	1	1	1	1	1	1
86	87	1	1	1	1	2	2
87	88	1	1	1	1	1	1
88	89	1	1	1	1	1	2
89	90	1	1	1	1	1	1
90	91	1	1	1	1	1	1
91	92	1	1	1	1	1	1
92	93	1	1	1	1	1	1
93	94	1	1	1	1	1	1
94	95	1	1	1	1	1	1
95	96	1	1	1	1	1	2
96	97	1	1	1	1	1	1
97	98	1	1	1	1	1	1
98	99	1	1	1	2	2	2
99	100	1	1	1	2	1	1
100	101	1	2	1	1	1	2
101	102	1	2	1	1	1	1
102	103	1	2	1	2	2	2
103	104	1	1	1	2	2	2
104	105	1	1	1	1	2	1
105	106	1	1	1	1	1	2
106	107	1	2	1	1	1	2
107	108	1	3	1	1	2	1
108	109	1	3	1	1	1	1
109	110	1	1	1	1	1	1
110	111	1	1	1	2	2	1
111	112	1	2	1	2	2	2
112	113	2	2	2	2	2	2
113	114	2	2	2	2	2	2
114	115	2	2	2	2	2	2
115	116	2	2	2	2	2	2
116	117	1	2	2	2	2	2
117	118	2	2	2	2	2	2
118	119	2	2	2	2	2	2
119	120	2	2	2	2	2	2
120	121	2	2	2	2	2	2
121	122	2	2	2	2	2	2
122	123	1	2	2	2	2	2
123	124	2	2	2	2	2	2
124	125	2	1	1	1	2	2
125	126	2	1	1	2	2	2
126	127	2	1	1	1	1	1
127	128	2	1	1	2	2	2
128	129	2	1	2	2	2	2
129	130	2	2	2	2	2	2

4.5 Research methodology

The modelling process follows several steps which are summarized in the figure below:

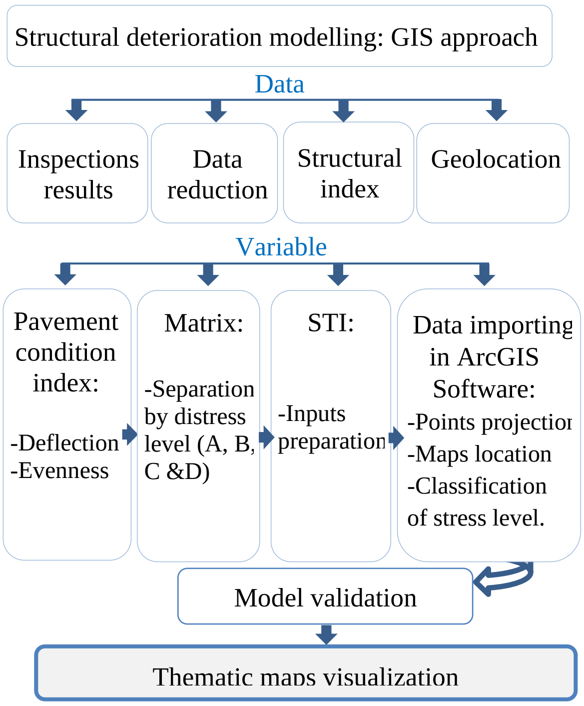


Fig.3 Research methodology

The map geolocation was based on the junction of two area maps relating to Meknes and Khemisset cities, to create an initial database for this road link.

4.5.1 Points Projection

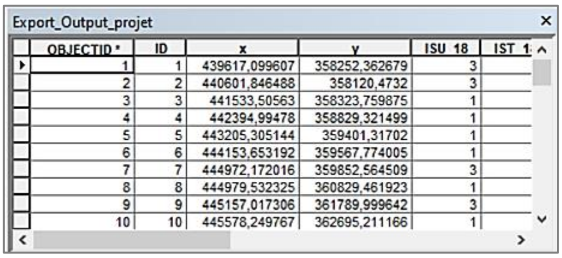
The point's projection in coordinates (X, Y) is essential to represent the road axis projection. It was subdivided into two steps: the import of the prepared road database, and the cartographic projection.

4.5.2 Classification of Deteriorations levels

The classification by level of deterioration opted on the ArcGIS software as follows:

- Making the buffer (Fig.4) [22]: the road being linear, we propose a buffer of 200 m to simplify the analysis;
- Data export (Fig.5) and classification of the deterioration levels.

Fig.4 Making Buffer



Export_Output_projet

OBJECTID *	ID	x	y	ISU 18	IST 1
1	1	439617,099607	358252,362679	3	
2	2	440601,846488	358120,4732	3	
3	3	441533,50563	358323,759875	1	
4	4	442394,99478	358829,321499	1	
5	5	443205,305144	359401,31702	1	
6	6	444153,653192	359567,774005	1	
7	7	444972,172016	359852,564509	3	
8	8	444979,532325	360829,461923	1	
9	9	445157,017306	361789,999642	3	
10	10	445578,249767	362695,211166	1	

Fig.5 Data export

4.5.3 GIS model validation

The proposed model verification is performed by Kringing before compiling the model. In geostatistics, Kringing is a linear estimation method that guarantees the minimum variance.

Kringing performs the spatial interpolation of a regionalized variable by the mathematical expectation calculating of a random variable, using the interpretation and modeling of the experimental variogram. It is the best non-bias linear estimator.

It takes into consideration not only the distance between the data and the estimation point but also the distances between the two data. Once the Kringing has been verified and validated, the GIS model process is represented as follows:

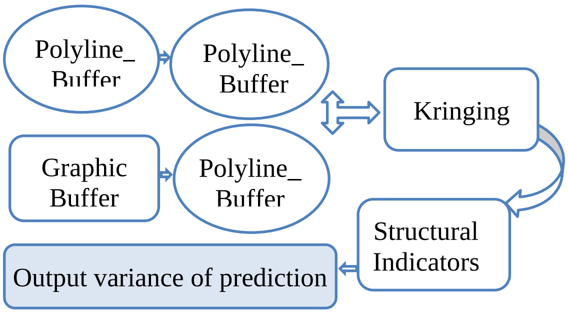


Fig 6. GIS Model process

5. RESULTS AND DISCUSSION

The results of the present mapping modeling related to structural indicators (STI) are represented in the following figures:

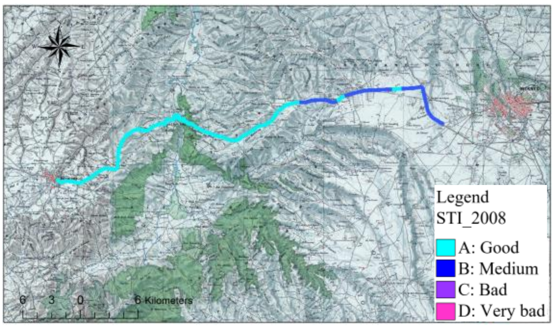


Fig.7 STI map in 2008

Fig.8 STI map in 2010

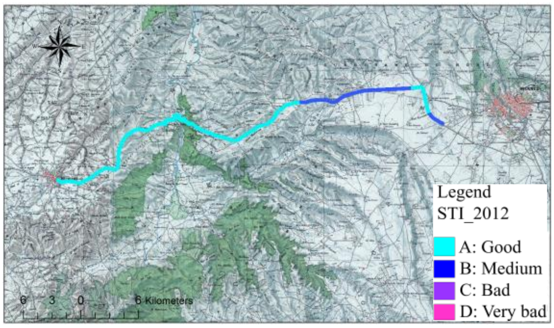


Fig.9 STI map in 2012

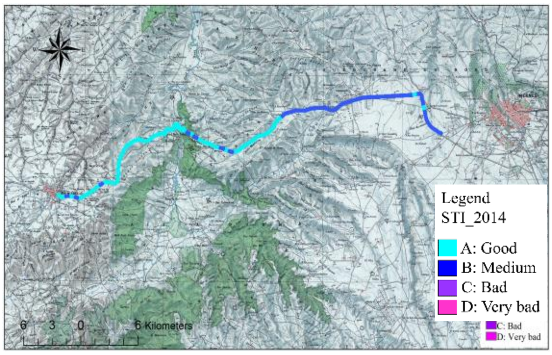


Fig.10 STI map in 2014

Fig.11 STI map in 2016

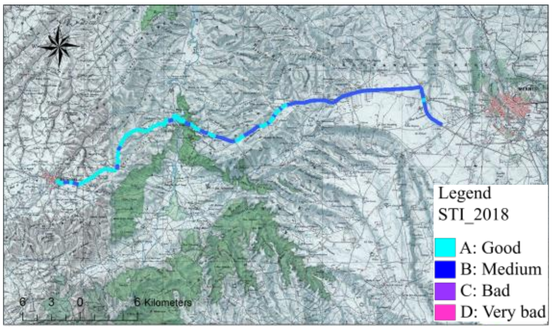


Fig.12 STI map in 2018

Once combining deflection and evenness results, and considering that the degraded condition percentage (A+B %) is the most dominant, the structural condition is considered good, this does not allow to emphasize that it has experienced some variability. The structural indicator of showed the comfort and bearing capacity instability from 2008 to 2018. Several elements are responsible for this variability, such as the traffic has experienced a strong increase, increases in the last five years due to the increase in the vehicle number, the decrease in comfort level (Evenness), and the presence of the deflection fluctuations results.

With a gravel layer overlaid with asphalt surfacing, it was reported that in 2008, this 50 km long section is divided into sub-assemblies in advanced fatigue level C condition, which did not allow for enhancing the maintenance work carried out, including tears, level C and D cracks that have disturbed the structural condition indicator stability between kilometer point 113 and 130. On the other hand, the comfort level on this link was well marked through the reflectography and evenness results, which represent structural indicators in average to a good condition reflecting the percentage variability of A+B along the studied kilometers.

Concerning the National Road 06 situation, the inspections were carried out with the administration's presence on a monthly and annual basis. Since 1999, this roadway has undergone several repair interventions aimed at protecting users and ensuring a level of comfort and quality on this roadway that has always been in great demand due to the traffic importance and its interesting geographical location. These interventions will include all measures taken by the company. These interventions will include all measures taken by the contractor to ensure the desired level of service through reprofiling, localized resurfacing of shoulders, vegetation control, and drainage structures maintenance, as well as the waste management implementation and pavement deterioration repair to maintain the service desired level.

The project will include drainage structure maintenance, as well as pavement deterioration repair to keep the service level desired, including spot overlays, spot staining, crack sealing, and trimming for pavement body repair. All of these parameters are designed to ensure the roadway's viability as it is open to two-way traffic 24 hours a day. Traffic has increased significantly after this date, from 4521 AADT to 5999 AADT calculated in 2012, and to 6883 AADT in 2014. This increasing variability has undoubtedly influenced the predefined safety and sustainability calculations, noting the decrease in the structural indicator between 2008 and a poor condition in 2014. As regards the year 2016, the traffic increased by 6.5%, and despite the repair interventions that the pavement has experienced, we note a decrease in the level of comfort and regularity in 2018.

6. CONCLUSION AND PERSPECTIVES

The following conclusions can be drawn from this work:

1) The spatial nature of transportation data makes GIS a logical choice on which to base systems such as the ArcGIS tool. GIS has proven to be an effective tool for integrating, managing, storing, displaying, mapping, querying, and spatially analyzing roadway data.

2) Thematic maps should be considered as a decision support tool. These systems are not intended to replace experimental judgments, but rather to assist in making cost-effective and efficient decisions.

3) In this work, 50 sections were selected on the Moroccan National Road number 06 and all condition changes are due to different causes such as weathering, aging, and estimated traffic load.

4) Future developments including other elements of the maintenance management system should be considered. The completion of the entire road database with all kinds of surveys recorded all deterioration, construction, maintenance, and upkeep.

5) There is a great need for a medium-term commitment to pavement conservation and protection by pavement managers, the public, and

road users.

In this project, it was shown that one of the main advantages of an integrated pavement management system is its flexibility to visualize data in thematic maps. To visualize macroscopically the level of pavement structural condition, the capability of this tool will allow managers to easily read the data, and compare them in a non-conflicting manner, so that it will be used to assist agencies in the process of allocating funds and justifying their budget requests, for pavement maintenance and reconstruction.

This objective is achieved by implementing the graphical capabilities of GIS to manage data and generate thematic maps.

As perspectives, a predictive analysis of future scenarios for this pavement is proposed, to predict the future thematic map. For this purpose, we prepare the same perspective on the following research elements:

- Structural indicator evolution prediction;
- Modelling of the probable future maps;
- Variation of surface deteriorations and their impacts on the pavement's structural condition, based on the analysis of the environmental inspections carried out;
- Integration of the results obtained in the pavement management system (PMS).

7. ACKNOWLEDGMENTENT

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