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Application of the HDM-4 model on local road network: case study of the Herzegovina-Neretva Canton in Bosnia and Herzegovina

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Abstract

The World Bank Highway Development and Management (HDM-4) tool has been used extensively for the management of road networks, particularly in developing countries. The paper describes the application of HDM-4 model for local roads in Bosnia and Herzegovina (BiH), in the Herzegovina-Neretva Canton (HNC). The HDM-4 study was performed with the aim to define road works program and investment priorities by analyzing impacts of different budgets on future network condition.
The 396 km-long HNC road network consists of 13 roads that are either graveled or paved. A large part of these roads do not have sufficient pavement width. This road network is in relatively poor condition due to its age (the average age is over 30 years) and limited spending on maintenance in the past. Only a small percentage of the network has been reconstructed in recent years. The Average Annual Daily Traffic (AADT) has a wide range, and varies from 27 to 12735 vpd. The major challenge in the study was to obtain HDM-4 input data with limited resources, since usually this task requires extensive investigations. In addition to inventory data, it is necessary to define the condition of the road network, traffic volume, traffic data, etc. Road geometry data were obtained from previous studies and project documentations. The IRI data were taken from the earlier surveys or estimated where no data were available. Other parameters were obtained by field tests. Traffic data were available from regular network traffic counts.
After analyzing the parameters, the network was divided into 65 homogeneous sections, based on the AADT and road condition (IRI and other parameters) classes. HDM-4 program analysis was performed for a period of 30 years. Due to very low traffic

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loading and relatively large investment needed for improvement, for majority of sections a negative NPV and IRR were obtained for maintenance alternatives other than routine maintenance, and for significant number of sections they were on the verge. Out of 65 homogeneous sections, only 29 sections proved cost-effective (NPV/CAP ratio is positive).
The implementation of developed road work programs would result in a substantial improvement of the overall network condition. The IRI of paved road network would change from current value of 4.5 m/km to 4.0 m/km and 3.7 m/km for budget levels of 2.0 and 3.0 mill. BAM after five years. The better road network condition would also result in improved traffic safety, social and economic impacts, since many of these roads are crucial links in the HNC.

Keywords: Low Volume road network; road maintenance program; HDM-4; local roads; Herzegovina-Neretva Canton

1. Introduction

The Herzegovina-Neretva Canton (HNC) is located in south-east part of Bosnia and Herzegovina (Figure 1) and covers the area of about 4,400 km^2, with population of about 236,000 inhabitants, according to the 2013 census. The largest city in the canton and the fifth largest city in the country is Mostar. Other notable cities in this canton are Čapljina, Stolac, Neum, Konjic, and Međugorje, the most significant Marian shrine in the region [Hercegovina--Neretva Canton, 2015a].

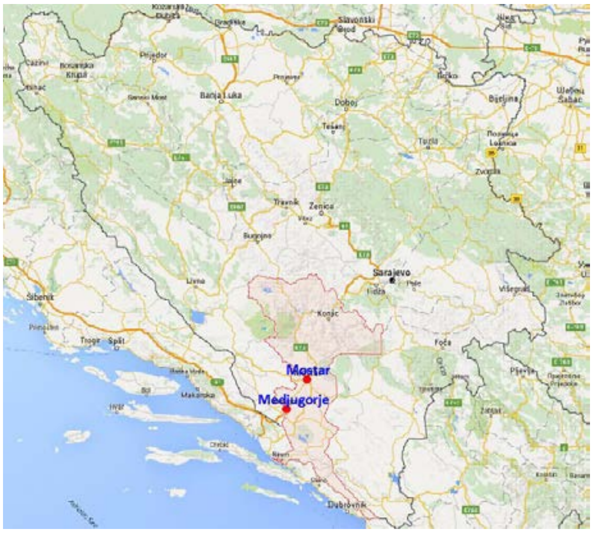

Fig. 1. The Herzegovina-Neretva Canton in Bosnia and Herzegovina [Hercegovina-Neretva Canton, 2015b].

The county is responsible for maintenance of 393 km long network which consists of 13 regional roads. Traffic volumes and quality of the roads are widely ranging. The available resources for the maintenance and rehabilitation of the network are extremely limited and therefore it is important to ensure their optimal use.

The aim of the study was primarily to define a list of priority works and work programs to help policy makers to assess the consequences of different budget levels on road network condition. One of the programs that are most often used for this analysis, particularly in developing countries like Bosnia and Herzegovina, is the HDM model.

The paper presents summary of road network, vehicle fleet and traffic data, the approach used in the study and the outcome of the analysis.

2. Data collection and interpretation for use in HDM-4

For the analysis using the HDM-4 model it is necessary to collect a large number of input data such as inventory and current condition of the network data, vehicle characteristics and traffic loading, climatic conditions, etc. The initial step was to use data from the existing Database for roads, bridges and tunnels for which the field survey was carried out as part of the "Road rehabilitation" project financed by the World Bank [Spernol, 2005]. The initial road network survey was performed in 2004 using an ARAN vehicle in order to obtain the best possible information of the geometry, the cadaster and road conditions. The distress types that have been identified and recorded are the longitudinal and transverse cracks, fatigue cracking, potholes and patches, rutting, raveling, bleeding, edge break, and surface deformations. In addition, International Roughness Index (IRI), as one of the most important parameters, was also measured. The raw IRI data were stored in 200m long sections.

2.1. Road network inventory data

Approximately two thirds of the HNC road network (Figure 2) has been built in the 1970s and 1980s and since then the most part of the network has been just routinely maintained (Figure 3). Only about 20 percent (77 km) of the network has been rehabilitated since 2000. Consequently, the overall road network condition is relatively poor. About 315 km of roads are asphalted and the rest of them are gravel roads. The year of construction/rehabilitation is only available for asphalt paved roads.

Fig. 2. The HNC road network.

Almost half of the road sections are relatively narrow, with the width below 5 m, as presented in Figure 4a.

2.2. Traffic data

Traffic data are taken from the study “Traffic volume on the network of regional roads of the Herzegovina--Neretva Canton” [Lovrić, 2013]. At the canton level traffic counting is performed annually in three ways; continuous automatic counting (stationary counters), occasional automatic counting (portable counters) and manual counting.

The Average Annual Daily Traffic (AADT) on the HNC road network in 2012 ranged between 27 and 12735 vpd. Figure 4b presents the distribution of network by traffic level.

More than 76 percent of network had AADT below 1000 vpd, and more than 17 percent had very low AADT below 100 vpd. However, there were two sections leading to Medjugorje, with very high traffic levels, above 10000 vpd.

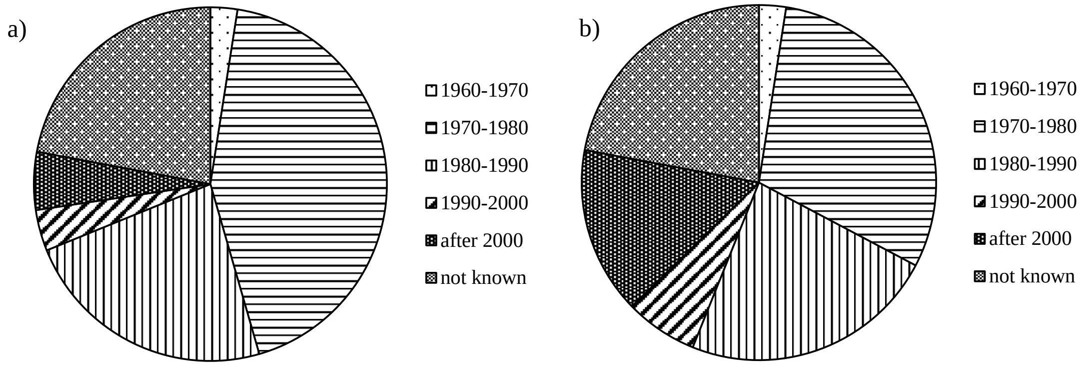

Fig. 3. The HNC road network split by (a) year of initial construction; (b) year of last major pavement works.

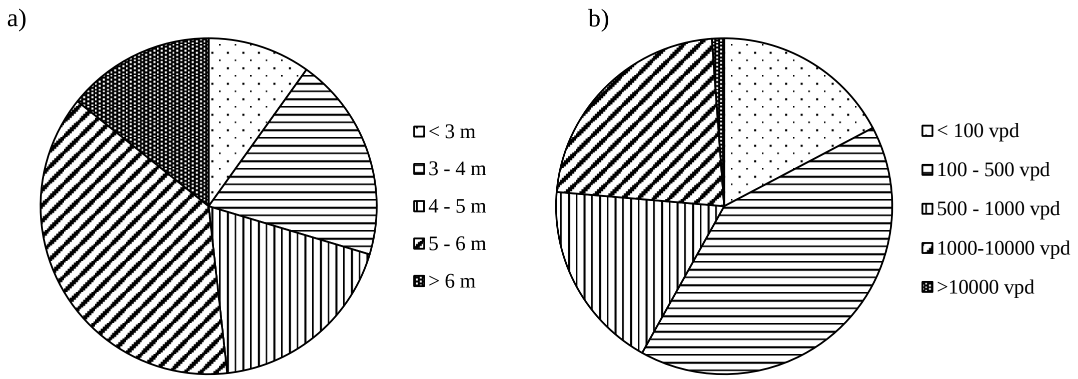

Fig. 4. The HNC road network split by (a) road width; (b) AADT.

Based on the traffic in the past years and the overall condition of economy in the country, the increase of traffic of 2% per year was assumed for traffic projection for the current study.

2.3. Geometry data

The characteristics of individual sections are defined by the most important parameters of road horizontal alignment and vertical profile, like the average horizontal curvature, vertical slopes, etc., and elements of the cross section, like pavement and shoulder width and number of lanes, design speed, etc. Data were obtained from road database, project documentation and field measurements.

Generally, this type of road network should have a design speed of 60 km/h. However, on the HNC road network this is not the case and the speed is mostly in the range between 40 and 50 km/h. The reason is poor geometry and also country development level that does not allow for proper reconstruction. Only few sections of roads R419 and R424 have operative speed above 60 km/h.

2.4. Assessment of pavement structure

For evaluation of the pavement structure, historical data were taken from the existing database and they were complemented with extensive field measurements. The data included identification of pavement type, layer thickness, the layer coefficients, structural number, and CBR of subbase and subgrade. The parameters were determined on homogeneous segments (subsections of roughly equal parameters).

Generally, pavement structures (that have not been reconstructed) are flexible, and consist of a compacted unbound aggregate layer, that is typically 25–30 cm thick, and an asphalt layer, 4–6 cm thick. Since these roads are built 30–40 years ago, the asphalt is severely aged, brittle and fractured with a substantial amount of edge break and fatigue and block cracking, primarily as a result of insufficient pavement width, ageing and loading (Figure 5).

Fig. 5. Asphalt roads built 30–40 years ago.

In order to be able to determine the thickness and condition of the layers, samples of pavement structures were extracted. The Dynamic Cone Penetration Test was performed to calculate CBR of subbase and subgrade. The subbase and subgrade are mostly in excellent condition, with sufficient bearing capacity.

Fig. 6. The pavement structure of roads built 30–40 years ago.

Roughness (IRI) data are taken from databases, and the missing data were estimated. Data taken from the databases are increased for the past period (from completion of the database to preparation of this study) based on the roughness progression model used in the HDM-4 (Figure 7). The estimated average IRI on the paved road network is 4.49 m/km.

Condition survey was performed in order to determine cracking, damaged edges, potholes and patches, textures, rutting, shoving, polished aggregate, raveling and bitumen bleeding.

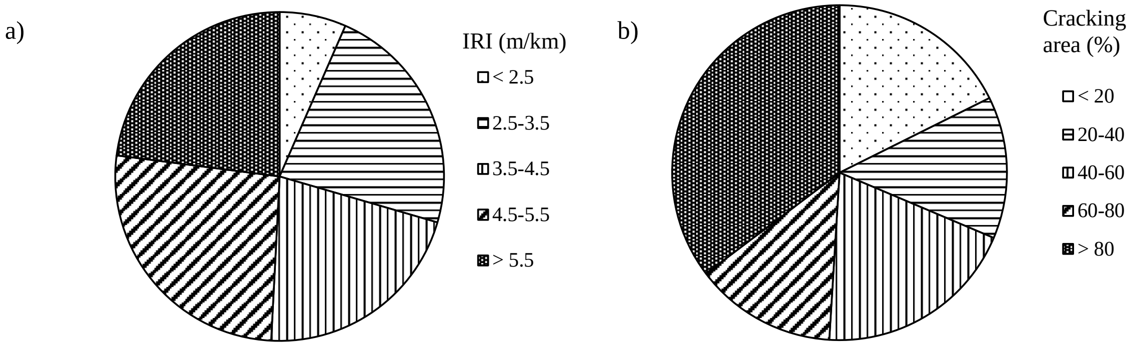

Fig. 7. The HNC paved road network split by a) IRI (m/km) and b) Cracking Area (%).

Other parameters are obtained by field surveys. Table 1 presents the summary of the current road condition data on section Citluk – Canton border.

Table 1. An example of a field condition survey – section Citluk – Canton border.

Chainage of homogenous section (km)	Len. (km)	Asph. width (m)	Distress (m^2) Cracking < 3 mm Lin.[1]	Fatigue[2]	Block[3]	Cracking > 3 mm Lin.[1]	Fatigue[2]	Block[3]	Edge Crack.	Poth.[4]	Macro-texture (mm)	Micro-texture[5]	Rutt.[6] (mm)	Total Crack. (%)
0+000-6+900	6.90	5.0					29325		1710				5	90
6+900-8+670	1.77	6.6	53	230							0.6	good	2	2
8+670-9+160	0.49	5.0					2450		185	6			4	100
9+160-10+100	0.94	6.0	45	110					20		0.9	good	1	3
10+100-10+600	0.50	5.0					5640		200	3			5	100
10+600-13+300	2.70	6.0	210	2430							0.8	good	2	16
13+300-14+000	0.70	6.0					4200		430	4			6	100
14+000-19+600	5.60	6.0	3450	8400		1650	260		380		0.6	good	4	42
19+600-23+000	3.40	6.0	2300	4080		1460	3060		630		0.6	good	6	57
23+000-27+100	7.10	6.0	4250	8520		2350	4120		915		0.7	good	4	47

* Note: - CBR of Subgrade = 100%; CBR of Subbase = 80%.
- Necessary works: Reconstruction 10 cm + 25 cm and asphalt widening from 5 to 6 m on subsections: 0+000 - 6+900; 8+670 - 9+160; 10+100 - 10+500.

Legend: [1]Damaged area = crack length × 0.5 m;
[2]Area about 0.3 × 0.3 m.
[3]Area about 3 × 3 m.
[4]Number of potholes, area about 0.1 m^2.
[5]Condition: good, medium or poor.
[6]Mean rut depth in both wheelpaths.

2.5. Homogeneous sections

Since there is a large diversity of individual sections of regional roads (traffic loading, geometry, pavement condition, etc.), it is necessary to define homogeneous sections (similar traffic load and approximately equal other characteristics) of each regional road. There are 23 sections of the regional network in the Herzegovina-Neretva Canton. The section length ranges between 1.91 km and 39.90 km.

As can be seen in the foregoing, there is a great difference between sections. The biggest difference is in the condition of paved sections and the traffic loading (range 53-12375 vpd).

The main criteria used to define homogeneous sections were:

- Traffic loading
- Geometry (speed, horizontal and vertical geometry and road width)
- Pavement type (layer thickness) and age
- Condition (IRI, cracks, rut depth, texture, etc.)

According to these criteria, 65 homogenous sections were defined on the network of regional roads in HNC.

3. Defining maintenance strategies in the HDM-4 model

The maintenance/improvement treatments were defined depending on the AADT and the average section roughness (IRI). At this stage, cracking was not considered, given the state and age of paved sections and asphalt layers. The improvement treatments were planned as measures that would bring the road into a good condition, with appropriate width, which was necessary given the importance of the road and AADT. This applies mainly to paving and widening of road profile of unpaved roads. The summary of maintenance and improvement treatments is presented in Table 2.

Table 2. Work strategies and network improving for the HNC road network.

Work strategies	**AADT (vpd)**	**Initiation**	**Type of Work**
Maintenance treatments			
Routine maintenance of paved roads	All	Annual	Repairing edges, patching potholes, etc.
Maintenance of gravel road	<200	for IRI 8–16 m/km	Maintenance – regraveling
Resurfacing			
a) with layer of AC 4 cm	200–1000	for IRI= 3.5–5.5 m/km	resurfacing
b) with layer of AC 5 cm	1000–3000	for IRI= 3.0–5.0 m/km	resurfacing
c) with layer of AC 5 cm	>3000	for IRI= 2.5–4.5 m/km	resurfacing
Reconstruction			
a) Small (Asphalt 5 cm, Subbase 20 cm)	200–1000	for IRI= 5.5–8.0 m/km	reconstruction
b) Medium (Asphalt 4+6 cm, Subbase 20 cm)	1000–3000	for IRI= 5.0–8.0 m/km	reconstruction
c) Large (Asphalt 4+11cm, Subbase 20 cm)	>3000	for IRI= 4.5–8.0 m/km	reconstruction
Improving treatments			
Paving of gravel roads	≥200	AADT reaches 200 vpd	Asphalt 6 cm, Subbase 25 cm
Widening of the asphalt roads from 3 m to 6 m	≥1000	AADT reaches 1000 vpd	Asphalt 6 cm, Subbase 25 cm
Widening of the asphalt roads from 5 m to 6 m	≥1000	AADT reaches 1000 vpd	Asphalt 6 cm, Subbase 25 cm

The analysis used the “cost-benefit” method, which is based on a comparison of the economic costs of the intervention and the economic benefits expected in the exploitation.

A discount rate of 10% was adopted and the economic indicators, like net present value (NPV) and internal rate of return (IRR) were calculated. An important indicator of the economic feasibility of the intervention is the ratio of NPV and investment. The analysis was made for several return periods and will be discussed in more detail below.

The intervention costs that were used in the analysis are based on the market prices of individual works. Reconstructions involve the rebuilding of the complete pavement structure. Sections that require widening of the roadway also require additional works, such as digging, drainage, etc. Therefore, the costs for widening are given as estimates per km of section.

Table 3. Unit costs of road works.

Road type	Work type	Work strategies	Unit	Unit costs*
Paved (asphalt) roads	Patching potholes	Routine maintenance	m^2	35 KM/m^2
	Repairing edge breaks		m^2	25 KM/m^2
	Other works		km	200 KM/km
	AC overlay 4 cm	Resurfacing	m^2	12 KM/m^2
	AC overlay 5 cm		m^2	15 KM/m^2
	Asphalt 5 cm, Subbase 20 cm	Reconstruction	m^2	22 KM/m^2
	Asphalt 4+6 cm, Subbase 20 cm		m^2	38.5 KM/m^2
	Asphalt 4+11cm, Subbase 20 cm		m^2	56.38 KM/m^2
	Asphalt 6 cm, Subbase 20 cm	Improving treatments	km	225 000 KM/km
	Widening of the asphalt roads from 3 m to 6 m		km	400 000 KM/km
	Widening of the asphalt roads from 5 m to 6 m		km	300 000 KM/km
Unpaved (gravel) roads	Regraveling 15 cm	Routine maintenance	m^3	25 KM/m^3

Note: * 1 Euro = 1.955 KM

4. Defining the priorities of road works at the network level

The main parameter for assessing the cost-effectiveness is the ratio of NPV/CAP (net present value/investment), which is favorable for longer analysis periods. Analyses for shorter periods (15 and 20 years) were giving a very small number of sections with cost-effective treatments other than the base alternative that includes routine maintenance only, due to relatively low traffic level on most of the sections. For a period of 15 years, out of 65 homogeneous sections of the road network, for only 23 sections the alternative that involved maintenance and improvement treatments was feasible. The corresponding number of sections for longer period of 20 years was 27. Therefore, it was decided to extend the analysis period of 30 years.

In the first phase, the analysis was performed for Unconstrained budget, to estimate the total needs at the road network. The total value of the needed road works amounts to 21.16 mill. KM (10.82 mill. Euro), out of which 20.63 mill. KM (10.55 mill. Euro) are needed immediately, in the first year of analysis.

Programs for a limited budget (Constrained budget) were defined for the annual allocations of 2 and 3 million KM, which is within the budgetary possibilities of the relevant HNC Ministry. The sections/treatments are ranked according to the cost-effectiveness (NPV/CAP) for each year of the analyzed period. Out of 65 analyzed homogeneous sections, only 29 sections for paving works and 6 gravel sections proved profitable. In the first two years the road works program is mainly concentrated on paved sections and includes asphalt resurfacing, while in later years it covers bot paved and unpaved sections and corresponding improvement treatments. Routine maintenance was assumed to be performed on the entire network annually. Sections that are not included in the program typically have low traffic level resulting in negative NPV. The total length of sections included in the program is 69.2 km and 96.5 km for annual budgets of 2 mill. KM and 3 mill. KM respectively.

The average roughness on the paved road network would improve from current 4.5 m/km to 3.95 m/km for annual budget of 2 mill. KM and to 3.65 m/km for annual budget of 3 mill. KM (Figure 9).

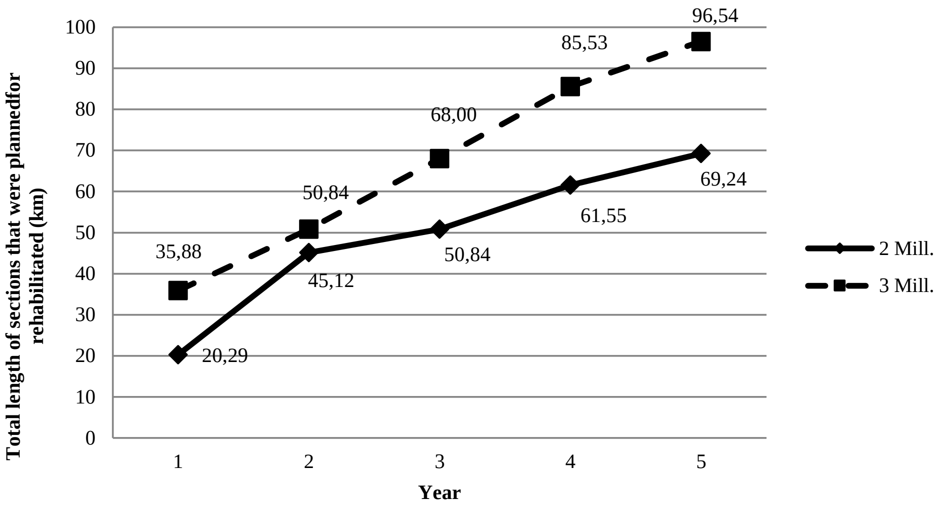

Fig. 8. The percentage of network length (121.15 km) for investments 2 and 3 million KM annually (%).

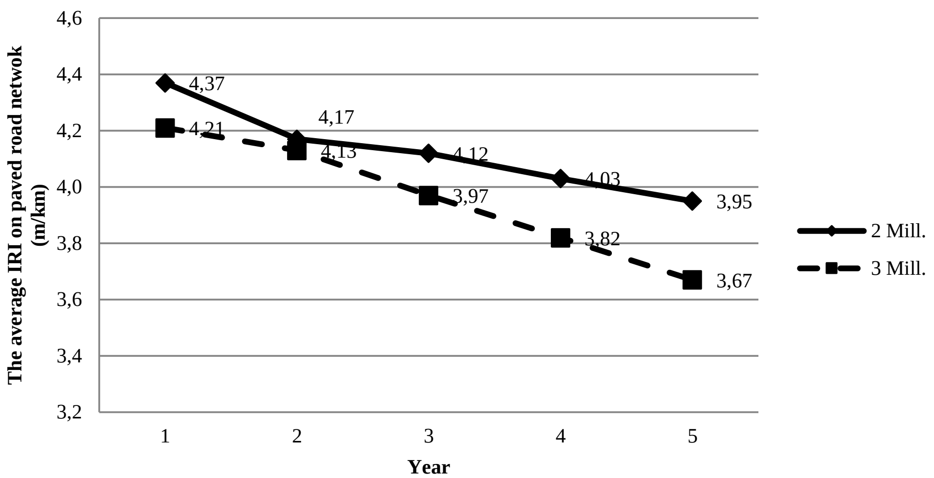

Fig. 9. The anticipated improvement in IRI (m/km) for different budget levels.

5. Conclusion

The paper presented the application of the HDM-4 model for the local road network in the Herzegovina-Neretva Canton (HNC) in Bosnia and Herzegovina. The objective of the study was primarily to define a list of priority works and work programs to help policy makers to assess the consequences of different budget levels on road network condition.

The traffic levels on the network range widely, from less than 100 vpd to more than 12000 vpd. In addition, most of road sections were built more than 30 years ago, do not have the appropriate width and are currently in very poor condition with the average IRI on the HNC road network being 4.49 m/km (for paved roads).

The study defined road works program for two realistic budget levels of 2 and 3 million KM (approximately 1 and 1.5 million Euros, respectively). The program includes works on 29 out of 65 homogeneous sections. However, due to the very low traffic loading and relatively large investment needed for improvement, for majority of sections a negative NPV and IRR were obtained for maintenance alternatives other than routine maintenance, and for significant number of sections they were on the verge.

The Study showed the overall paved road condition would be improved substantially if systematic approach to the network maintenance, presented in the study, is realized.

This type of study would help local road agencies to manage their road networks and define road works priorities, in particular in developing countries, and in condition of very limited budget constraints, like in the case with most of local communities in the countries in south-east Europe.

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