KENYA ROADS BOARD
MINISTRY OF TRANSPORT AND INFRASTRUCTURE
AfCAP Africa Community Access Partnership
INTERNATIONAL CONFERENCE ON TRANSPORT AND ROAD RESEARCH
16TH-18TH MARCH 2016 | WHITESANDS HOTEL, MOMBASA, KENYA

ASPHALTIC CONCRETE PAVEMENT DESIGN INCORPORATING LIFE CYCLE ANALYSIS – CASE STUDY OF BENIN

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ABSTRACT

Most road pavement design methods currently in use do not give opportunity to undertake critical evaluation of life cycle of the performance of the newly design road pavement. In the absence of this assessment, it is always assumed that existing road agency's maintenance management systems will have the capacity to meet the maintenance requirements. The setting of road maintenance policies used in the road maintenance management systems are also not informed by the respective road pavement designs. In some instances, a general rule is used to establish the maintenance policy, say, all asphaltic concrete roads are due for overlay at 10 years interval. The challenge is that current practice in road pavement design and the maintenance are not coterminous. This paper presents an objective methodology using Mechanistic-Empirical (M-E) pavement design approach and HDM-4 life cycle modelling to address these problems using Benin as a case study. The case study has given a practical demonstration of how to select and calibrate the M-E design tool appropriate for Benin condition. Estimation of the Residual Life of the existing road pavements to determine the investment options (rehabilitation, reconstruction, upgrading, etc.) and the selection of appropriate pavement designs were achieved. The selected investment options were optimised by economic analysis with the HDM-4 which was also used to carry out Life Cycle Analysis of the optimised pavement design to establish the maintenance regime. Finally, the financial outlay during the design lives of the respective optimum pavement designs was established.

Keywords; Mechanistic-Empirical design, HDM-4, Life-Cycle Analysis, Road Maintenance, Kenlayer

1.0. INTRODUCTION

As part of preparation of Benin's application for Second Compact under the Millennium Challenge Account (MCA), selection and justification of the project roads were required to be technically demonstrated. The Millennium Challenge Corporation (MCC) required the following of the project roads;

- A 20-year design life will be adopted;
- Incorporation of parts of the existing pavement layers;
- Carry out a deflection survey at selected locations to determine residual life for 20-year projection;
- Propose optimised pavement design options for various road sections;
- Demonstrations of several rehabilitation/reconstruction options identified for each road project the selection of the most economically effective solution; and
- Recommendation of a maintenance strategy for the completed road for each project alternative, covering routine and periodic, including cost estimates and implementation.

2.0. OBJECTIVE

Koranteng-Yorke, Ghataora and Odoki (2014) have developed a rational approach for tropical pavement design using life cycle principles. The objective of this paper is to demonstrate the practicality of the approach and how it has been applied to achieving all expected deliverables under the Benin Case Study.

3.0. METHODOLOGY

In order to address MCC's requirements, the following methodology was adopted;

1. Selection of a design approach and field validation of the underlying principles.

2. Examination of the design tools and selection of most appropriate tool that addresses Benin situation and with the capacity to design different types of pavements based on local data.
3. Calibration of the design tool based on field deflection information.
4. Estimation of projected traffic and establishing the residual life of existing pavement to inform the type of intervention.
5. Production of pavement designs using local materials.
6. Calibration of the HDM-4 model for Benin environment.
7. Selection of optimum pavement design via HDM-4 economic analysis.
8. Carry out life cycle cost analysis for respective optimum pavement designs using HDM-4.
9. Selecting of a maintenance regime over the design life which gives a minimum overall transport cost.
10. Financial assessment of optimum pavement over the design life for planning and budgeting.

4.0. PAVEMENT DESIGN

Lister et al (1982) established that in situation where, traffic volume is exceeding 10 million equivalent standard axle loads (ESALs), using empirical design method is inaccurate. Most of the roads used under this case study have their projected traffic loads exceeding 10 million ESALs. Table 1 shows the 12 project roads. From the table, only four have projected traffic below 10 million ESALs. Therefore Mechanistic-Empirical (M-E) Design approach was adopted because of its capacity to design for uncontrolled traffic situation.

Table 1: Design Loads for the various roads

Code	Description	Estimated 20-Year Load (ESALs)	Average per Year (ESALs)[1]
1.1	Sèmè–Porto-Novo	95,683,594	4,784,180
3.1	Porto-Novo-Ouando	48,387,082	2,419,354
3.2	Ouando–Carrefour Zian	23,760,311	1,188,016
4.1	Porto-Novo-Avrankou	15,833,775	791,689
4.2	Avrankou–Igolo	16,347,347	817,367
8.1	Bohicon–Dassa	82,527,034	4,126,352
9.3	Savalou-Okoutaossé	30,073,314	1,503,666
14.6A	Misséssinto–Zinvié	8,923,963	446,198
14.6B	Zinvié–Sèdjè Dénou	1,850,507	92,525
15	Tori Bossito–Abomey Calavi	4,783,350	239,168
22	Adja Ouèrè–Massè–Ciment. – RN4	914,962	45,748
29	Ansèkè–Ouessè-Kilibo	4,380,803	219,040

The M-E design approach addresses three main empirical pavement design challenges as follows;

1. It takes into account the impact of environmental conditions on characteristics and properties of the pavement layer materials.

2. It allows for the use of design variables relevant to the local conditions under which the road pavement will be trafficked and avoids the mechanical application of default values; and

3. It removes the restrictions on unitary pavement designs and enables the production of a catalogue of candidate pavements, which allows economic comparison and the selection of most economic pavement design, before construction.

4.1. Validation of M-E Design Theory

The M-E design principle is based on the elastic response theory. This has been validated by Koranteng-Yorke (2012) from a research work carried out in Ghana which has the same environmental and climatic condition as Benin. Once the theory

[1] This is predicted load repetitions required by the Kenlayer to predict pavement life from damage analysis.

is validated, predictions of stresses and strains could be performed for any flexible-pavement design during any period of the year.

The elastic theory shows that the asphaltic concrete layer undergoes plastic deformation. The theoretical elastic response is shown below as Figure 1.

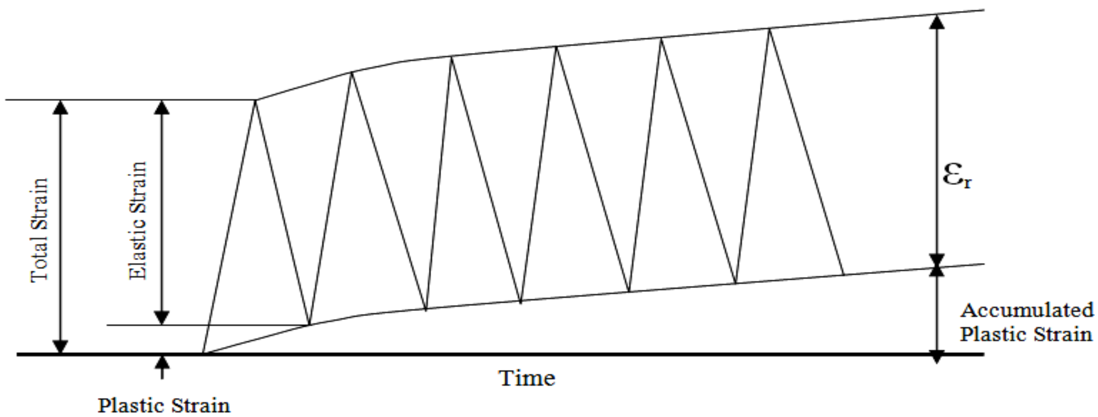

Figure 1 – Elastic Response Theory

The theory was validated in the field using FWD equipment. Figure 2 gives the actual elastic behaviour of the asphaltic concrete layer.

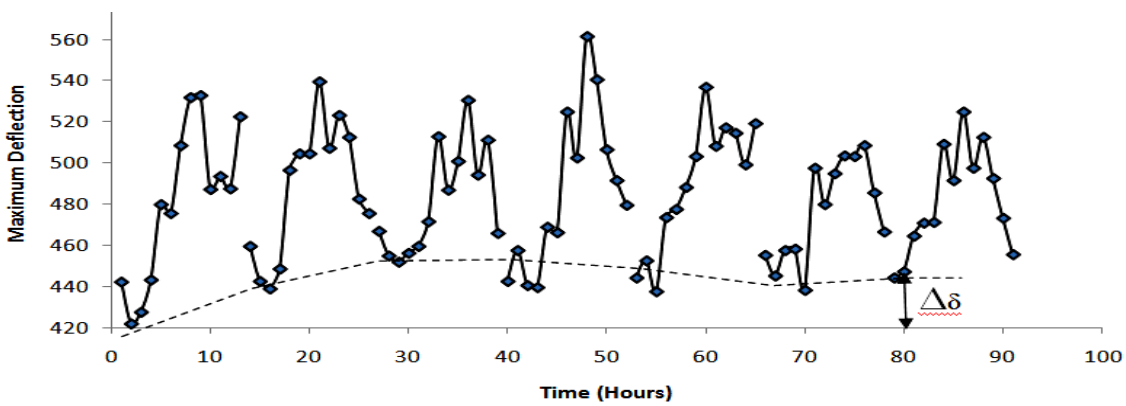

Figure 2 – Field Elastic Behaviour

4.2. Selection of M-E Design Tools

Three M-E design tools were evaluated with the objective of establishing which tool is most appropriate and with the capacity to simulate Benin local traffic loading conditions and also to meet MCC's requirements. The following M-E packages were evaluated; Alize-LCPC[2], WinJulea and KENLAYER.

The capabilities and limitations of the tools have been summarized in Table 2. Considering the design requirements by MCC, Kenlayer was found to be most suitable.

Table 2: Summary of Results from the Evaluation of M-E Design Tools

Design Requirement	**Kenlayer**	**Alize LCPC**	**WINJulea**
Calibration of tool	√	×	×
Estimation of in-place responses to reference loads	√	√	√
Allowance for different material characterization	√	×	×
Establishing critical stresses and strains and their points in pavement layers	√	√	×
Establishing residual life and modelling future performance from only existing pavement properties	√	×	×
Modelling of new pavements with projected traffic	√	√	×
Conformance to French Design Method	√	√	×
Readily available pavement catalogue to select from	×	√	×
√ - *Applicable* × - *Not Applicable*			

4.3. Kenlayer M-E Design

4.3.1. Selection of Pavement Properties

From the field geotechnical investigation, the structure of the existing pavements and the nature of the materials were established. The existing materials are;

- Asphaltic Concrete Surfacing (AC)
- Double Surface Dressing (DSD)
- Cement Stabilised Laterite (CSL)

[2] Laboratoire Central des Ponts & Chaussées (LCPC)

- Laterite Subbase (SB)
- Subgrade (SG)

The following materials were also to be considered as per MCCs recommendation;

- Dense Bitumen Macadam (DBM)
- Bituminous Foam Mix (BFM)
- Graded Crushed Stones (GCS)

Due to the similar nature of Benin's climatic and environmental conditions to Ghana, Nigeria and other countries in West Africa, where information were not available for a selected pavement material, typical values found in works done within countries in the sub-region were considered. Table 3 below shows the structure of the existing pavements.

Table 3: Characteristics of Existing Pavements

Road Name	No.	Layer No.	Existing Pavement Material	Thickness (cm)	Material Characterization
Sèmè–Pont de Porto-Novo	1.1	1	AC	5	Viscoelastic
		2	CSL	20	Linear
		3	SB	25	Nonlinear
		4	SG	-	Linear
Porto-Novo-Ouando	3.1	1	AC	4	Viscoelastic
		2	CSL	25	Linear
		3	SB	20	Nonlinear
		4	SG	-	Linear
Ouando–Carrefour de Zian	3.2	1	AC	5	Viscoelastic
		2	CSL	20	Linear
		3	DSD	3	Linear
		4	SG	-	Linear
Porto-Novo-Avrankou	4.1	1	AC	4	Viscoelastic
		2	CSL	15	Linear
		3	SB	20	Nonlinear
		4	SG	-	Linear
Avrankou–Igolo	4.2	1	AC	4	Viscoelastic
		2	CSL	22	Linear
		3	SB	20	Nonlinear
		4	SG	-	Linear
Bohicon–Dassa	8.1	1	AC	7	Viscoelastic
		2	CSL	20	Linear
		3	DSD	3	Linear

Road Name	No.	Layer No.	Existing Pavement Material	Thickness (cm)	Material Characterization
		4	SG	-	Linear
Savalou-Okoutaossé	9.3	1	DSD	2.8	Viscoelastic
		2	CSL	20	Linear
		3	SB	25	Nonlinear
		4	SG	-	Linear

Table 4 shows the various selected pavement materials and their properties considered for the proposed pavement design.

Table 4: Properties of pavement materials

Material		Elastic Modulus MR (Kpa)	Poisson Ratio PR	Unit Weight (kN/m3)	Material Characterization	Reference
Asphaltic Concrete	AC	2,589,500	0.35	22.8	Viscoelastic	FWD Data*
Double Surface Dressing	DSD	N.A.	-	-	-	-
Cement Stabilized Laterite	CSL	565,000	0.2	21.2	Linear	Samb et al (2013)
Subgrade	SG	varies	0.45	19.6	Linear	Geotechnical Report
Subbase	SB	453,000	0.35	21.2	Nonlinear	FWD Data*
Dense Bitumen Macadam	DBM	2,589,500	0.35	22.8	Viscoelastic	FWD Data*
Selected Fill	FILL	190,500	0.35	21.2	Nonlinear	FWD Data*
Graded Crushed Stone	GCS	856,000	0.35	21.2	Nonlinear	FWD Data*
Stabilized with Bituminous Foam	BFM	2,450,000	0.35	22.8	Linear	Marquis et al (2003)

All input parameters required by the Kenlayer have been discussed in detail by Huang (2004) and Koranteng-Yorke (2012) and have selected typical values for tropical soils.

4.3.2. Calibration of Kenlayer

In order to ensure that results obtained from the Kenlayer are reliable, calibration of the Kenlayer was undertaken. Table 5 gives the results of the calibration.

Table 5: Summary of results from calibration

Road	Measured Deflection - Benkelman Beam (cm)	Estimated Surface Deflection - Kenlayer (cm)	Design Resilient Modulus (kPa)	Platform depth (cm)
1.1	0.043	0.04301	58,412	50.00
3.1	0.055	0.05505	40,728	49.00
3.2	0.060	0.06083	49,383	28.00
4.1	0.058	0.05800	46,163	39.00
4.2	0.053	0.05302	45,504	46.00
8.1	0.064	0.06400	44,839	30.00
9.3	0.089	0.08901	21,363	47.80

4.3.3. Estimation of Residual Life of Existing Road Pavements

After establishing the resilient moduli of the subgrade layers, the residual life of the existing pavements were assessed to inform the type and level of intervention required to meet the design objectives. Table 6 gives information on the residual life of the road pavements.

Table 6: Residual lives of existing pavements

<table>
<tr><th>Road</th><th>Layer No.</th><th>Existing Pavement Material</th><th>Thickness (cm)</th><th>Estimated 20-Year Load (CSA)</th><th>Allowable Traffic Load[3] (million CSA)</th><th>Residual Life[4]</th></tr>
<tr><td rowspan="3">1.1</td><td>1</td><td>AC</td><td>5</td><td rowspan="3">95.684</td><td rowspan="3">13.04</td><td rowspan="3">2.73</td></tr>
<tr><td>2</td><td>CSL</td><td>20</td></tr>
<tr><td>3</td><td>SB</td><td>25</td></tr>
<tr><td rowspan="3">3.1</td><td>1</td><td>AC</td><td>4</td><td rowspan="3">48.387</td><td rowspan="3">4.495</td><td rowspan="3">1.86</td></tr>
<tr><td>2</td><td>CSL</td><td>25</td></tr>
<tr><td>3</td><td>SB</td><td>20</td></tr>
<tr><td>3.2</td><td>1</td><td>AC</td><td>5</td><td>23.760</td><td>1.825</td><td>1.54</td></tr>
</table>

[3] The allowable load repetitions is the maximum number of standard axle load passes that the pavement can take before it yields or fail.
[4] This is the number of years remaining for the pavement to yield or fail considering the 20 year projected traffic for the various roads.

Road	Layer No.	Existing Pavement Material	Thickness (cm)	Estimated 20-Year Load (CSA)	Allowable Traffic Load[3] (million CSA)	Residual Life[4]
	2	CSL	20			
	3	DSD	3			
4.1	1	AC	4	15.834	2.169	2.74
	2	CSL	15			
	3	SB	20			
4.2	1	AC	4	16.347	4.361	5.34
	2	CSL	22			
	3	SB	20			
8.1	1	AC	7	82.527	1.675	0.41
	2	CSL	20			
	3	DSD	3			
9.3	1	DSD	2.8	30.073	0.793	0.53
	2	CSL	20			
	3	SB	25			

4.3.4. Design of Pavements for Reconstruction Option

The selection of pavement thickness was guided by consideration of the traffic load, materials of pavement layers and modulus of subgrade. For each road, 2 pavement options for reconstruction were considered based on the type of base material.

The following limits, as recommended by Austroads Guide to Pavement Technology (2014), were set as a guide to practical design of pavement structures;

1. The asphaltic concrete wearing course shall not be less than 40mm.
2. All base layers shall not be less than 100mm.
3. The lateritic gravel subbase layer shall not be less than 200mm.
4. Capping layers shall not be less than 400mm.

The summary of results after the Kenlayer runs are given in Table 7.

Table 7: Reconstruction Options for Existing Bituminous Roads

Road Name (Code)	Layer No.	Option 1			Option 2		
		Layers	Thickness (cm)	Design Life (Years)	Layers	Thickness (cm)	Design Life (Years)
Seme-Port Novo (1.1)	1	AC	5	22	AC	5	22
	2	GCS	20		BFM	20	
	3	CSL	20		CSL	15	
	4	SB	30		SB	28	
Port Novo Pont-Ouando (3.1)	1	AC	4	22	AC	4	23
	2	GCS	23		BFM	20	
	3	CSL	20		CSL	15	
	4	SB	30		SB	30	
Ouando – Zian Carrefour (3.2)	1	AC	4	23	AC	4	22
	2	GCS	15		BFM	12	
	3	CSL	15		CSL	15	
	4	SB	30		SB	30	
Porto Novo – Avrankou (4.1)	1	AC	4	22	AC	4	23
	2	GCS	12		BFM	12	
	3	CSL	15		CSL	13	
	4	SB	30		SB	30	
Avrankou -Igolo (4.2)	1	AC	4	23	AC	4	21
	2	GCS	13		BFM	12	
	3	CSL	15		CSL	13	
	4	SB	30		SB	30	
Bohicon – Dassa (8.1)	1	AC	5	22	AC	5	21
	2	GCS	26		BFM	18	
	3	CSL	20		CSL	20	
	4	SB	30		SB	30	
Savalou - Okutaosse (9.3)	1	AC	5	22	AC	5	23
	2	GCS	28		BFM	20	
	3	CSL	23		CSL	22	
	4	SB	30		SB	30	

5.0. ECONOMIC EVALUATION OF PAVEMENTS

5.1. Calibration of HDM-4 for Benin Condition

One of the basic requirement in the use of the HDM-4 is the configuration and calibration of the tool to simulate local conditions and to improve on the reliability of its output.

Configuration of HDM-4 model is basically restructuring of the default values in line with local conditions, standards and practices. The primary objective of configuration is to make the analysis from the model relevant and compatible to the particular environment it is being used. Configuration focused on the climate, traffic categories, among others.

5.1.1. Climate Data

Benin's Direction Nationale de la Meteorologie (DNM) has given climate data for the respective climatic zone over the last 30 years. This has been used to compute averages for climate parameters required for the HDM-4.

The following four climate zones was used to configure the HDM-4:

- Sub-Equatorial Zone average 1200 mm per annum (Zone 1)
- Sudaneese–SudZone average of 1200per annum (Zone 2a)
- Sudaneese –Nord Zone average of 900 per annum (Zone 2b)
- Atacorien average of 1300mm per annum (Zone 3)

Climatic data required for Benin are as summarised in Table 8.

Table 8: Representative Average Zonal Climatic Attributes

Name	Description	Moisture Classification	Temperature Classification	Number of Days when Temperature Exceeds 32ºC	Average Temperature Range (ºC)	Freeze Index	Moisture Index	Mean Monthly Precipitation	Mean Temperature	Duration of Dry Season(month)	Percentage of Driving on Snow Covered Roads	Percentage of Driving Done on Water Covered Roads
Zone 1	Sub-Equatorial Zone average 1200 mm per annum	Sub humid	Tropical	179	8.66	0	12	98.07	27.93	6	0	50%
Zone 2a	Sudaneese – Sud Zone average of 1200 per annum	Sub humid	Tropical	225	12.79	0	3.2	98.40	27.46	6	0	50%
Zone 2b	Sudaneese – Nord Zone average of 900 per annum	Sub humid	Tropical	270	12.45	0	-11.5	83.48	28.28	6	0	50%
Zone 3	Atacorien average of 1300mm per annum	Sub humid	Tropical	241	11.42	0	3.9	100.10	27.45	5	0	58%

5.1.2. Traffic Categories

The traffic classes used to set the threshold High, Medium and Low traffic for the various functional classes (RNIE, RN and RC) and AADT in Benin are given in Tables 9 and 10 respectively.

Table 9: Traffic Categories for the Functional Classes

Traffic Category	**Code**	**RNIE Roads**	**RN Roads**	**RC Roads**
High Traffic	H	PL>750	PL>750	PL>150
Medium Traffic	M	300 < PL< 750	300 < PL< 750	50 < PL <150
Low Traffic	L	PL< 300	PL< 300	PL< 50

Table 10: Traffic Categories based on AADT

Traffic Category	**Code**	**Paved**	**Unpaved**	**Concrete**
High Traffic	H	≥ 7500	≥ 800	≥ 1500
Medium Traffic	M	≥ 750	≥ 175	≥ 7500
Low Traffic	L	≥ 300	≥ 75	≥ 3000

5.1.3. Calibration

Calibration of HDM-4 is intended to improve the accuracy of predicted pavement performance and vehicle resource consumption. The pavement deterioration models incorporated in HDM-4 were developed from results of large field experiments conducted in several countries. Level 2 calibration was undertaken. Due to in sufficient data for the analysis, the cross-sectional method was used. The main activity undertaken was the calibration of the deterioration models.

Cracking is very predominant on Benin road network. Information obtained from experienced engineers is that cracking is initially seen on bituminous roads between 2 and 3 years after construction.

The cracking initiation factors K_{ci} were calculated for each climatic zone. The summaries of calibrated crack initiation and progression adjustment factors for the selected climate zones of Benin are given below in Tables 11 and 12.

Table 11: Cracking for Sub-Equatorial Zone 1

Pavement Type	Mean Observed Values (yrs)	Mean Predicted Values (Years)	K_{ci}	$K_{cp} = 1/K_{ci}$
AMGB	2.5	4	0.625	1.6
AMSB	2.5	5	0.5	2.0
STGB	2.5	9	0.278	3.60

Table 12: Cracking for Atacorien Zone 3

Pavement Type	Mean Observed Values (yrs)	Mean Predicted Values (Years)	K_{ci}	$K_{cp} = 1/K_{ci}$
STGB	2.5	9	0.278	3.60
STSB	2.5	10	0.25	4.0

5.2. Results of Economic Analysis of Ouando – Zian Carrefour Section

Out of the total of 7 project roads, Ouando – Zian Carrefour has been selected to demonstrate the economic and financial evaluation using HDM-4.

This road is as single carriageway (see Table 13). The first 4.3 km lies in an urban enclave. The strategy is to explore the benefits of dualising the urban section to ensure adequate capacity in line with Benin Government plan over the medium term.

Table 13: Ouando – Zian Carrefour (3.2)

Road Name	Homogenous Section	Corridor Characteristics	Carriageway	IRI
Ouando – Zian Carrefour	H1: km 0.0-1.1	Urban	Single	7.8
	H2: km 1.1-4.0		Single	5.6
	H3: km 4.0-4.3		Single	4.2
	H4: km 4.3-16.6	Rural	Single	4.2
	H4: km 16.6-22.6		Single	5.6

5.2.1. Pavements Alternatives

Upon detailed examination of the traffic and investigation of the pavement condition, preliminary pavement design Alternatives were evolved for each road taking into account the homogenous sections and their rural and urban characteristics.

The proposed pavement alternatives with the respective unit costs are given in Table 14.

Table 14: Preliminary Design Pavement Alternatives

Road Code	Alternative 1 Design	Cost/km (USD)	Alternative 2 Design	Cost/km (USD)
3.2A	• Km 0 – Km 4+300 (junction): Widen to accommodate 4 No. 3.5m wide traffic lanes + 1.5m wide motorbike lanes either side + 2.0m wide drain/footpath either side.	**2,548,418**	• Km 0 – Km 4+300 (junction): Widen to accommodate 4 No. 3.5m wide traffic lanes + 1.5m wide motorbike lanes either side + 2.0m wide drain/footpath either side.	**2,784,449**

Road Code	Alternative 1 Design	Cost/km (USD)	Alternative 2 Design	Cost/km (USD)
3.2B	• Pre-pulverize the upper 280mm horizon of existing pavement. • Create a new 300mm thick subbase over the new width. • construct a new 150mm thick cement stabilized base • construct a new 150mm thick Crushed Stone Base • Construct a new 40 mm thick AC wearing course. • In rural areas beyond Km 4+300, the existing surfacing is to be repaired by means of patching potholes, sealing cracks and repairing edge breaks, followed by 25mm thick AC wearing course. • Through urban areas, Mill and Replace the existing surfacing with 45mm thick AC. • Upgrade all drainage requirements.	**230,757**	• Pre-pulverize the upper 280mm horizon of existing pavement. • Create a new 300mm thick subbase over the new width. • construct a new 150mm thick cement stabilized base • construct a new 120mm thick Bituminous Foam Mix • Construct a new 40 mm thick AC wearing course. • In rural areas beyond Km 4+300, the existing surfacing is to be repaired by means of patching potholes, sealing cracks and repairing edge breaks, followed by 25mm thick AC wearing course. • Through urban areas, Mill and Replace the existing surfacing with 45mm thick AC. • Upgrade all drainage requirements.	**230,757**

5.2.2. Strategies for HDM-4 Analysis for Paved Roads

Do Minimum Scenario

A realistic do minimum scenarios have been assumed for the respective paved roads in the event the proposed projects are not funded by MCC. The selected do minimum situations also reflects current maintenance standards and practices for paved roads in Benin. The Do Minimum case was based on the surface type. For surface dressed roads, the Do Minimum was Resealing, whiles for asphaltic concrete it was overlay (see Table 15).

Table 15: Do Minimum Scenario by Road Section

Alternative Description	Surface Type	Details of Improvement/Maintenance
Base Alternative (Do-Minimun)	Asphaltic	Carry out 25 mm thick overlay

Road Improvement and Maintenance Strategies

All homogeneous sections were subjected to a series of Intervention Options and the appropriated maintenance required over the analysis period of 20 years after the investments. Table 16 gives the details of the respective options.

Table 16: Details of Improvement and Maintenance Standards

Option	Alternative Description	Details of Improvement/Maintenance
1	Rehabilitation of Paved Roads - Surface Treated (ST) or Asphaltic Concrete (AC)	It entails the following activities : • Partial Widening to the Standard Carrriageway Width • Improvement and Repair of Drainage Structures • Pavement works –See cross-section below • Intervention is in Calendar Year 2017 • Construction Period – 2 years (2017-2018) Schedule Maintenance • Perform Paved Road Routine Maintenance Annually • Annual Routine Maintenance for Paved Roads • Resealing/Overlay (25mm) @ 6IRI
2	Upgrading of Surface Treated (ST) to Asphaltic Concrete (AC)	Improvement Activities include the following activities: • Partial Widening to the standard carriageway width • Improving and repair of drainage facilities • Pavement Works – See cross-section below • Calendar year of intervention 2017 • Construction Period 3 years (2017-2019) Schedule Maintenance • Perform Paved Routine Maintenance Annually • Schedule Resealing @ 6yrs interval • Start year 2019-2040

Option	Alternative Description	Details of Improvement/Maintenance
3	Upgrading of Single Carriageway to 2-Lane Dual Carriageway	Improvement Activities include the following activities: • Partial Widening to the standard carriageway width • Improving and repair of drainage facilities • Pavement Works – See cross-section below • Calendar year of intervention 2017 • Construction Period 3 years (2017-2019) Schedule Maintenance • Perform Paved Routine Maintenance Annually • Schedule Overlay 50mm @ 6yrs interval • Start year 2019-2040

5.2.3. Project Economic Evaluation Parameters

Discount Rate

A discount rate of 10% has been adopted for this project in line with guidance from the MCC for infrastructure investment in Benin.

Residual Value

Residual value has been assumed the paved road to be 15% at the end of design period of 20 years. It is expected that the economic life of the road will be beyond the design period.

The minimum target Economic Internal Rate of Return (EIRR) to qualify for investment is 10.0%, thus investment with EIRR less than 10% may not be recommended to MCC for investment.

5.2.4. Results of the Economic Evaluation

Three options were considered for the HDM-4 runs for all the homogenous sections. Summary of the HDM-4 results is given in Tables 17.

Table 17: Summary Result of HDM-Runs for Ouando -Zian Carrefour

Section	Investment Options	Savings in MT VOC	Savings in MT Travel Time Costs	Total Agency Costs (RAC)	NPV	NPV / RAC	EIRR
Km 0.0 - 1.1	Rehabilitation of Existing 2-Lane Dual AC Pavement	1.58	3.16	0.276	4.68	16.925	23.6
	Upgrading Existing SC'way to 2-Lane Dual Alt 1 Pavement	1.65	4.44	2.11	4.19	1.990	16.40
	Upgrading Existing SC'way to 2-Lane Dual Alt 2 Pavement	1.65	4.44	2.29	4.01	1.750	15.90
Km 1.1 - 4.0	Rehabilitation of Existing 2-Lane Dual AC Pavement	4.58	9.02	0.729	13.43	18.436	30.60
	Upgrading Existing SC'way to 2-Lane Dual Alt 1 Pavement	5.13	3.20	5.55	13.21	2.380	18.9
	Upgrading Existing SC'way to 2-Lane Dual Alt 2 Pavement	10.61	3.20	6.04	12.72	2.100	18.2
Km 4.0 - 4.3	Rehabilitation of Existing 2-Lane Dual AC Pavement	0.49	0.96	0.075	1.44	19.086	39.3
	Upgrading Existing SC'way to 2-Lane Dual Alt 1 Pavement	0.57	1.41	0.57	1.46	2.540	20.3
	Upgrading Existing SC'way to 2-Lane Dual Alt 2 Pavement	0.57	1.41	0.63	1.41	2.260	19.5
Km 4.3 - 16.6	Upgrading Existing SC'way to 2-Lane Dual Alt 1 Pavement	23.29	57.80	23.552	59.92	2.544	20.3
	Rehabilitation of Existing Carriageway	20.72	40.78	3.120	60.76	19.473	44.5
	Upgrading Existing SC'way to 2-Lane Dual Alt 2 Pavement	23.29	57.80	25.628	57.85	2.257	19.5
Km 16.6 - 22.6	Upgrading Existing SC'way to 2-Lane Dual Alt 1 Pavement	10.61	27.03	11.489	27.32	2.378	18.9
	Rehabilitation of Existing Carriageway	9.72	19.29	1.522	28.66	18.829	32.6
	Upgrading Existing SC'way to 2-Lane Dual Alt 2 Pavement	10.61	27.03	12.502	26.31	2.104	18.2

All the alternatives were economically viable for all the investment options with EIRRs ranging between 18.2 – 44.5 % and NPVs between US$ 4.68 – 60.76 million.

The results showed Rehabilitation of Existing Carriageway to be the best option for all the homogenous sections as it gave the highest NPVs and EIRRs.

5.2.5. Sensitivity Analysis

A sensitivity analysis was conducted on the results of the HDM-4. The main objective is to test the robustness of the selected option for implementation. The following scenarios have been modelled within the sensitivity analysis:

- +20% scheme capital costs
- -20% scheme capital costs
- -20% base year traffic (motorised)
- +20% base year traffic (motorised)
- Low traffic growth (pessimistic scenario)
- High traffic growth (optimistic scenario)

In order to establish the reliability of the selected option under the different scenarios, a sensitivity analysis was carried out on all the investment options. The NPVs under various sensitivity scenarios are summarised in Tables 18 and 19.

Table 18: NPVs from Sensitivity Analysis for Overlay Existing 2-Lane Dual AC Pavement - Ouando -Zian Carrefour

Sensitivity	Net Present Value (NPV)		
	Km 0.0-1.1	Km 1.1-4.0	Km 4.0-4.3
+20% Increase in AADT	6.792	19.233	2.049
+20% Increase in Capital Cost	4.639	13.332	1.428
+50% High Traffic Growth (Optimistic Scenario)	8.035	22.309	2.358
-20% Decrease in AADT	2.541	7.577	0.823
-20% Decrease in Capital Cost	4.716	13.535	1.449
-50% Low Traffic Growth (Pessimistic Scenario)	2.030	6.428	0.713
Base Sensitivity Scenario	4.678	13.433	1.439

Table 19: NPVs from Sensitivity Analysis for Rehabilitation of Existing Carriageway - Ouando -Zian Carrefour

Sensitivity	Net Present Value (NPV)	
	Km 4.3-16.6	Km 16.6-22.6
+20% Increase in AADT	83.393	39.496
+20% Increase in Capital Cost	60.332	28.451
+50% High Traffic Growth (Optimistic Scenario)	96.406	46.026
-20% Decrease in AADT	35.635	16.604
-20% Decrease in Capital Cost	61.191	28.870
-50% Low Traffic Growth (Pessimistic Scenario)	31.343	14.331
Base Sensitivity Scenario	60.762	28.660

The sensitivity tests show that the selected investment for the all the homogenous sections are sufficiently robust to achieve the specified criteria of economic viability under each of the modelled scenarios, for both optimistic and pessimistic cases.

6.0. LIFE CYCLE ANALYSIS OF THE OPTIMUM PAVEMENT

There is the need to subject the respective roads to critical maintenance needs assessment to ensure that timing of the maintenance interventions is optimised. The HDM-4 has the capacity to model the Life-Cycle of road pavement over a period of 40 years. The Life Cycle Analysis takes into consideration the initial capital cost and the various maintenance cost over the intended life of the pavement.

The overall objective of carrying out the Life-Cycle analysis is to minimise the Total Transport Cost on a given road. In order to minimise the transport cost The User and Road Agency cost streams for the Life Cycle period are added to establish the minimum transport cost.

6.1. Maintenance Standards and Strategies

All the sections were subjected to number of probable maintenance policy alternatives, with the intention to obtain a life cycle Cost which is most economic at least total transport cost. The policies consisted of different maintenance strategies, with scheduled time and responsive maintenance interventions. Roughness levels and % damage area were used to set the triggers for the responsive maintenance.

In order to have a fair basis for selection of life cycle option, the NPV, Agency Cost with respect to construction and maintenance Cost and the Vehicle Operating Cost (VOC) for various construction option and maintenance strategies were examined at a unit rate (i.e. Cost or benefit per kilometre). Table 20 gives the summary of the maintenance standards and alternatives used. The Maintenance Policy Alternative matrix has been evolved based on maintenance standard used by MTPT to trigger interventions.

Table 20: Maintenance Policy Alternatives for Asphaltic Concrete

Periodic Maintenance			
	Type of Trigger		**Trigger Level**
25 mm Overlay	Schedule		5 Years Interval
			6 Years Interval
			7 Years Interval
			8 Years Interval
			9 Years Interval
			10 Years Interval
	Responsive	IRI	4IRI
			5IRI
			6IRI
			7IRI
		Damage Area	50%
			40%
			30%
			25%

6.2. Results of the Life Cycle Analysis

From Table 20 maintenance policy alternatives were subjected to Life Cycle Analysis to determine which maintenance policy is most economic and with the Least Total Transport Cost. Results are as presented in Table 21.

All the alternatives include basic Routine Maintenance, such as drainage cleaning, vegetation clearing, repair of shoulder and miscellaneous activities. The Routine Maintenance intervention used under this project is scheduled annually in line with Benin road maintenance practices.

Table 21: Results of Life Cycle Analysis (Km 1.1 – 4.0)

Section	Alternative	Present Value of Total Agency Costs (RAC)	Net Present Value (NPV)	NPV / Cost Ratio (NPV / RAC)	Economic Internal Rate of Return (EIRR)	Total Transport Cost
Ouando -Zian Carrefour Km 1.1 -4.0	Base Alternative	0.538	0.000	0	0.000	156.664
	Total Life Cycle @ 10yrs Interval	0.912	13.022	14.276	56.1	143.641
	Total Life Cycle @ 4IRI	0.712	12.843	18.039	58.4	143.820
	Total Life Cycle @ 5IRI	0.700	12.717	18.179	58.2	143.946
	Total Life Cycle @ 5yrs Interval	1.458	12.724	8.729	39.7	143.939
	Total Life Cycle @ 6IRI	0.688	12.429	18.059	57.9	144.234
	Total Life Cycle @ 6yrs Interval	1.247	12.885	10.329	43.9	143.779
	Total Life Cycle @ 7IRI	0.678	11.744	17.321	57.3	144.920
	Total Life Cycle @ 7yrs Interval	1.152	12.933	11.231	47.8	143.730
	Total Life Cycle @ 8yrs Interval	1.007	13.025	12.931	51.4	143.639
	Total Life Cycle @ 9yrs Interval	0.956	13.033	13.627	54.1	143.630
	Total Life Cycle 25% Damaged Area	0.757	13.005	17.176	58.2	143.659
	Total Life Cycle 30% Damaged Area	0.757	13.004	17.175	58.2	143.659
	Total Life Cycle 40% Damaged Area	0.741	12.965	17.505	58.4	143.699
	Total Life Cycle 50% Damaged Area	0.726	12.913	17.796	58.4	143.750

A summary of the results and the selected optimum alternative for each section is as presented in Table 22.

Table 22: Optimum Maintenance Strategy for Ouando – Zian Carrefour

Section	Alternative	Total Agency Costs (RAC)	NPV	NPV / RAC	EIRR	Total Transport Cost
Km 0.0 - 1.1	Total Life Cycle @ 9yrs Interval	0.363	4.944	13.627	54.1	55.337
Km 1.1 -4.0	Total Life Cycle @ 9yrs Interval	0.956	13.033	13.627	54.1	143.630
Km 4.0 - 4.3	Total Life Cycle @ 9yrs Interval	0.099	1.348	13.627	54.1	14.758
Km 4.3 - 16.6	Total Life Cycle @ 50% Damaged Area	3.078	68.835	22.36	63.8	602.595
Km 16.6 - 22.6	Total Life Cycle @ 50% Damaged Area	1.502	33.578	22.36	63.8	295.958
Km 4.0 - 16.6	Total Life Cycle @ 50% Damaged Area	3.154	70.514	22.36	63.8	617.292

The selected investment options and the required maintenance over the entire design period is given in Table 23.

Table 23: Summary of Selected Investment Options

Section	Capital Investment	Maintenance	
		Routine	Periodic
Ouando – Carrefour Zian	Rehabilitation of Existing Carriageway	Annual	Overlay @ 9yrs Interval

During the period 2017 – 2041, it is estimated that an amount of US$ 14.89 Million will be required as investment for Ouando-Zian Carrefour road. MCC will be required to provide US$ 5.22 Million during the compact period. Government of Benin will responsible for the maintenance at a cost of US$ 9.67 Million over the entire design life (see Table 24).

Table 24: Summaries of Financial Cost of Road Works for the Period 2017-2041

Code	Section	Financial Cost of Works (Million US$)			Total (Million US$)
		Improvement	Periodic	Routine	
3.2	Ouando - Zian Carrefour	5.22	8.18	1.49	**14.89**

The breakdown of the financial cost of works for the entire life cycle of the road is as presented in Table 25.

Figure 3 shows a typical roughness profile before and after the initial investment and the maintenance of the entire life of the road.

Table 25: Breakdown of Financial Cost of Works

Year	Improvement	Financial (US$)	Periodic	Financial (US$)	Routine	Financial (US$)	Total (US$)
2017	Rehab of 3.2 Km 0 - 22.6 Urban – Option 1 Rural - Option 2	2,090,000.00	Urban - Overlay 30mm @ 9 Yrs Interval & Rural - Overlay 25mm @ 50% Damaged Area	0	Routine M'tce (Grass Cutting + Stone Pitching + Ditch Cleaning (2sides - twice per annum))	0	**2,086,043.36**
2018		3,130,000.00		0		0	**3,129,065.02**
2019		0		0		0	0.0
2020		0		0		0	0.0
2021		0		0		70,000.00	**70,406.93**
2022		0		0		70,000.00	**70,406.93**
2023		0		0		70,000.00	**70,406.93**
2024		0		0		70,000.00	**70,406.93**
2025		0		0		70,000.00	**70,406.93**
2026		0		0		70,000.00	**70,406.93**
2027		0		1,340,000.00		70,000.00	**1,414,156.94**
2028		0		0		70,000.00	**70,406.93**
2029		0		0		70,000.00	**70,406.93**
2030		0		0	Routine M'tce + Crack sealing	80,000.00	**75,360.93**
2031		0		0		80,000.00	**75,360.93**
2032		0		0		80,000.00	**75,360.93**
2033		0		5,490,000.00	Routine M'tce (Grass Cutting + Stone Pitching + Ditch Cleaning (2sides - twice per annum))	70,000.00	**5,560,406.93**
2034		0		0		70,000.00	**70,406.93**
2035		0		0		70,000.00	**70,406.93**
2036		0		1,340,000.00		70,000.00	**1,414,156.94**
2037		0		0		70,000.00	**70,406.93**
2038		0		0		70,000.00	**70,406.93**
2039		0		0		70,000.00	**70,406.93**
2040		0		0		70,000.00	**70,406.93**
2041		0		0		70,000.00	**70,406.93**
Total (US$)		**5,220,000.00**		**8,180,000.00**		**1,490,000.00**	**14,886,015.93**

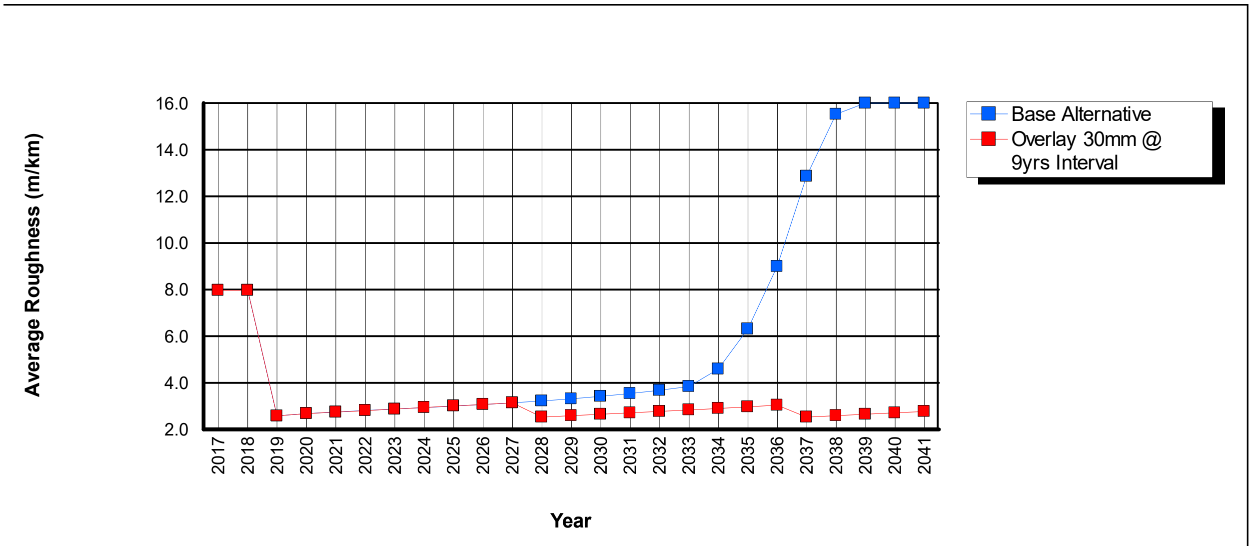

Figure 3: Typical Roughness profile of Ouando-Zian Carrefour road

7.0. CONCLUSION

The Life Cycle approach using the Rational Pavement Design Method addresses all issues from design through the maintenance regime and finally the financial budgeting issues.

The methodology can be used to update the pavement management system of the Road Agency. It is practical and engineers can be trained to use it. The inputs can be obtained locally without using assumptions which are alien to a given environment.

From the economic analysis, the life cycle cost of the road investment is known before construction starts. It will ensure proper planning and programming of maintenance activities during the design life of the pavement. It will also help proper monitoring by funding agencies of government maintenance responsibilities after initial investment by the developing partners.

8.0. RECOMMENDATIONS

1. It is recommended that M-E pavement design parameters be developed for countries especially the field temperature of the AC layer.
2. A research can be undertaken to develop a system that links the M-E tool to HDM-4 as one package.
3. This approach can be used to update the maintenance management system of the Road Agency.

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