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

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OUTLINE OF PRESENTATION

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INTRODUCTION

- Most pavement design approaches lack critical evaluation of the life cycle and performance of the designed road pavement.
- The challenge is that current practice in road pavement design and the maintenance are not coterminous.
- Koranteng-Yorke, Ghataora and Odoki (2014) have developed a rational approach for tropical pavement design using life cycle principles.
- This presentation will demonstrate the practicality of the approach using a Benin road project as case study.

BACKGROUND OF PROJECT

- Benin applied for Second Compact under the Millennium Challenge Account (MCA). The following were required for the selection and justification of the selected candidate roads;

✓A 20-year design life;

✓Recycling of the existing pavement materials;

✓Deflection survey to determine residual life of pavements;

✓Justification of rehabilitation or reconstruction;

✓Recommendation of a maintenance and implementation strategies including cost estimates.

METHODOLOGY

The following were methods were adopted;

- Selection of a design approach and pavement design tool that addresses project requirements.
- Calibration and use of Kenlayer tool for analysis and candidate pavement designs.
- Calibration and use of HDM-4 model for;
  - ✓economic and life cycle cost analysis;
  - ✓the establishment of maintenance regime; and
  - ✓the financial assessment for planning and budgeting.

SELECTION OF DESIGN APPROACH

- Empirical design method for traffic volume exceeding 10 million ESALs is inaccurate (Lister et al, 1982).
- Projected traffic loads of most roads are exceeding 10 million ESALs.
- Mechanistic-Empirical design approach was adopted because of its capacity to design for uncontrolled traffic situation and other inherent advantages.

Description	Estimated 20-Year Load (ESALs)
Sèmè-Porto-Novo	95,683,594
Porto-Novo-Ouando	48,387,082
Ouando-Carrefour Zian	23,760,311
Porto-Novo-Avrankou	15,833,775
Avrankou-Igolo	16,347,347
Bohicon-Dassa	82,527,034
Savalou-Okoutaossé	30,073,314
Misséssinto-Zinvié	8,923,963
Zinvié-Sèdjè Dénou	1,850,507
Tori Bossito-Abomey Calavi	4,783,350
Adja Ouèrè-Massè-Ciment. - RN4	914,962
Ansèkè-Ouessè-Kilibo	4,380,803

SELECTION OF DESIGN TOOLS

- Alize-LCPC , WinJulea and KENLAYER are the M-E tools evaluated.
- The most appropriate tool must have the capacity to achieve design requirements.
- The suitability of the tools are as summarized in the table.
- Kenlayer was found to be most suitable.

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			

CALIBRATION OF THE DESIGN TOOL

- Calibration of Kenlayer was necessary to establish reliability of results.
- Input parameters were selected from geotechnical reports and also typical values found in works done within the sub-region.
- Huang (2004) and Koranteng-Yorke (2012) have selected typical values for tropical soils.

- Results of Calibration

Road	Measured Deflection (cm)	Estimated Deflection (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

ESTIMATION OF RESIDUAL LIFE

- The residual life of the existing pavements were assessed to inform the appropriate type and level of intervention required.
- Existing materials are; Asphaltic Concrete Surfacing (AC); Double Surface Dressing (DSD); Cement Stabilised Laterite (CSL) and Laterite Subbase (SB).

Road	Material	Thickness (cm)	Estimated 20-Year Load (CSA)	Allowable Traffic Load (million CSA)	Residual Life
1.1	AC	5	95.684	13.04	2.73
	CSL	20			
	SB	25			
3.1	AC	4	48.387	4.495	1.86
	CSL	25			
	SB	20			
3.2	AC	5	23.760	1.825	1.54
	CSL	20			
	DSD	3			
4.1	AC	4	15.834	2.169	2.74
	CSL	15			
	SB	20			
4.2	AC	4	16.347	4.361	5.34
	CSL	22			
	SB	20			
8.1	AC	7	82.527	1.675	0.41
	CSL	20			
	DSD	3			
9.3	DSD	2.8	30.073	0.793	0.53
	CSL	20			
	SB	25			

CANDIDATE PAVEMENT DESIGNS

- New materials considered are Graded Crushed Stones (GCS) and Dense Bitumen Macadam (DBM)

- Reconstruction options for Ouando – Zian Car Road (3.2)

Option 1			Option 2		
Layers	Thickness (cm)	Design Life (Years)	Layers	Thickness (cm)	Design Life (Years)
AC	4	23	AC	4	22
GCS	15		BFM	12	
CSL	15		CSL	15	
SB	30		SB	30	

- Rehabilitation options for Ouando – Zian Car Road (3.2)

Option 3			Option 4		
Layers	Thickness (cm)	Design Life (Years)	Layers	Thickness (cm)	Design Life (Years)
AC	4	22	AC	5	22
GCS	26		BFM	19	
CSL*	20		CSL*	20	
Existing layers (*)					

CONFIGURATION & CALIBRATION OF HDM-4 MODEL

- Configuration of HDM-4 model is basically restructuring of the default values in line with local conditions, standards and practices.
- It entails; climatic data, road functional class, pavement classification, traffic categories and traffic growth.
- The HDM-4 has three sub-models which were calibrated using actual data from Benin.
- They are; Road Deterioration (RD);Road Works Effect (WE); and Road User Effects (RUE).

SELECTION OF OPTIMUM PAVEMENT DESIGN

- Out of the total of 7 project roads, Ouando – Zian Carrefour has been selected to demonstrate the economic and financial evaluation using HDM-4.
- The results showed rehabilitation to be the best option as it gave the highest NPVs, NPV/RAC ratios and EIRRs.

Section	Investment Options	Savings		Total Agency Costs (RAC)	NPV	NPV / RAC	EIRR
		VOC	Travel Time Costs				
Km 0.0 - 1.1	Rehabilitation	1.58	3.16	0.276	4.68	16.925	23.6
	Upgrading to 2-Lane Dual Alt 1 Pavement	1.65	4.44	2.11	4.19	1.990	16.40
	Upgrading to 2-Lane Dual Alt 2 Pavement	1.65	4.44	2.29	4.01	1.750	15.90
Km 4.3 - 16.6	Upgrading to 2-Lane Dual Alt 1 Pavement	23.29	57.80	23.552	59.92	2.544	20.3
	Rehabilitation	20.72	40.78	3.120	60.76	19.473	44.5
	Upgrading 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 to 2-Lane Dual Alt 1 Pavement	10.61	27.03	11.489	27.32	2.378	18.9
	Rehabilitation	9.72	19.29	1.522	28.66	18.829	32.6
	Upgrading to 2-Lane Dual Alt 2 Pavement	10.61	27.03	12.502	26.31	2.104	18.2

LIFE CYCLE COST ANALYSIS

- Sections were subjected to probable maintenance alternatives, to obtain the most economic life cycle cost.
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Periodic Maintenance			
25 mm Overlay	Type of Trigger		Trigger Level
	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%

- 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	13.62 7	54.1	55.337
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

PLANNING AND BUDGETING

- The breakdown of the cost of works for the life cycle of the road is as presented in the table.

Year	Improvement	Financial (US$)	Periodic	Financial (US$)	Routine	Financial (US$)	Total (US$)
2017	Rehabilitation	2,090,000.00	Urban - Overlay 30mm @ 9 Yrs Interval & Rural - Overlay 25mm @ 50% Damaged Area	0	Routine Maintenance	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		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		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

CONCLUSION & RECOMMENDATION

- With this approach, the life cycle cost of the road investment is known before construction starts.
- This 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.
- This approach can be used to update the maintenance management system of the Road Agency.