International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2020): 7.803

Prioritization of Pavement Segments Maintenance Using Analytical Hierarchy Process - Case study: Palapye, Botswana

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Abstract: ***The department of transportation in Botswana has been experiencing maintenance budget fluctuations for many years. The budget fluctuations have caused a negative impact on road maintenance causing increasing risks of accidents for road users. For decades, road maintenance has been carried out based on expert's judgement without taking into consideration the actual physical condition of the roads. This paper proposes the application of Analytical Hierarchy Process (AHP) to determine road maintenance priority. Three criteria and thirteen sub criteria were used whereby eleven (11) experts in the field of highway and traffic engineering were selected as respondents. Sixteen (16) maintenance function groups were identified and a hierarchy structure was developed based on the objectives and function groups. Three road segments were selected as representatives of different road conditions in Palapye. The result shows that, the Overall Relative Weight (ORW) of each alternative in order of their importance is pothole patching with 21%, Base repair 16.7%, pavement overlays 16.4%, signage repair 13.2%, edge repairs 10.1%, road paintings 8.9%, Drainage maintenance 6.6%, and clearing vegetation 6.0%. In addition, the results indicated that Analytical Hierarchy Process (AHP), provided unbiased ranking of road segments that avoids individual judgements.***

Keywords: Analytical Hierarchy Process, Decision Making, pavement maintenance strategy

1. Introduction

Roads after being constructed are vulnerable to deterioration due to different factors including loading from moving traffic and other environmental factors. Road deterioration is an unavoidable process which poses different problems such as: poor aesthetic look, which creates unsafe road conditions, increases vehicle accidents, vehicle maintenance cost, slows down traffic and discomfort to users. Based on these factors, there is an urgent need for periodic road maintenance or rehabilitation after being constructed. The objective of road maintenance is to minimize the above mentioned effects and improve road conditions. Most roads in Botswana are constructed using taxpayers money therefore it is crucial to ensure that roads are safe, maintained and rehabilitated to safe guard the investment and prolong the serviceable life of the roads. In Botswana management and maintenance of roads falls under two authorities. First the central government through the department roads which manages the major road network that connects towns, villages and cities. Secondly, the local government/ authorities which manages internal road networks through councils. In Botswana, there are 16 local authorities which are divided by district, city and town. In 2014 Botswana public road network was about 30275.64km with 18507km under the management of central government and 11768.64km were under the management of local authorities. According to statistics Botswana, roads managed by central government on which 21.7% were, 37.4% had bitumen layer and 40.8% were gravel roads (Statistics Botswana, 2015). Local authorities only manage the unpaved roads that carry low traffic volumes. These roads are made of either sand/track, earth or gravel. In addition, 2011 the government spent more than P70 million on routine maintenance using Labor Based Methods and 30 local contractors were employing more than 7,000 people. Also, the road asset replacement value was estimated to be P28 billion whereby about 25% of the total budget for Roads Department was spent on road maintenance and rehabilitation. In order to ensure that funds on road maintenance are effectively utilized, the government issued a Road Maintenance Manualto guide engineers and contractors on how to maintain and rehabilitate roads in the country. The Botswana Road Maintenance Manual (RMM) uses clear procedures and objectives to guide engineers and contractors in performing daily maintenance works.In the BRMM manual, there are three threshold service levels to indicate the amount of defects or deficiencies that can be tolerated over a specified period of time depending on traffic levels and road function. These threshold service levels are not clearly specified and the implementation depends on an individual judgement and assessment which in most cases there are qualitative instead of being quantitative. This individual judgement makes maintenance and rehabilitation operations very subjective.

Ranking process of road sections for maintenance is carried out in an orderly manner starting by identification of the road segments based on their urgent need for rehabilitation. At this level, engineers are required to rank road segments and prepare maintenance schedule. Given the fact that there is limited capital resources from the government for road rehabilitation, it is impossible to adequately maintain all roads that require rehabilitation and maintenance at the same time. Lack of adequate financial resources, road maintenance may result in road network dropping below restoration threshold and preventative maintenance treatments. This would require resources that could be used for reconstruction new road networks of the damaged road sections. It is therefore pivotal to ensure that prioritization process of roads segments for rehabilitation is effectively established to the best interest of serving the community and economy. Any form of decision-making whether formal or informal requires engineers and decision makers to rank roads in an orderly manner. Ranking of roads for rehabilitation in an orderly manner using different alternatives, is usually done by judging different criteria and sub criteria is very important as it eliminates bias in judgement.

For decades, the Department of Transportation in Botswana has been experiencing maintenance budget fluctuations for many years. The budget fluctuations has a negative impact on the department to select priority road segments for rehabilitation and maintenance causing deterioration of conditions of roads, increasing the risks for car accidents and road users. In many government departments, evaluation and ranking of road segments for rehabilitation and maintenance has been by using Cost Benefit Analysis, individual, committee judgements and availability of resources (Mayunga, 2020). These methods have proven to be very biased, subjective and does not take into consideration quantitative and physical conditions of road sections. In order to overcome such problems, it is therefore vital that a sequential, systematic, consistent and unbiased methods be used to rank road segments for rehabilitation. This also was noticed by (Oladele (2014) that a more optimized approach in which maintenance intervention is carried out before structural deterioration becomes evident.

2. Existing road maintenance strategies

In 1998 a Routine Maintenance Planning System (ROMAPS) was developed in Botswana for the management and maintenance of the Botswana road network. The ROMAPS system was implemented and then modified to nROMAPS (Albie Hanekom, 2013). This new system is currently used to manage road network features, bridges and Road signs. The limitations of nROMAPS system is that it depends on individual judgment and assessment which are qualitative in nature. Sahadev, B.B., 2014 used Spatial Multi-Criteria Assessment and the least cost path analysis to identify an ideal by-pass street arrangement in the Tlokweng planning area in Botswana using economic, environmental and social criteria then compared with the proposed Tlokweng Development Plan. Thirteen different sub criteria were used for evaluation using a standardized decision making utilizing 1 to 5 scale. Moazani (2011) applied AHP method in priority rating of pavement maintenance using 6 districts in Tehran municipality. The author used three criteria as modelling parameters, namely traffic volume, road type criteria and Pavement Condition Index (PCI). The PCI uses a general scale of 0-100 to measure the severity of pavement distress with zero being most severe and hundred being in excellent condition.

Sahedev, B.B., (2014) used a multi criteria evaluation to rank road projects in the rural areas in Nepal. He highlighted the importance of multi criteria analysis in decision making instead of cost benefit analysis due to inaccuracy in cost estimations. The study revealed that, cost minimization alone leads to negligence of other important factors. Sarfaraz, A., (2020) used objective Analytical Hierarchy process in prioritization of pavement maintenance by evaluating 28 road sections in Mumbai India. To avoid biasness in evaluating pavement and ranking for maintenance he used priority index computed by empirical expression. The study shows that, not all factors are expressed qualitatively. Based on the studies discussed above it is clear that, quantitative methods of multi-criteria analysis would be of great importance for prioritizing road sections for maintenance.

Saaty, T.L., (1994) introduced a multiple criteria scaling method to help in judgement from different alternatives. The approach is designed to cope with both the rational and the intuitive to select the best from a number of alternatives evaluated with respect to several criteria (András F., 2010). In this study, a Multi-Criteria Approach or commonly known as Analytical Hierarchy Process (AHP) method is used proposed where a pairwise comparison matrix is created based on the collected field data from a road network for road maintenance

3. Method

3.1 Study Area

Palapye is a rapidly growing town in Botswana with a population of 36,211 as indicated from the last national census conducted in 2011(StatisticsBotswana, 2011). Palapye town is in the Central District between Francistown and Gaborone. The Town has one coal mine which produces coal for the Power station which generates most of the domestic electricity. In this study, three road sections were selected in close proximity to each other in the commercial center of Palapye Town.

Table 1 below shows the location of three road segments.

Name of the road	*Length of the road segment*	*Number of segments*
Road segment 1 Engine Mall Bus stop- Railroad crossing (22°32’39”S 27°05’11”E) – (22°32’10”S 27°05’22”E)	2.4km	2
Road segment 2 Total Petrol Station- Engine Mall (22°32’29”S 27°05’32”E) – (22°32’30”S S 27°05’15”E)	1.8 km	13
Road segment 3 Engine mall-BHC/BPC housing (22°32’32”S 27°05’20”E) – (22°32’52”S 27°05’09”E)	2.1km	2

3.2 Data Collection

In this study, the Analytical Hierarchy process was used whereby data from experts in Civil and Traffic Engineering were collected in the form of pairwise comparison matrix using scale as suggested by (Saaty, 2008). Eleven experts were selected to be respondents to the questionnaire. A structured questionnaire was designed and submitted to the respondents and designed in such a way that the respondents can make pairwise comparisons using the scale in a simple and color-coded manner. Fourteen deterioration aspects were selected as key items to assess road segment deterioration for the case study. These aspects include: rutting, cracking, bleeding, corrugation, depression, pedestrian walkway, pothole, raveling, edge deterioration, vegetation condition, unclear markings, damaged signs and drainage blockage. The Analytic Hierarchy Process(AHP) which supports multi-criteria decision making process as initially developed by Thomas L. Saaty (1980) was used to prioritize road segments for rehabilitation. AHP determines the proportion weightsfrom matched correlations of criteria and takes into account some irregularities in the judgments. Multi-Criteria approach is based on pairwise comparisons matrix which relies on the judgements to derive priority scales. The judgements may be inconsistent but it can be improvedin order to gain better consistency. TheMulti-Criteria approach not only evaluates different alternatives with respect to selected criteria but it evaluates and ranks the criteria in terms of the higher goal.

3.3 Setting of pairwise comparison matrices with each element

The determination of priorities allows to create relationship between choices and alternatives. The AHP model uses pairwise comparisons to match criteria and sub criteria in a pairwise fashion where preference for one item over the other can be observed. In this study, each tier level of the hierarchy is assessed by comparing each group against the other one at a time using a point system to indicate preference of one item over the other. Groups on each tier is places in a matrix of (a x a) to compare them in a pairwise fashion. The point system was used to indicate strength of preference in the one-to-nine scale. The number of pairwise comparisons in a (n × n) matrix can be computed using equation (1).

$$\text{Number of pairwise comparisons}= \frac{n\times(n-1)}{2} \quad \ldots\ldots\ldots (1)$$

Table 2: A pairwise comparison on pavement maintenance objectives

	Aesthetics	Safety	System operation	System Preservation
Aesthetics	1	1/9	1/5	1
Safety	9	1	7	7
System Operation	5	1/8	1	3
System Preservation	1	1/8	1/3	1

3.4 Combining the Pairwise Comparison Matrices using Geometric Mean

Data on pairwise comparison of pavement maintenance objectives and maintenance alternatives was collected in the form of a questionnaire for the convenience of answering by respondents. The information however is required to be represented in the form of a matrix for analysis to obtain accurate ranking of priorities. Two types of matrices were used for this research including matrix for pairwise comparison of the four key maintenance objectives and matrix for pairwise comparison of the Alternatives of each objective. Table 3 below shows the data compiled from one of the ten respondents in the form of a matrix. The matrices were created using excel software showing the pairwise comparison of the respondents on the objectives and alternatives.. Table 3, 4,5 and 6Shows data compiled from one of the ten respondents in the form of a matrix.

Table 3 showing pairwise comparison on pavement maintenance alternatives in the context of Aesthetics

	Clearing vegetation	Road Painting	Pothole Patching	Edge repairs	Pavement Overlays	Signage Repair	Drainage Maintenance	Base
clearing vegetation	1	3	1/3	1/3	1/5	1/3	1/3	1/5
road painting	1/3	1	1/5	1/5	1/5	1/5	1/5	1/5
Pothole patching	3	5	1	5	5	5	5	5
Edge Repairs	3	5	1/5	1	1/5	3	5	5
Pavement Overlays	5	5	1/5	5	1	5	5	1
Signage Repair	3	5	1/5	1/3	1/5	1	1	1/5
Drainage Maintenance	3	5	1/5	1/5	1/5	1	1	1/5
Base Repair								1

Table 4: Pairwise comparison on pavement maintenance alternatives in the context of Safety

	Clearing vegetation	Road Painting	Pothole Patching	Edge repairs	Pavement Overlays	Signage Repair	Drainage Maintenance	Base Repair
clearing vegetation	1	5	1	1/5	1/3	1/5	1/3	1/7
road painting	1/5	1	1/7	1/7	1/7	1/7	1/7	1/7
Pothole patching	1	7	1	5	1/5	5	5	1/5
Edge Repairs	5	7	1/5	1	1/7	1/7	7	1/7
Pavement Overlays	3	7	5	7	1	5	5	1/5
Signage Repair	5	7	1/5	7	5	1	5	7
Drainage Maintenance	3	7	1/5	1/7	1/5	1/5	1	1/5
Base Repair	7	7	5	7	5	1/7	5	1

Table 5: Pairwise comparison on pavement maintenance alternatives in the context of System operation

	Clearing vegetation	Road Painting	Pothole Patching	Edge repairs	Pavement Overlays	Signage Repair	Drainage Maintenance	Base Repair
clearing vegetation	1	3	1/5	1/5	1/5	3	3	1/5
road painting	3	1	1/5	1/5	1/5	1/5	1/5	1/5
Pothole patching	5	5	1	5	1/5	5	5	1/5
Edge Repairs	5	5	1/5	1	1/5	1/5	1/5	1/5
Pavement Overlays	5	5	5	5	1	5	1/5	1/5
Signage Repair	1/3	5	1/5	5	1/5	1	1/5	1/5
Drainage Maintenance	1/3	5	1/5	5	5	5	1	1/5
Base Repair	5	5	5	5	5	5	5	1

Table 6: Pairwise comparison on pavement maintenance alternatives in the context of System Preservation

	Clearing vegetation	Road Painting	Pothole Patching	Edge repairs	Pavement Overlays	Signage Repair	Drainage Maintenance	Base Repair
clearing vegetation	1	5	1/3	1/3	1/5	3	1/3	1/5
road painting	5	1	1/7	1/3	1/7	1/3	1/5	1/5
Pothole patching	3	7	1	3	1/5	3	5	1/5
Edge Repairs	3	3	1/3	1	1/7	1/3	1/3	1/5
Pavement Overlays	5	7	5	7	1	7	7	7
Signage Repair	1/3	3	1/3	3	1/7	1	1/5	1/7
Drainage Maintenance	3	5	1/5	3	1/7	5	1	1/7
Base Repair	5	5	5	5	1/7	7	7	1

3.5 Determination of Consistency Index

For AHP to provide an accurate results, the inconsistency of the decision matrices should be within a tolerable range of 0-10%. This value is determined by finding the consistency ratio of each decision matrix. The maximum eigenvalue (λ max) is calculated by dividing the product of the original matrix and the priority vector matrix divided by value of vector of priority. This value is used to find the Consistency Index (CI) as shown in equation 2. The size of the matrix is then used to determine Random Consistency Index (RI) which is shown in table 14. Using equation 3 the Consistency ratio is found by dividing CI with RI

$$CI = \frac{\lambda max - n}{n-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where:
λ = max= Maximum Eigen value and n = Size of square matrix

Table 7: Random Index (RI)V_sn

N	1	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.00	0.55	0.94	1.14	1.28	1.37	1.43	1.48	1.51	1.54

The Consistency Ratio is calculated as:

$$CR = \frac{CI}{RI} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where: CR= Consistency Ratio, CI= Consistency Index and RI= Random Index

In this study, Consistency Ratio was calculated using an online AHP system developed by (Goepel, 2021). When consistency is greater than 10% the software changes specific parts of pairwise comparison to provide consistency within acceptable range.

3.6 Combining Individual Judgement Matrices

The individual judgement matrices were combined using geometric mean to obtain the group judgement on the objectives and the alternatives in context of each objective. Geometric mean is calculated using equation 4 below. The data was then entered into excel and the geometric mean function was used to combine the each possible pairwise judgement from the ten evaluators as shown in Table 8.

$$Geometric\ mean = \sqrt[n]{x_1 * x_2 * x_n} \ldots\ldots\ldots\ldots(4)$$

Where:
x = number value and n= number of values

Table 8: Geometric mean values for combined Objectives judgement matrix

	Evaluators										
Objectives	1	2	3	4	5	6	7	8	9	10	Geometric mean
Aesthetics vs Safety	1/9	1/9	1/9	1/3	1/9	1/9	1/9	1/7	1/7	1/9	0,1301
Aesthetics vs System Operation	1/5	1/4	1/9	1	1/3	1/4	1/9	1/5	1/7	1/4	0,2273
Aesthetics vs System Operations	1	1/4	1/9	1/5	1/3	1/4	1/9	1/5	3	1/4	0,3081
Safety vs System Operations	7	5	1	3	5	9	1	2	1/3	5	2,6286
Safety vs System Preservation	7	5	1	1	2	9	1	2	5	5	2,8173
System Operations vs System Preservation	3	1	1	1/5	1	1	1	1	7	1	1,1543

Table 9: Geometric mean values for combined Alternatives in context of Aesthetics judgement matrix

	Evaluators										
Alternatives	1	2	3	4	5	6	7	8	9	10	**Geometric mean**
clearing vegetation vs road painting	5	1	1	3	1/7	1/5	9	1/5	1	1	0,9744
clearing vegetation vs pothole patching	1	3	1	1/3	1/9	1/7	5	1/3	1/3	3	0,6954
clearing vegetation vs Edge Repairs	1/5	1	1	5	1/5	1/9	9	1/5	1/3	1	0,6494
clearing vegetation vs Pavement Overlays	1/3	1	1	3	1/3	1/7	1	1/5	1/5	1	0,5345
clearing vegetation vs Signage Repair	1/5	1	1	1	1/3	1/7	1/9	1/7	1/5	1	0,3532
clearing vegetation vs Drainage Maintenance	1/3	3	1	7	1	5	1/9	1/9	1/5	3	0,8737
clearing vegetation vs Base repairs	1/7	3	1	3	1/3	1/7	1/9	1/7	1/5	3	0,4749

road painting vs Pothole repairs	1/7	3	1	1/5	1/7	1	9	1/5		3	0,7395
road painting vs Edge repairs	1/7	3	3	1	1/5	1	9	7	1/5	3	1,2554
Road painting vs Pavement Overlays	1/7	1	9	3	1/3	1	9	5	1/3	1	1,3445
road painting vs Signage Repairs	1/7	1	1	1/3	1/3	1	9	1	1/7	1	0,6776
road painting vs Drainage Maintenance	1/7	3	5	1	1	7	9	5	1/7	3	1,7625
road painting vs Base Repairs	1/7	5	1	1	1	1	9	5	1/7	5	1,3680
Pothole patching vs Edge Repairs	5	1	5	7	5	1	5	1/3	1/7	1	1,7056
Pothole patching vs Pavement Overlays	1/5	1/3	1	5	5	1	5	5	1/7	1/3	1,0709
Pothole patching vs Signage Repair	5	1/3	9	1	3	5	5	1/3	1/5	1/3	1,3797
Pothole patching vs Drainage Maintenance	5	1	9	7	5	7	5	7	1/5	1	3,0813
Pothole patching vs Base Repair	1/5	1	9	3	3	1/9	5	5	1/5	1	1,2457
Edge repairs vs Pavement Overlays	1/7	1/5	1	1	1	1/9	9	1	1/5	1/5	0,5079
Edge repairs vs Signage Repair	1/7	1/5	1	1/3	1	7	9	1/5	1	1/5	0,6887
Edge repairs vs Drainage Maintenance	7	1	1	3	1	7	9	5	1	1	2,4102
Edge repairs vs Base Repair	1/7	1	1	1/3	1	5	9	1	1	1	1,0792
Pavement Overlays vs Signage repair	5	1	1	1/3	3	7	1	1/7	1/3	1	1,0524
Pavement Overlays vs Drainage management	5	3	1	1	3	1	1	3	7	3	2,2144
Pavement Overlays vs Signage repair	1/5	1	1	3	1	1/7	1	1	1	1	0,7822
signage Repair pair vs Drainage Maintenance	5	3	5	3	1	1/5	1/9	7	1	3	1,5926
signage Repair vs pair Base Repair	7	3	3	3	1	1/9	1/9	5	3	3	1,5926
Drainage Maintenance vs Base Repair	1/5	1	1	1/7	1	1/9	1/9	3	3	1	0,5626

3.7 Priority Vector of the Combined Matrix

From combined matrix, the relative importance of each criteria over the other through a series of mathematical manipulations was quantitatively derived. The matrix is firstly normalized by dividing each column element by the corresponding column sum. The second step is adding the elements in each row of the column to create a new n x 1 matrix, then finally each element in the new matrix is divided by the size value of the square matrix (n). This operation was performed using excel for the objectives matrix and for matrices of the alternatives with respect to each objective as shown in Table 13 and Table 14 below

Table 10: Priority vector and Ranking of normalized Objective matrix from Group Judgement

	Aesthetics	Safety	system operation	system preservation	Row sums	priority Vector	rank
Aesthetics	0,060606061	0,078392681	0,051580439	0,0583616	0,248940781	0,062235195	4
Safety	0,484848485	0,602357725	0,596616862	0,533603593	2,217426665	0,554356666	1
System operation	0,272727273	0,192754472	0,226969483	0,218631442	0,911082669	0,227770667	2
system Preservation	0,181818182	0,126495122	0,124833216	0,189403365	0,622549884	0,155637471	3

Table 11: Priority vector and ranking of normalized matrix of Alternatives the context of aesthetics from Group Judgement

	Clearing vegetation	Road Painting	Pothole Patching	Edge repair	Pavement Overlays	Signage Repair	Drainage Maintenance	Base Repair	Row sums	priority vector	Ranking
clearing vegetation	0,076086	0,14280	0,11829	0,0705	0,07431	0,0551	0,059498	0,058	0,655	0,08191	7
road painting	0,076086	0,14656	0,12578	0,1273	0,186889	0,1058	0,120022	0,168	1,057	0,13216	4
Pothole patching	0,114130	0,19541	0,17010	0,1730	0,148874	0,2155	0,209835	0,153	1,380	0,17257	1
Edge Repairs	0,114130	0,11724	0,09922	0,1014	0,070609	0,1075	0,164128	0,133	0,907	0,14377	6
Pavement Overlays	0,152173	0,10992	0,17010	0,2028	0,139015	0,1643	0,150794	0,096	1,185	0,14822	3
Signage Repair	0,228260	0,09770	0,12371	0,1521	0,139015	0,1562	0,108455	0,196	1,202	0,15025	2
Drainage Maintenance	0,086956	0,08374	0,05670	0,0422	0,062557	0,0976	0,068097	0,069	0,567	0,0709	8
Base Repair	0,152173	0,10659	0,13608	0,1304	0,178733	0,0976	0,11917	0,123	1,044	0,130521	5

3.8 Overall Relative Weights (ORW)

To find out the overall relative importance of each alternative in all objectives in consideration, the overall relative weights were calculated using equation 5 (Gonzalez, 2012). The values were then ranked in order of their magnitude to determine overall ranking of alternatives shown in Table12.

$$ORW = \sum_{l=1}^{m} w_l X_{li} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where:
ORW= Overall Relative Weight, W_i= weight of ith objective and Xli= weight of ith alternative with respect to lth objective.

Table 12: The Overall Relative weight

Alternatives	ORW	Rank
Clearing vegetation	0,060462	8
Road painting	0,088201	6
Pothole patching	0,211778	1
Edge Repairs	0,109619	5
Pavement Overlays	0,164319	3
Signage Repair	0,13242	4
Drainage Maintenance	0,065898	7
Base Repair	0,167303	2

2.4.9 Final Road Segment Ranking index

Each of the deteriorations from the road segments were matched to a particular alternative as in Table 20 aimed at fixing the deterioration.

Table 13: Matching alternative with Deterioration

Pavement maintenance Alternatives	Deterioration
Clearing vegetation	1 Vegetation condition
Road painting	2 Unclear markings
Pothole patching	3 Pothole
Edge Repairs	4 pedestrian walkway 5. Edge deterioration
Pavement Overlays	6. Depression 7. Cracking 8. Bleeding 9. Ravelling
Signage Repair	10. Damaged signs
Drainage Maintenance	11. Drainage blockage
Base Repair	12. Corrugation 13. Depression

The final ranking index for each road segment was calculated by using the equation 6 below.

$$RI = ORWi \times \frac{Di}{Dmax} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Where:

R.I= Ranking Index, *ORW*= Overall Ranking Weight, *Di*= Deterioration at ith road and *Dmax*= Maximum value for deterioration recorded

Table 14: Ranking index of Engine mall- BHC road section

Pavement maintenance Alternatives	Deterioration	ORW	Di	Dmax	Di/Dmax	RI	Ranking
Clearing vegetation	1) Vegetation condition	0,060462	208	296	0,70270	0,04248	8
Road painting	2) Unclear markings	0,088201	700	700	1	0,08820	6
Pothole patching	3) Pothole	0,211778	227,53	227,5	1	0,21177	1
Edge Repairs	4) Pedestrian walkway	0,109619	27,7	95,4	0,29035	0,03182	9
	5) Edge deterioration	0,109619		0,4	0	0	10
Pavement Overlays	6) Rutting	0,164319	284	284	1	0,16431	4
	7) Cracking	0,164319		75,9	0	0	10
	8) Bleeding	0,164319				0	10
	9) Ravelling	0,164319	138	138	1	0,16431	4
Signage Repair	10) Damaged signs	0,13242		19	0	0	10
Drainage Maintenance	11) Drainage blockage	0,065898	120	120	1	0,06589	7
Base Repair	12) Corrugation	0,167303	85	85	1	0,16730	3
	13) Depression	0,167303	139,09	139	1,00064	0,16741	2
SUM						**1,10354**	

Table 15 Ranking index of Total filling station- Engine mall road section

Pavement maintenance Alternatives	Deterioration	ORW	Di	Dmax	Di/Dmax	RI	Ranking
Clearing vegetation	1) Vegetation condition	0,060462	200	296	0,675676	0,040853	6
Road painting	2) Unclear markings	0,088201	500	700	0,714286	0,063001	5
Pothole patching	3) Pothole	0,211778	4,16	227,53	0,018283	0,003872	8
Edge Repairs	4) Pedestrian walkway	0,109619	95,4	95,4	1	0,109619	3
	5) Edge deterioration	0,109619	0,4	0,4	1	0,109619	3
Pavement Overlays	6) Rutting	0,164319	49	284	0,172535	0,028351	7
	7) Cracking	0,164319	75,9	75,9	1	0,164319	1
	8) Bleeding	0,164319				0	11
	9) Ravelling	0,164319	128,5	138	0,931159	0,153007	2
Signage Repair	10) Damaged signs	0,13242		19	0	0	11
Drainage Maintenance	11) Drainage blockage	0,065898		120	0	0	11
Base Repair	12) Corrugation	0,167303	1	85	0,011765	0,001968	9
	13) Depression	0,167303	1,29	139	0,009281	0,001553	10
SUM						**0,676161**	

Table 16: Ranking Index of Engine mall – Rail road crossing segment

Pavement maintenance Alternatives	Deterioration	ORW	Di	Dmax	Di/Dmax	RI	Ranking
Clearing vegetation	1) Vegetation condition	0,060462	296	296	1	0,060462	2

Road painting	2) Unclear markings	0,088201	410	700	0,585714	0,051661	3
Pothole patching	3) Pothole	0,211778	0,29	227,53	0,001275	0,00027	8
Edge Repairs	4) Pedestrian walkway	0,109619	40,3	95,4	0,422432	0,046307	4
	5) Edge deterioration	0,109619		0,4	0	0	9
Pavement Overlays	6) Depression	0,164319		284	0	0	9
	7) Cracking	0,164319		75,9	0	0	9
	8) Bleeding	0,164319				0	9
	9) Ravelling	0,164319	35,8	138	0,25942	0,042628	5
Signage Repair	10) Damaged signs	0,13242	19	19	1	0,13242	1
Drainage Maintenance	11) Drainage blockage	0,065898	35	120	0,291667	0,01922	6
Base Repair	12) Corrugation	0,167303		85	0	0	9
	13) Depression	0,167303	3	139	0,021583	0,003611	7
SUM						**0,356578**	

Table 17: Ranking of road segments for Maintenance

Road Segment Name	Ranking Index	Ranking	Number of Segments
Road segment 3 Engine mall- BHC/BPC housing (22°32’32”S27°05’20”E)–(22°32’52”S 27°05’09”E)	1,103545	1	2
Road segment 2 Total petrol station- Engine Mall (22°32’29”S 27°05’32”E) – (22°32’30”S S 27°05’15”E)	0,676161	2	13
Road segment 1 Engine mall bus stop- Railroad crossing (22°32’39”S 27°05’11”E) – (22°32’10”S 27°05’22”E)	0,356578	3	2

4. Analysis of Results

The data collected from the ten respondents, ranking of the objectives of pavement maintenance in order of importance are Safety with a Priority Vector (PV) (55.4%), System Operation with priority vector of (22.8%), System Preservation with a priority vector of (15.6%), and Aesthetics with a priority vector of (6.2%). The raking of alternatives in the context of Aesthetics shows that pothole patching is with PV of 17.3%, signage repair with PV of 15.0%, pavement overlay with PV of 14.8%, road painting with PV of 13.2%, Base repair with PV of 13.1%, edge repair with PV of 11.3%, clearing vegetation with PV 8.2%, drainage maintenance with PV of 7.1%. Ranking of importance alternatives in the context of safety are, pothole patching with PV of 22.0%, pavement overlay with PV of 15.3%, signage repair with PV of 14.7%, Base repair with PV of 13.5%, Edge repairs with PV of 12.3%, road painting with PV of 9.8%, clearing vegetation with PV of 6.3% and drainage maintenance with PV of 6%. Ranking of importance of alternatives in the context of system operation is, Pothole patching with PV of 21.7%, Base repair with PV of 21.5%, Pavement overlay with PV of 15%, signage repair with PV of 12%, edge repairs with PV of 9.6%, road painting with PV of 7.3%, drainage maintenance with PV 6.6%, clearing vegetation with PV of 6.3%.

Ranking of importance of alternatives in the context of system preservation is, pavement overlay with PV of 23.2%, base repair with PV of 22.6%, pothole patching with PV of 18.9%, signage repair with PV of 9.0%, drainage maintenance with PV of 8.5%, edge repairs with PV of 8.2%, road painting with PV 5.7%, clearing vegetation with PV of 4.0%. From the above obtained results, the Overall Relative Weight (ORW) of each alternative with regard to all the given objectives in order of importance is pothole patching 21%, Base repair 16.7%, pavement overlays 16.4%, signage repair 13.2%, edge repairs 10.1%, road paintings 8.9%, Drainage maintenance 6.6%, and clearing vegetation 6.0%.

The results obtained indicates that, pothole patching must be prioritized first and clearing of vegetation prioritized last when performing road maintenance and rehabilitation of a particular road section within Palapye town. The selected road pavement showed varying types of deteriorations measured using area and lengths of affected areas shown in tables 5, 6 and 7.Using the Ranking Index to rank priority of alternative action to be taken during pavement maintenance and rehabilitation the following was revealed. The Engine mall – BHC road segment showed that pothole patching was to be prioritized to address the problem of potholes. Base repairs come as the second priority in terms of prioritization to address the depressions and corrugation visible on the road segment, followed by pavement overlay. The total Ranking Index (RI) score for the road segment is 1.103545 showing severity of deterioration and priority for maintenance compared to other road segment.

The Total filling station - Engine mall road segment has a total Ranking Index score of 0.676161 with pavement overlay requiring prioritization over other alternatives to specifically address the cracking deterioration on the road segment. The final road segment, which is the Engine Mall-Railway crossing, has a total Ranking Index of 0.356578 with prioritization of signage repairs. This is attributed to the fact that this road segment has a lot of junctions and the highest traffic volume of all the road segments in Palapye. This section has recently fixed with pavement overlay which shows no sign of deterioration. This has then affected visibility of road makings because funds were unavailable to mark the road segment. Final ranking of road segments shows that the Engine mall- BHC road segment should be prioritized for maintenance followed by the Total filling station-Engine mall road segment then last is the Engine-Rail road crossing.

5. Conclusion

The results from this study on ranking road pavement sections for maintenance and rehabilitation in Palapye, Central District Botswana using multi criteria approach is concluded as follows:

1) The AHP has given an accurate ranking of road segments that require urgent maintenance and rehabilitation.
2) Based on the road segments selected in this study it shows that there is an urgent need to prioritize the rehabilitation of the Engine mall- BHC road segment which is in a state of complete despair.
3) The current methods used by the Palapye town council to select road segments for maintenance and rehabilitation is qualitative and does not provide room for quantitative decision.
4) The Palapye council uses traffic volume factor as a criteria for road maintenance and rehabilitation which is always bias. Although traffic volume plays a vital role in prioritization of road segments for maintenance, using only one factor for prioritization will always tend to neglect important road segments for rehabilitation. For example, the Palapye town council decided to maintain the Total- Engine mall road segment leaving the Engine mall- BHC road segment and taking into consideration the status of Engine mall- BHC road segment which will soon require complete reconstruction.
5) This study therefore proves that AHP is a convenient approach for solving complex MCDM problems in engineering as it has an ability to rank choices in the order of their effectiveness in meeting conflicting objectives.
6) In this study, comparisons matrices were developed as weighs of AHP process according to judgments of experts who have an experience in road maintenance projects.

6. Acknowledgement

We would like to Thank Experts in Civil and Transport Engineers and the Department of Transport in Palapye for their support during data collecting.

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