SUSTAINABLE DATA ACQUISITION METHODS FOR ROAD MAINTENANCE MANAGEMENT IN DEVELOPING COUNTRIES

N.K.M. Mushule
Department of Transportation and Geotechnical Engineering, Faculty of Civil Engineering and the Built Environment, University of Dar es Salaam, P.O.Box 35131,
Dar es Salaam, Tanzania

Whilst it may be argued that manual methods of pavement data collection are subjective, unsafe, involve high personnel costs and have low repeatability, the initial costs of acquiring automated systems coupled with the technology required to operate and maintain them can be prohibitive for most developing countries. Moreover, automatic measurement of surface distress has proved to be a difficult challenge to instrument designers. In many cases, manual methods are the only ones that can be employed. A research project was carried out to design a sustainable data collection scheme for network level management system for developing countries. A simple procedure of surface distress assessment was developed and tested. This involved the determination of values to be used to translate data obtained by windshield visual assessment to equivalent actual data measurements. Kappa statistic was used to assess the reliability of the results. Furthermore, the research presents a filtering mechanism to reduce the annual number of road sections which should be tested for structural adequacy to a sustainable level, Finally, the timing, detail and frequency of data collection appropriate to a network level management system in Tanzania have been proposed.

Keywords: *Data acquisition, road maintenance management, information quality level, data hierarchy*

INTRODUCTION

Roads are provided in order to serve traffic economically, comfortably and safely. A good pavement should provide adequate riding comfort to road users, require less maintenance, provide adequate structural support to traffic loading and have adequate skid resistance for safety purposes (Haas et al, 1994). In order to assess the extent to which a pavement fulfils its functions data on pavement condition should be collected. However, the data collection component of a maintenance management system consumes a lot of resources in terms of time and money. Naturally, funds used to collect data would no longer be available for pavement maintenance. Excessive data collection is one of the problems causing pavement management systems to fail or to be discontinued. To avoid this particular problem, data design should be made in such a way that only the absolute minimum data necessary to provide the required management information is collected at appropriate level of detail. This paper presents a sustainable data acquisition scheme appropriate for road management for Tanzania and applicable to other developing countries. It presents a sustainable data collection scheme for surface distress, structural evaluation and skid resistance data. The scheme considered economy, comfort and safety as key factors. A sustainable procedure of conducting road roughness measurements in developing countries is presented elsewhere (Mushule, 2002).

The paper is organised in several sections namely, introduction, background and significance of the study, methodology, results and discussions, recommendations and conclusions. After the introduction, the paper presents the background and the significance of the study. This section lays out a framework upon which the research was conducted. It shows the deficiency in the current use of the data hierarchy concept which this research has tried to address. Furthermore, this section summarises methods used to collect data in other parts of the world and gives reasons why most of them are not appropriate in developing countries. This section is followed by the presentation of the methodology used for data collection. The results are presented and discussed after which the recommendations based on the results and experience gained from the fieldwork are put forward. Finally, concluding remarks outlining the core findings are given.

BACKGROUND AND SIGNIFICANCE OF THE STUDY

Decision support systems produce outputs after processing input data by the use of underlying models. Inevitably, data on pavement condition is the most valuable asset and is essential in order to make valid decisions on highway pavement maintenance. However, it is no exaggeration to say that the cost of data acquisition is likely to be the most expensive aspect of implementing and operating a pavement management system. Annual data collection costs are typically five to ten times the cost of purchasing the computer hardware in which to run the system (CEC, 1994). It is therefore necessary to make sure that the most essential data is collected. Any data item should be collected considering its relevance, appropriateness and reliability for the intended purpose (Paterson and Scullion,1990). The affordability of the respective agency in terms of the financial capability and staff resources required to collect and keep the data current should also be considered.

The concept of data hierarchy complies with that of Information Quality Level (IQL) whereby data is specified at different levels of detail for different purposes (Paterson and Scullion, 1990). For a network level road management system data is normally specified at aggregate level. For example, the surface condition of the pavement may be specified in three bands such as good, fair and poor. However, for the computation and preparation of road programmes, all models require that the aggregate data be converted into detailed data. Many road agencies use default values provided by the model being used which might not be realistic in the situation where the analysis is being carried out. This research addresses this problem by determining the values of translating aggregate data into equivalent detailed data for two predominant types of surface defects in Tanzania as well as for pavement structural strength evaluation.

Numerous methods and equipment of collecting data are being employed worldwide. For surface distress evaluation, available methods currently used for surface distress assessment range from visual surveys, to detailed manual measurements to the use of automated systems with little manual interventions. These methods vary in costs and quality of the information they provide. Some users of manual methods argue that the methods are subjective, non-repeatable, unsafe and involve high personnel costs. They feel that visual methods should be completely replaced by automated systems in order to fully utilise the available modern technology (Kalikiri et al, 1994). As much as these arguments may sound reasonable and realistic, initial costs of acquiring automated systems coupled with the technology required to operate and maintain them can be prohibitive for most developing countries. Moreover, automatic measurement of surface distress has proved to be a difficult challenge to instrument designers. Currently, there are no production machines that are able to undertake and analyse distress fully automatically although research in this area is very active. A good example is the difficulty of measuring cracking in a meaningful and consistent way. An on-going research at the

University of Birmingham in the United Kingdom, which has the aim of automating the crack detection and analysis process, has not reached a stage when it can be exploited commercially. In many cases, therefore, manual methods are the only ones that can be employed. For the purpose of network level aggregate data collection, windshield visual assessments are appropriate. However, visual assessment of pavement condition requires a proper selection of a rating scale. This research designed and tested a scale which can be used to carry out the visual assessment. The assessment forms were designed to be simple and easy to use.

Methods used in pavement structural evaluation are classified as destructive or non-destructive. Destructive methods include digging of test pits so that existing pavement materials and layer thickness can be obtained. To avoid pavement destruction and minimise traffic interruption, non-destructive methods are normally used. These methods determine pavement responses to loading and relate those responses to pavement performance. Non-destructive devices for pavement evaluation include deflection measurements using devices such as the Benkelman beam and Falling Weight Deflectometer (FWD).

The Benkelman beam has been extensively used in most developing countries because of its simplicity and low cost. However, the device is very slow compared to the Falling Weight Defloctometer. On the other hand, the sophistication and the acquisition and maintenance costs of the Falling Weight Defloctometer are extremely prohibitive for most countries with low income economies like Tanzania.

An alternative method, which utilises a Dynamic Cone Penetrometer (DCP) to determine in-situ structural properties of existing road pavements, exists. The method, which can be classified as semi-destructive, is cheaper than the Benkelman beam and requires less resources to operate. While an actual DCP test requires only three operators, a Benkelman beam requires two operators, a loaded truck and a driver. In addition, Benkelman measurements have been known to be uncertain because of the fact that they do not take into account the thickness and stiffness of different pavement layers (Kristiansen et al, 1996).

In the light of the above discussion, the DCP was selected for pavement structural evaluation. A major problem, however, is to determine the detail and frequency at which this information can be collected. This research proposes a filtering mechanism in order to reduce the annual number of road sections which should be tested for structural adequacy to a sustainable level.

METHOLOGY OF THE STUDY

Surface Distress Assessment

Surface distress assessment was performed visually for both paved and unpaved roads. It was recognised that visual assessment of surface distress is subjective and may differ from one person to another. For this reason, at least four raters with considerable knowledge and experience in road maintenance were involved in this exercise. All these raters were holders of at least a BSc. (Eng.) degree and had worked in the area of road maintenance for at least 10 years. A scale of 1 to 5 in which 1 represents perfect condition and 5 represents extremely bad condition was used.

Surface distresses were categorised into two groups. Firstly, group A considered those defects which can be observed on the surface of the carriageway. These include rutting, potholes, cracking and ravelling. For ease of evaluation, raters were required to identify and rate a predominant defect in this group which, in their opinion, if it is fixed, the treatment used would take care of other carriageway defects which are not as severe. Secondly, group B considered edge deterioration only, which sometimes requires a different treatment from that provided on the carriageway. This defect was rated separately. Samples of assessment forms for paved and unpaved roads are shown in Tables 1 and 2, respectively.

Following a training session by the author, each person independently rated the road section in question, from a vehicle moving at 32 kph. This was done in conjunction with roughness measurements (Mushule, 2002).

Structural Evaluation

The structural evaluation was carried out by the use of the TRL Dynamic Cone Penotrometer (DCP). The principles of operation of the equipment and its background are presented in Overseas Road Note No. 8 (TRRL, 1990).

Table 1: Road Condition Visual Assessment Form for Paved Roads

ROAD CONDITION VISUAL ASSESSMENT			REGION:		
			DISTRICT:		
			ROAD:		
			SECTION No:		
INSPECTOR:			SECTION NAME:		
			TOPOGRAPHY:		
			SURFACE TYPE:		
			DATE:		
PREDOMINANT CARRIAGEWAY DEFECT	RUTTING		NONE	1	
	CRACKING		V. SLIGHT	2	
	POTHOLES		SLIGHT	3	
	RAVELING		SIGNIFICANT	4	
	PATCHING		SEVERE	5	
EDGE BREAK			NONE	1	
			V. SLIGHT	2	
			SLIGHT	3	
			SIGNIFICANT	4	
			SEVERE	5	

Table 2: Road Condition Visual Assessment Form for Unpaved Roads

ROAD CONDITION VISUAL ASSESSMENT	REGION:		
	DISTRICT:		
	ROAD:		
	SECTION No:		
INSPECTOR:	SECTION NAME:		
	TOPOGRAPHY:		
	SURFACE TYPE:		
	DATE:		
SURFACE DISTRESS	NONE	1	
	V. SLIGHT	2	
	SLIGHT	3	
	SIGNIFICANT	4	
	SEVERE	5	
IMPASSABILITY	NONE	1	
	V. SLIGHT	2	
	SLIGHT	3	
	SIGNIFICANT	4	
	SEVERE	5	

For the purpose of this research a random sampling which covered the entire range of pavement surface condition was used. The sampling was done on roads ranging from good to poor as per visual assessment. This range was only available on Morogoro - Gairo and Iyovi- Ruaha Mbuyuni road sections. Other paved road sections in Morogoro region were in good condition. During the analysis of the results, the obtained sample was poststratified into three groups (strata) of good, fair and poor locations.

A TRL computer software was used to analyse the data collected from the field (TRRL, 1990). This software which was developed by TRL in 1990 is still relevant todate only that the pavement strength which is provided in terms of Modified Structural Number (MSN) exaggerates the pavement strength for deep pavements. This is adjusted using the procedure developed at TRL in the United Kingdom (Parkman and Rolt, 1997). Furthermore, the software is capable of identifying different pavement layer thickness and their strength. The inputs required are the number of blows used to penetrate different depths of the pavement structure. Additionally, from the same software run, in-situ subgrade strength (CBR) was obtained.

For the evaluation of structural adequacy of existing pavements, pavement design methods that are used in Tanzania were used as the basis for determining the required pavement strength. Considering a range of subgrade strength and the range of traffic levels found in Tanzania, the required adjusted structural numbers were obtained (Mushule, 2002). For roads carrying heavy traffic, a pavement section with an adjusted structural number below 3.0 was considered to have inadequate structural strength. On the other hand, sections with structural numbers between 3.0 and 4.0 were rated as having critical structural condition. A pavement section with a structural number of more than 4.0 was considered to have adequate structural strength.

Evaluation of the Contribution of Surface Condition to Road Accidents

In order to assess the contribution of surface condition to road accidents skid resistance measurements should be carried out at the identified black spots. However, it was recognised that there are a number of other contributory factors to the high number of accidents. Studies carried out by the Transport Research Laboratory indicated that accidents are rarely caused by a single factor (Staughtoun and Storie, 1977; Kemp et al, 1972). They identified a combination of interacting components involving vehicle factors, road user factors and road factors. Of these, road user factors (pedestrian and driver behaviour) were shown to cause the highest number of accidents. In their study, road factors responsible for road accidents included road surface (skidding resistance), bridge locations, poor visibility (geometry), and inadequate road signs. Consequently, it was found essential to assess the general physical condition of the road at the black spots. This was a necessary step in trying to establish whether the skidding resistance measurements would be justified. The Morogoro Regional Traffic Police provided accident data for the identification of black spots.

RESULTS AND DISCUSSIONS

For pavement distress assessment, it was found that there was very close agreement by the raters for the road sections in good and poor conditions. Using a scale of 1 to 5, observers rated good sections as 1 or 2. Poor sections were rated as either 4 or 5. In only one case of carriageway distress of paved roads, observers rated the road section as 3. However, if all types of distresses for both paved and unpaved roads are taken into account, there were 7 cases which showed close agreement for the sections rated as 3. These cases include 1 case of carriageway distress, 4 cases of edge deterioration and 2 cases of impassability rating. These sections were therefore grouped as fair for the aforementioned distress types. Consequently, the description of rating specifications presented in Table 3 was deduced. The results of visual condition assessment are presented in Tables 4 and 5.

Table 3 Visual Assessment Rating

RATING No.	DESCRIPTION	CONDITION RATING
1	NO DEFECTS SEEN	GOOD
2	SLIGHT DEFECTS OCCASIONALLY SEEN	
3	SLIGHT DEFECTS FREQUENTLY SEEN	FAIR
4	MODERATE DEFECTS SEEN	
5	SEVERE DEFECTS SEEN	POOR

Table 4 Visual Condition Assessment for Paved Roads

Section No.	Section Name	Visual Assessment Rating							
		Carriageway Distress				Edge Deterioration			
		R1	R 2	R 3	R 4	R 1	R 2	R 3	R 4
T0010105	Ngerengere- Lubungo	2	2	1	1	1	1	2	1
T0010110	Lubungo – Msanvu	2	1	1	1	2	1	1	1
T0010115	Msanvu – Sangasanga	2	1	2	2	1	1	2	1
T0010120	Sangasanga – Melela	1	2	1	1	1	2	2	2
T0010125	Melela – Mikumi	1	1	1	1	2	1	2	2
T0010130	Mikumi – Iyovi	1	1	1	2	2	2	2	1
T0010135	Iyovi - Ruaha Mbuyuni	4	4	3	4	3	4	3	3
T0160100	Mikumi – Kidatu	1	1	1	2	2	1	1	1
T0030605	Msanvu – Sokoine	3	3	3	3	3	3	3	4
T0030610	Sokoine - Dar Brew	4	4	5	4	3	3	3	3
T0030611	Dar Brew – Magole	5	5	5	4	4	4	5	5
T0030612	Magole – Dumila	4	4	4	5	4	4	4	5
T0030615	Dumila – Gairo	4	4	4	4	3	3	4	3

R1 - Rater 1

Table 5 Visual Condition Assessment for Unpaved Roads

Section No.	Section Name	Visual Assessment Rating							
		Surface Distress				Impassability			
		R 1	R 2	R 3	R 4	R 1	R 2	R 3	R 4
T0160101	Kidatu – Mang'ula	4	5	4	5	2	1	2	2
T0160102	Mang'ula – Kibaoni	4	4	5	5	2	1	1	2
T0160106	Kibaoni – Ifakara	5	4	4	4	2	2	1	2
T0160107	Ifakara – Kivukoni	4	5	5	5	2	2	2	2
T0160110	Kivukoni – Lupiro	4	5	4	4	3	3	3	3
T0160115	Lupiro – Mahenge	4	4	5	5	3	3	3	3

From the visual condition assessment results presented in Tables 4 and 5 the surface condition were deduced in aggregate terms as presented in Tables 6 and 7.

Table 8 presents the analysis of how close the raters agree with the proposed rating scale presented in Table 3. In addition, it was found that the four raters were within at least 94% agreement with the given recommendations as shown in Table 9.

Table 6 Road Surface Condition for Paved Roads (in aggregate terms)

Section No.	Section Name	Visual Assessment Rating	
		Carriageway Distress	Edge Condition
T0010105	Ngerengere- Lubungo	Good	Good
T0010110	Lubungo – Msanvu	Good	Good
T0010115	Msanvu – Sangasanga	Good	Good
T0010120	Sangasanga – Melela	Good	Good
T0010125	Melela – Mikumi	Good	Good
T0010130	Mikumi – Iyovi	Good	Good
T0010135	Iyovi – Ruaha Mbuyuni	Poor	Fair
T0160100	Mikumi – Kidatu	Good	Good
T0030605	Msanvu – Sokoine	Fair	Fair
T0030610	Sokoine – Dar Brew	Poor	Fair
T0030611	Dar Brew – Magole	Poor	Poor
T0030612	Magole – Dumila	Poor	Poor
T0030615	Dumila – Gairo	Poor	Fair

Table 7 Road Surface Condition for Unpaved Roads (in aggregate terms)

Section No.	Section Name	Visual Assessment Rating	
		Surface Distress	Passability
T0160101	Kidatu – Mang'ula	Poor	Good
T0160102	Mang'ula – Kibaoni	Poor	Good
T0160106	Kibaoni – Ifakara	Poor	Good
T0160107	Ifakara – Kivukoni	Poor	Good
T0160110	Kivukoni – Lupiro	Poor	Fair
T0160115	Lupiro – Mahenge	Poor	Fair

Table 8 Agreement of Surface Distress Field Results With The Proposed Rating Scale

Surface Condition (1)	Condition Rating (2)	No. of Cases (3)	Total No. of Responses From Raters (4)	Reponses in Agreement with Column (2)	% Agreement With Field Results
Good	1, 2	18	72	72	100.0
Fair	3	7	28	25	89.3
Poor	4, 5	13	52	51	98.1
Total		**38**	**152**	**148**	**97.4**

Table 9 Agreement of Individual Ratings With the Given Recommendations

Rater	Total No. of Responses	Responses in Agreement With Table 8 (Column 2)	% Agreement
1	38	38	100
2	38	37	97.3
3	38	36	94.7
4	38	37	97.3
Total	**152**	**148**	**97.4**

However, in order to assess the reliability of the results, kappa statistic was used to assess the strength of agreement between different raters. The results of this analysis are presented in Table 10.

As can be seen from Table 10, kappa coefficient (k) ranged from 0.65 to 1.0. Kappa coefficients ranging from 0.61 – 0.80 indicate a strong agreement between raters, and those ranging from 0.81 – 1.00 indicate almost perfect agreement (Landis and Koch, 1977). Consequently, the results of this analysis indicate that, for the rating of paved roads, there was almost a perfect agreement (k=0.86) and substantial agreement (k=0.65) for surface distress and edge deterioration rating, respectively. On the other hand, considering rating of all defects on paved roads, the rating results from different raters were in substantial agreement (k=0.75). Furthermore, perfect agreement was obtained in rating unpaved roads. In addition, overall rating of all road sections showed an almost perfect agreement (k=0.93).

The preceding discussion indicates that it is possible for the road agency to have several teams working concurrently. Ideally, each region can have its own team for the purpose of data collection if the training is done at one place where common instructions are given. The results obtained suggest that, with proper training, one rater can visually collect the surface distress data with reasonable accuracy. However, it should be recognised that the organisation is likely to get better results by using more than one assessor since they know that their results are to be cross checked.

However, modelling and all computations in the preparation of road maintenance management programmes are done using actual amount of defect rather than aggregate defect rating. For this reason, road management models require the user to provide values which would relate aggregate defect rating to actual defect measurement. The values to be used to translate surface distress aggregate data into equivalent actual defects were determined for predominant defects found in Tanzania. The study compared data collected by windshield assessment, done at Information Quality Level IV (IQLIV), with physical measurements done at Information Quality Level I (IQLI). For 90 sections measured, the results obtained are presented in Table 11.

Table 10 Reliability Assessment Using Kappa Statistic

Pavement Type	Defect Type	Kappa Coefficient (k)	Strength of Agreement (Landis and Koch, 1977)
Paved Roads	Surface Distress	0.86	Almost Perfect
	Edge Deterioration	0.65	Substantial
	ALL	0.75	Substantial
Unpaved Roads	Surface Distress	1.0	Perfect
	Impassability	1.0	Perfect
	ALL	1.0	Perfect
ALL	ALL	0.93	Almost Perfect

Table 11 Comparison of Windshield Data With Physical Measurements

Surface Condition (wind shield assessment at IQLIV)	No of sections	Average % area affected (physical measurement at IQLI)	
		Potholing*	Cracking
Good	30	0.02 (14)	2.53
Fair	30	0.39 (270)	15.87
Poor	30	3.38 (2366)	38.85

*Number of standard potholes in brackets

The results show that the averaged pothole measurements were 0.02%, 0.39% and 3.38% for pavement sections rated as good, fair and poor respectively. On the other hand, the averaged cracking measurements were 2.5%, 15.9% and 38.8% for paved sections rated as good, fair and poor respectively. These average values could be used to translate aggregate distress data into equivalent detailed data.

For paved road sections, the pavement strength was estimated by calculating the adjusted structural number of the pavement structure. The results of pavement structural evaluation, as presented in Table 12, clearly show that for locations with good surface condition the structural strength was consistently adequate. Locations with fair surface condition showed either adequate or critical structural strength. By contrast, locations with poor surface condition may have adequate, critical or inadequate structural strength. These findings suggest that a road section with poor surface condition may or may not have adequate pavement strength. The summary of these results is presented in Table 13.

Similarly, for unpaved roads, the surface layer thickness and strength were obtained from the analysis of DCP results. Once again, surface layer thickness and strength were found to vary from location to location. The same assumption of considering a layer as having approximately the same strength was made. Table 14 presents these results for a range of unsealed trunk road surface condition from good to poor as assessed by visual evaluation. However, the surface of unpaved trunk roads was mostly poor. For the purpose of this part of the study, it was therefore decided to increase the sample from some regional roads in Morogoro Region. The DCP results from these roads are shown in Table 15.

As seen from Tables 14 and 15 **some** locations with poor surface condition were found to have thick surface layers with high strength. This suggests that a poor surface condition does not necessarily mean that the surface material is of inferior quality. Nevertheless, the results indicate that for fair to poor road surfaces the surface layer was, **in most cases**, weak.

On the other hand, surface layer material on locations with good surface condition showed relatively higher strength. The CBR of surface material at these locations never fell below 40%. The Ministry of Works specifies a minimum CBR of 25% for surface material of major gravel roads (MoW, 1999). From Tables 11 and 12 it can be seen that all locations with good surface condition satisfied this requirement. Conversely, 4 locations out of 20 (20%) with fair surface condition had CBR below 25%. Similarly, the CBR of around 36% (8 out of 22) of locations with poor surface condition fell below 25%.

Examination of the identified black spots revealed that, in all cases, the surface condition was good, without any sign of bitumen bleeding. There was a clear indication that the physical condition of the road (geometry), driver behaviour and condition of the vehicles were the probable major contributory factors to the high number of accidents at those locations.

At these locations, there are fairly long stretches on both sides followed by sharp and sometimes blind corners. This situation results into overspeeding of the vehicles along the straight portions which might result into loss of vehicle control during the negotiation of the corners. At some locations, there is a combination of uphill/downhill and blind sharp corners.

The observation that was made at those locations during the study revealed that more than 90% of the vehicles travel at speeds much higher than the legal speed limit (80kph). In some cases, as it was observed during this study that, despite the 'no overtaking' sign marked on the road surface, overtaking takes place at these locations. Additionally, there are no prior warning signs to the drivers.

The above observations suggest that the skid resistance of the road surface at the identified black spots might not be a major contributory factor to the high number of accidents. For this reason, skid resistance measurements were not carried out at these locations.

Table 12 Pavement Structure Evaluation From DCP Measurements (paved roads)

No.	Section Number	Chainage (km)	Cond. (visual)	S (mm)	B (mm)	SB (mm)	SG CBR (%)	SNP	Structural Adequacy
1	T0030605[1]	1+00	Good	20	267	238	20	4.27	Adequate
2	-ditto-	3+28	Poor	20	162	373	16	3.75	Critical
3	-ditto-	7+50	Fair	15	186	259	10	3.39	Critical
4	-ditto-	12+25	Poor	10	295	215	5	3.26	Critical
5	-ditto-	18+36	Poor	10	193	202	20	3.72	Critical
6	-ditto-	23+45	Fair	18	158	346	8	3.28	Critical
7	-ditto-	28+60	Good	21	417	200	60	5.45	Adequate
8	-ditto-	32+65	Fair	23	242	302	8	3.69	Critical
9	T0030610[1]	36+50	Good	15	242	275	21	4.16	Adequate
10	-ditto-	37+00	Fair	16	212	303	9	3.56	Critical
11	-ditto-	39+45	Poor	21	194	302	7	3.32	Critical
12	-ditto-	41+10	Fair	20	332	242	20	4.63	Adequate
13	-ditto-	42+28	Good	23	332	282	16	4.59	Adequate
14	-ditto-	44+10	Poor	16	192	323	10	3.55	Critical
15	-ditto-	47+75	Fair	19	292	200	16	4.20	Adequate
16	-ditto-	49+15	Good	25	205	232	23	4.02	Adequate
17	T0030610[1]	51+30	Poor	15	188	374	9	3.54	Critical
18	-ditto-	52+20	Poor	21	199	203	5	2.78	Inadequate
19	-ditto-	54+45	Poor	24	113	200	4	2.09	Inadequate
20	-ditto-	57+68	Poor	23	265	200	10	2.11	Inadequate
21	-ditto-	61+75	Poor	16	205	252	4	2.72	Inadequate
22	T0030612[1]	64+00	Poor	25	295	310	15	4.41	Adequate
23	-ditto-	65+20	Poor	20	257	249	27	4.37	Adequate
24	T0030615[1]	72+00	Fair	10	183	304	18	3.76	Critical
25	-ditto-	81+50	Good	24	280	215	17	4.24	Adequate
26	-ditto-	87+25	Poor	22	65	270	39	3.48	Critical
27	-ditto-	93+35	Fair	24	325	200	12	4.23	Adequate
28	-ditto-	98+55	Fair	25	367	200	7	4.04	Adequate
29	-ditto-	102+90	Poor	20	398	200	9	4.38	Adequate
30	-ditto-	121+85	Good	24	276	200	37	4.56	Adequate
31	-ditto-	130+50	Fair	16	172	278	38	4.07	Adequate
32	T0010135[2]	33+70	Good	54	193	200	100	4.86	Adequate
33	-ditto-	37+65	Poor	58	131	350	9	3.87	Critical
34	-ditto-	42+30	Poor	49	262	277	16	4.69	Adequate
35	-ditto-	47+70	Poor	41	139	200	11	3.43	Critical
36	-ditto-	52+65	Good	56	179	545	24	4.69	Adequate
37	-ditto-	60+85	Good	48	186	413	30	4.63	Adequate
38	-ditto-	64+70	Fair	55	220	429	89	5.11	Adequate
39	-ditto-	70+10	Fair	50	172	308	35	4.28	Adequate

Notes: 1- Chainage from Msanvu 2- Chainage from Mikumi S - Surface layer; B - Roadbase SB - Subbase ; SG – Subgrade SNP - Adjusted Structural Number

Table 13 Summary of Pavement Structure Evaluation (paved roads)

Surface Condition	Locations (No.)	Adequate		Critical		Inadequate	
		No.	%	No.	%	No.	%
Good	10	10	100	0	0	0	0
Fair	12	7	58.3	5	41.7	0	0
Poor	17	4	23.5	9	53.0	4	23.5

Table 14 Surface Layer Thickness and Strength of Unsealed Roads as per DCP Results (Trunk Roads)

Location No.	Section No.	Chainage (km)	Surface Condition	Surface Layer Thickness (mm)	CBR (%)
1	T0160105[1]	01+00	Poor	80	13
2	-ditto-	06+90	Poor	237	13
3	-ditto-	13+15	Fair	93	38
4	-ditto-	20+35	Poor	320	30
5	-ditto-	28+10	Fair	82	6
6	-ditto-	37+00	Poor	268	24
7	-ditto-	45+35	Good	64	42
8	-ditto-	53+70	Poor	174	40
9	-ditto-	59+85	Good	162	51
10	-ditto-	66+65	Poor	680	60
11	T0160106[1]	72+10	Poor	270	23
12	-ditto-	73+25	Good	97	43
13	-ditto-	74+10	Poor	65	31
14	-ditto-	75+00	Fair	67	28
15	T0160107[2]	01+00	Good	80	51
16	-ditto-	03+50	Poor	50	97
17	-ditto-	04+75	Poor	65	110
18	-ditto-	05+50	Fair	816	59
19	T0160110[2]	07+55	Poor	319	13
20	-ditto-	11+25	Good	124	79
21	-ditto-	14+70	Poor	148	44
22	-ditto-	17+35	Fair	640	25
23	-ditto-	19+60	Fair	60	31
24	-ditto-	22+75	Good	88	114
25	-ditto-	26+80	Poor	116	27
26	T0160115[2]	31+45	Good	148	62
27	-ditto-	36+50	Poor	283	36
28	-ditto-	40+95	Fair	50	32
29	-ditto-	46+25	Good	68	40
30	-ditto-	51+15	Poor	115	38
31	-ditto-	57+50	Fair	56	28
32	-ditto-	63+25	Good	43	65
33	-ditto-	69+00	Poor	54	9

Notes: 1 - Chainage from Kidatu
2 - Chainage from Ifakara

Table 15 Surface Layer Thickness and Strength of Unsealed Roads as per DCP Results (Regional Roads)

Location No.	Road Name	Chainage	Surface Condition	Surface Layer Thickness (mm)	CBR (%)
1	Melela – Kilosa[1]	5+00	Good	114	61
2	-ditto-	10+00	Poor	189	60
3	-ditto-	15+00	Fair	127	47
4	-ditto-	20+00	Fair	169	22
5	-ditto-	25+00	Good	59	51
6	-ditto-	30+00	Fair	334	61
7	-ditto-	35+00	Poor	42	25
8	-ditto-	40+00	Good	262	71
9	-ditto-	45+00	Good	311	49
10	-ditto-	50+00	Fair	372	49
11	Dumila – Kilosa[2]	5+00	Poor	40	70
12	-ditto-	10+00	Fair	166	92
13	-ditto-	15+00	Good	111	81
14	-ditto-	20+00	Good	239	49
15	-ditto-	25+00	Poor	40	13
16	-ditto-	30+00	Fair	202	39
17	-ditto-	35+00	Fair	219	67
18	-ditto-	40+00	Good	299	56
19	-ditto-	45+00	Good	152	43
20	-ditto-	50+00	Fair	90	71
21	Mikumi – Kilosa[3]	5+00	Fair	70	23
22	-ditto-	10+00	Fair	135	34
23	-ditto-	15+00	Good	280	63
24	-ditto-	20+00	Poor	69	23
25	-ditto-	25+00	Good	118	117
26	-ditto-	30+00	Fair	40	13
27	-ditto-	35+00	Good	91	42
28	-ditto-	40+00	Good	49	50
29	-ditto-	45+00	Poor	105	17
30	-ditto-	50+00	Fair	171	45

Notes: 1 - Chainage from Melela
2 - Chainage from Dumila
3 - Chainage from Mikumi

RECOMMENDATIONS

In order to have consistence between regions, the training of data collection personnel should be done at one place where common instructions are given including rating of sample road sections.

As for the frequency of data collection, it is recommended that the surface distress data should be collected concurrently with roughness data using the same vehicle for each team. Consequently, the frequency should be the same as for the roughness measurements (i.e. once per year and twice per year for the paved and unpaved roads respectively).

Furthermore, the findings lead to the recommendation that the pavement structural evaluation for paved roads should be done only for those roads in poor surface condition as determined by roughness measurement and visual surface distress assessment. Roads in good condition should be assumed to have adequate pavement strength. This filtering mechanism will reduce the time and resources required for the pavement structural evaluation.

Regarding the frequency of pavement structural evaluation, it is recommended that this should be done yearly. It was found that depending on the strength of pavement layers DCP measurements at one location take a maximum of one hour. For the network level evaluation, course sampling of 1 location per km is adequate. This would require a maximum of 1 hour per km. This means that a one km section requires a maximum of 3 person-hours of fieldwork. It was also found that one person takes about 30 minutes to process the data collected from one location. This means an additional 0.5 person-hour per km.

It was realised that initially the amount of resource required for this task may be high. However, this will happen only in the first year of implementation of these methods. In subsequent years the evaluation will only be required for sections which will have deteriorated from good/fair to poor condition. A section with poor surface condition and found to be structurally weak will not require structural re-evaluation in the following year. This should be the case regardless of whether the required maintenance action was taken or not.

On the other hand, sections with poor surface condition but proved to be structurally sound may require re-evaluation if the required maintenance action was not taken. This is proposed due to the fact that poor surfaces normally allow ingress of water into the pavement structure. This may weaken the underlying pavement layers which may, in the course of time, result into the lowering of the overall pavement structural strength. The re-evaluation should be done to cross-check whether the previous results are still valid. In this case, a courser sampling, say 1 location per 2 km, may be adopted. Consequently, the proposed plan shows that the long-term resource requirement for the structural pavement evaluation will be low.

For unpaved roads, it is recommended that the DCP measurements should be carried out on fair to poor surfaces. If the surface layer is found to be weak, then it means that the road section requires regravelling using stronger material. On the other hand, fair or poor surfaces but with strong surface layer would require heavy grading.

Since the condition of unpaved roads changes rapidly after the rainy season, it is recommended that this task should be carried out once per year immediately after the rainy season. At this time of the year, it is very easy to identify weak areas (i.e. areas with unsuitable surface materials). Furthermore, this test will help the country to avoid unnecessary regravelling on sections with poor surfaces but strong surface material.

In addition, it is recommended that accident black spots should be examined to identify probable causes of accidents. If it is suspected that the road surface condition is the probable cause, skid resistance should be measured by a pendulum tester along with sand patch method. This equipment was selected because of its simplicity, portability and low cost. Modern methods such as the Sideway-force Coefficient Routine Investigation Machine (SCRIM) used in the United Kingdom are too expensive for the road organisations in developing country to afford the acquisition and maintenance costs. On the other hand, if other factors are identified, then they should be rectified before spending resources on detailed skidding resistance measurements at any location.

CONCLUDING REMARKS

The main objective of this study was to specify sustainable methods to be used in data collection for road maintenance management in developing countries. In view of this objective, the following were the core findings of the study:

(i) Visual assessment methods can be devised to obtain consistent results. A very important factor is the calibration of people who are involved in the data collection process. This was demonstrated by the results of kappa statistic which showed that the strength of agreement between different raters ranged from substantial to perfect.

(ii) The existing pavements in good surface condition were consistently found to have a structural capacity that meets the design requirements for the prevailing traffic condition. Consequently, the research concluded that structural pavement evaluation should be done only on pavements with poor surface condition. This screening mechanism reduces the annual number of sections which should be tested for structural adequacy to a sustainable level.

(iii) Values to be used to translate aggregate distress and structural data into equivalent detailed data were determined and are summarised in Table 16.

Table 16 Translating Aggregate Data into Equivalent Detailed Data

Data Item	Rating		
	Good	Fair	Poor
Cracking (%)	< 6.0 (AV = 2.5)	6.0 – 22.0 (AV = 16)	> 22.0 (AV = 39)
Potholes (Number)	< 56 (AV = 14)	56 – 600 (AV = 270)	> 600 (AV = 2366)
Structural Capacity (SN)	**Adequate**	**Critical**	**Inadequate**
	> 4.0	3.0 – 4.0 (AV = 3.5)	< 3.0

*** Unpaved Roads**
AV = Recommended Average Value

NOMENCLATURE AND ACRONYMS

CBR	California Bearing Ratio
DCP	Dynamic Cone Penetrometer
FWD	Falling Weight Deflectometer
IQL	Information Quality Level
MoW	Ministry of Works
MSN	Modified Structural Number
SCRIM	Sideway-force Coefficient Routine Investigation Machine
TRL	Transport Research Laboratory
TRRL	Transport and Road Research Laboratory

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