The challenges faced by Tanzania`s Road Organization in running Maintenance Management System and Pavement Management System effectively

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Abstract

Running or developing the local MMS or PMS, be it for unsealed or sealed pavements, needs a team of well-trained and experienced road organization staff and appropriate equipment. The data employed to run a gravel roads MMS should reflect the capacity of the road organization personnel to collect them. In this regard, the team should be of adequate size, education and experience. It is, therefore, essential for the benefit of road users, road organization, the environment, and the sustainability of gravel roads to establish the capacity of road organization personnel responsible for running gravel road maintenance management with the intention of meeting social, economic, and political demands.
The need to establish the adequacy of Tanzania road organizations in running gravel road MMS and PMS was the reason for conducting the qualitative research aspect of this study. The survey also intended to find out which parameters are readily collected by the surveyed road organizations, so as to include them as variables in formulating a gravel loss prediction model.
This paper presents analysis and discussion of the questionnaire responses. The study notes the challenges being faced by road organizations responsible for the maintenance management of gravel road network in Tanzania and attempts to map a way forward.

Key words: Road organizations, Pavement Management System, Maintenance Management System, Distress, Serviceability, Parameters, Gravel loss

1 Introduction

There is a thin dividing line between gravel roads maintenance management system (MMS) and pavement management system (PMS). Road management in general has the intention of maintaining and improving the existing road network to enable its continued use by traffic in an efficient and safe manner (Robinson, Danielson and Snaith 1998:1-2).

Road maintenance can be defined as the function of preserving and restoring a road and keeping it in a condition of safe, convenient, and economical use (Wright, Dixon and Meyer 2004:620). The Local Authority Association (1989 cited in Robinson, Danielson and Snaith 1998:6) states that the aims of maintenance management systems include, but are not limited to: a) using a systematic approach to decision-making within a consistent and defined framework, b) assessing budget needs and resource requirements, c) adopting consistent standards for maintenance and for the design of associated works, d) allocating resources effectively, and e) reviewing policies, standards, and the effectiveness of programmes on a regular basis. Pearson (2012:208) is of opinion that MMS should answer questions such as: a) what budget is required? b) How many maintenance plants and staff are required? c) How often should each road be graded? d) What is the resulting level of serviceability? e) What volume of gravel material is needed to be replaced annually? And f) which roads should be upgraded to sealed standards? Huang (2012:424-425) argues that pavement management is not exact science; it depend to a large extent on past experience and engineering judgment of personnel involved. In this paper is respondents from Tanzania`s road organizations.

2 Attributes of respondents and their response rate

Two groups of respondents were selected for the study and had questionnaires sent to them. These are TANROADS regional offices and district/municipal council's engineers' offices. Each group uses a different package of PMS for conserving the gravel road network under their jurisdiction.
TANROADS staff responsible for managing the trunk and regional roads uses Road Maintenance Management Systems (RMMS), while the Local Government Authority (LGA) District/Municipal council engineers responsible for managing district roads use the District Roads Management Systems (DROMAS). Both these systems have been developed with experts and financial assistance from foreign countries, with the involvement of local experts at ministerial or top managerial levels (Mwaipungu and Allopi 2012a). These two groups of respondents have mutually exclusive experience on the performance of gravel roads under their jurisdiction and the extent of the effectiveness of the type of PMS employed.

Table 1: List of respondent TANROADS regional offices and district/municipal councils engineers' offices

TANROADS region offices	District/municipal council engineer's offices
1. Coast	1.Mugumu – Serengeti, 2.Arusha City Council
2. Bukoba	3.Chunya District Council, 4.Mbeya District Council
3. Rukwa	5.Iringa Municipal Council, 6.Morogoro District Council
4. Mbeya	7.Tukuyu District Council, 8.Njombe District Council
5. Iringa	9.Temeke Municipal Council, 10.Mkuranga District Council
6. Morogoro	11. Kasulu District Council, 12.Manyoni District Council
7. Manyara	13. Iringa District Council, 14. Mbozi District Council
8. Dar es Salaam	15. Kyela District Council, 16. Bahi District Council
9. Dodoma	17. Mvomelo District Council
10. Tabora	18. Arumeru District Council
11. Tanga	19. Kilolo District Council
12. Arusha	20. Dodoma Municipal Council

Although the questionnaires were sent to randomly selected TANROADS Regional offices and district/municipal council engineers all over the Tanzania mainland, the targeted areas were those TANROADS region officers and Districts and Municipal engineers surrounding and within the Iringa region.
The TANROADS regional offices sharing borders with the Iringa region are: Mbeya, Morogoro, Dodoma, Singida regions, and district and municipal council engineers' offices belonging to the mentioned regions. Table 1 is the list of TANROADS regional offices and district/municipal councils' engineers who responded to the questionnaire sent to them.
Table 2 presents the number of questionnaires mailed to each category of respondents, the returned responses and the response rate in percentage. It should be stressed at the outset that both categories of populations are homogeneous, and according to Holt (1998:94) the more homogeneous a population is, the smaller the sample that can be drawn from it, and vice-versa. Henrrink, Hutter and Bailey (2011:16) further stress that in a qualitative study with a homogeneous population the sample can be small and deliberately so selected.

Table 2: The number of questionnaires mailed to each category of respondents, and the response rate in percentage

Category of respondents	Number of questionnaires sent	Number of returned responses	Response rate (%)
TANROADS	20	12	60.00
District/Municipal/ City	50	20	40.00
Total	70	32	45.71

3 Data Analysis

The questionnaire comprised five main questions on the following themes: (i) management of gravel roads; (ii) local climatic conditions; (iii) statistical data on gravel road networks, condition survey and uses of collected road condition data after analysis; (iv) management of gravel materials borrow pits, quality control of gravel materials used for surfacing unsealed roads; and (v) construction and maintenance operation of unsealed roads. The analysis of responses follows the question order.

According to Henrrink, Hutter and Bailey (2011:17) qualitative data analysis is interpretive, whereby researchers seek to interpret the meanings of the participants responses, views and experiences. The following sections present the analysis of the survey results.

3.1 Management of gravel roads

Maintenance is essentially a management problem. The improvement of maintenance often involves institutional reform, human-resource development and changes to management practices before addressing technical issues (Mwaipungu and Allopi 2012b).

The task of managing a gravel road in an optimal manner still remains a technically complex practice, as it involves, among other variables, different personnel with distinct experiences and motivation. Responses obtained regarding the number of personnel running the gravel road management, and their experience of the work varies widely for the road organizations being funded by the same government. Technical personnel range from 2-28, with the minimum number at district council level. The supporting staff varies Between 1-71, with the lowest figure in the district council level and the highest at TANROADS Regional offices. This kind of huge variation puts those road organization's offices with less staff in a challenging position of managing effectively the gravel road network under their jurisdiction.

From Table 3, it can be confidently concluded that both road organizations have staff with more than five years' experience in supervising maintenance operations of gravel roads.

Table 3: Experience of road organization staff in supervising maintenance operations of gravel roads

Range of experience in years	Frequency	Percentage (%)
<3, 3-5, and > 5	7	22
<3 and 3-5	0	0
<3 and > 5	3	9
3-5 and > 5	3	9
< 3	0	0
3-5	5	16
> 5	14	44
Total	32	100

It can be noted that 69% of the road organization surveyed had staff with more than three years' experience, which implies that they do not recruit new staff. From the distribution of staff with less than three years, three to five years and more than five years' experience it seems that there is not any pattern giving room for transfer of knowledge and skills from those with greater than five years' experience to those with less experience.

3.2 Engineering and technical education

Table 4 shows road organization with the range of engineers and technicians It can, therefore, be noted from Table 4 that the range of staff with engineering education varies widely, with 13 (40.6%) road organizations, having between 1-2 engineers, and only two (6.3%) organizations having between 9-10 engineers. With this type of variation in technical education, it is a bigger challenge to organise a uniform formalized system of gravel road management, not to mention implementing it effectively. According to Department of Transport, Republic of South Africa (1989:42) each road organization should be free to develop a maintenance management system which characteristically reflects its own capacity.

Table 4: Frequency of road organization with the number of staff with engineering and technical education in the range indicated

Range of engineers/technician	Engineer		Technician	
	Frequency	Percent (%)	Frequency	Percent (%)
1-2	13	40.6	10	31.3
3-4	2	6.3	5	15.6
5-6	12	37.5	7	21.9
7-8	3	9.4	3	9.4
9-10	2	6.3	3	9.4
11-12	0	0	2	6.3
> 13	0	0	2	6.3
Total	32	100	32	100

3.2.1 The size of technical and supporting staff managing gravel roads

Although the number of regional and districts in Tanzania's mainland has increased by almost 2% since the beginning of this study in 2011, this is not reflected in the size of technical personnel running gravel road management system.

3.3 Training

Continuing training is a key feature of any pavement management system for it to be effective and implementable (Kuennen 2009:2). Training must be a central part of personnel management (Harral and Assif 1988:21). According to Robinson and Thagesen 1996b:452) the aim of training is to improve job performance by extending knowledge, inculcating skills, and modifying attitudes, so that individuals can work in the most economical, efficient and satisfying atmosphere. Twenty two (68.8%) road organizations responded positively to the question regarding the availability of funds for training staff, with only 10 (31.2%) respondents stating that there are no funds for such training. However, even such a number still raises an alarm, as training is a way of improving performance by changing the way work is done; also it is an indispensable requirement for improving resource allocation (Robinson and Thagesen 1996b:452).

4 Local climatic condition

Responses to the question on local climatic conditions indicate variations in the location of gravel roads with respect to climatic conditions.

Table 5: Frequency of local climatic condition experienced in each respondent`s area of jurisdiction

Climate	Frequency	Percentage (%)
Wet	3	9.4
Dry	2	6.3
Moderate	17	53.0
Wet and Dry	3	9.4
Wet and Moderate	3	9.4
Dry and Moderate	3	9.4
Wet, Dry and Moderate	1	3.1
Total	32	100

Some gravel roads fall either in one, two or three climatic conditions prevailing in Tanzania, which are wet, dry, and moderate climatic condition as shown in Table 5, with 53% falling in moderate climate.

On the question of whether there is an area which receives a unique climatic condition different from surrounding areas; three (9.4%) road organizations confirm that they have areas with a unique climatic condition. These areas' gravel roads might need a different performance prediction model to address the situation. Although such cases as the ones reported above are few, it is a call for road organization to constantly study the environment in which they work. Through that study, they will be aware of any changes in climate patterns in order to improve further or find a better way to maintain the performance of the gravel road networks under their management within their financial limitations.

5 Statistical data on gravel road networks, condition survey, and uses of data after analysis

Although the questionnaire included questions requiring data on the length of earth road and tracks, this study discusses only data of gravel roads, which is its central focus.

The length of gravel roads under the judiciary of the road organizations which responded vary widely. The extent of variation is from 10 km to 3000 km.

Figure 1 shows the length of gravel roads that engineers of the responding road organizations manage. Total length of all gravel roads under their jurisdiction is 21,226.2 km. There are 134 engineers, implying theoretically that each engineer is supposed to supervise an average length of 158.4 km of gravel road.

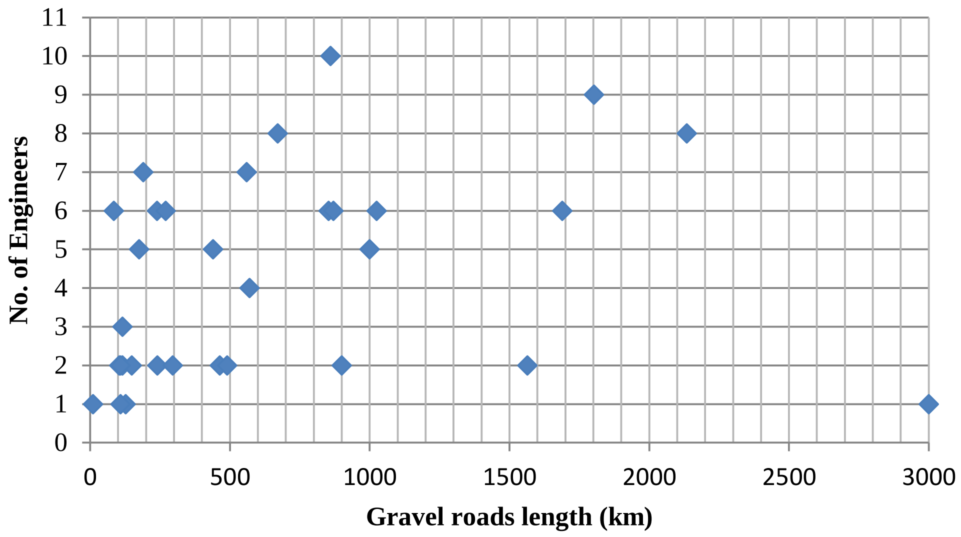

Figure 1: The total length of gravel roads managed by each civil engineer

It is noted from Figure 1 that one engineer in the same road organization, but different district or region is supervising 3000 km long of gravel road network, while in another district or region one engineer is supervising 10 km of gravel road. Figure 1 further indicates that there is no relationship between the numbers of engineers road organizations have and the total length of gravel road network under their jurisdiction.

i. Gravel roads inventory

All respondents stated that they have an inventory of gravel roads under their management. Most respondent agree that they perform gravel road condition survey annually. However, there was one contrary response from the district/municipal council, where the respondent reported that they never conducted such an exercise. Others unique responses were: road organizations which conduct road condition surveys once in the time frame of two years, two surveys a year, and no fixed schedule for the survey. The need to have a consistent time frame for conducting condition surveys cannot be overemphasized. Condition surveys are the benchmark for the performance of gravel roads and the measure of the quality and effectiveness of the maintenance regime.

ii. Traffic volume

According to Larsen, Hildebrand, and Macdonald (2002:5), traffic is one of the main causes of pavement deterioration, and therefore, it is essential for road organizations to be able to produce an accurate traffic forecast. It is no wonder that 90.32% of road organizations responded that they do collect traffic volume data and conduct distress surveys. Unfortunately, none of the respondents indicated a collection of local climatic condition data, although it is understood to affect the performance of gravel roads immensely (Paige-Green 1999:163-171).

iii. Time series performance data

None of the road organizations indicated that they conduct time-series performance studies in terms of longitudinal roughness or gravel loss surveys. According to Ellis (1979:5), improved time-series quantification of the rate of deterioration of gravel roads is necessary in order to assess maintenance needs in economic terms, and to plan cost effective maintenance strategies.

It is evident that for reliable quantified data to be collected from gravel roads, effort is needed not only to equip road organizations, but also to give them training on the need of such data. These data are required not only for developing gravel road prediction models but also for understanding the performance of gravel materials used to surface unsealed roads under their management. The data may also be used to formulate or improve gravel road specification. This understanding will have a longer-lasting effect on the performance and sustainability of gravel roads.

6 Quality control of gravel materials for surfacing gravel roads

Each respondent indicated they had an active borrow pit for winning gravel materials. Regarding whether these road organizations follow routine procedures in seeking approval from the Ministry responsible with mining or conduct environmental impact assessment before opening new borrow pit, 21 (65.6%) respondents indicated that they did not look for approval. Of the 32 respondents, two (6.3%) do conduct environment impact assessments through contractors who have been awarded construction or maintenance works, nine (28.1%) seek approval and conduct environments impact assessment. Only 12 (37.5%) respondents out of 32 do not determine the geologic natures of these borrow pits due to scarcity of geologic laboratory with such a capacity. The active laboratories for conducting such a test are located in Dodoma and Dar es Salaam regions.

Most districts and municipal councils do not own or have a materials laboratory within their district, and depend on TANROADS laboratories, which are situated in regional headquarters. Common tests conducted in these TANROADS laboratories for determining physical and mechanical characteristics of gravel materials are Atterberg limits, compaction, sieve analysis, and California Bearing Ratio (CBR). These tests are sufficient for quality control purposes.

Paige-Green (2007b) insists that the properties of the gravel materials should be tested regularly during construction to ensure that they do not differ from accepted specification. Among 32 respondents, 18 agreed that they do test gravel materials before using them, three district councils use the test results obtained by TANROADS, particularly those which share the same borrow pits with TANROADS regional offices. Three district councils declared that they do not test their gravel materials before use, while two district councils declared that there are no funds for such tests, implying that if funds are available, they will also perform all necessary tests on gravel materials before using them to surface their gravel roads.

Variations in materials test results are normally inevitable in gravel road construction or maintenance works. Eleven (34.4%) responded to this question by describing how variations in test results are addressed during quality control of construction or maintenance works on gravel roads. According to five (15.6%) respondents, variations in quality control test results are either addressed jointly by all stakeholders or by referring to standard specification. Four (11.3%) respondents said that they had not encountered variation as the tests are being conducted by the third parties who settle any variation if encountered with the parties involved, and one (3.3%) respondent said that variation encountered is within the acceptable range of ± 5 per cent.

7 Construction and maintenance operation of gravel roads

The seven questions on construction and maintenance operation of gravel roads were seeking to determine the type and availability rate of construction plant in the districts and regional offices concerned. These plant which are mainly applied during the construction and maintenance operation of gravel roads includes but not limited to graders, excavators, bulldozers, and compactors. Compactors come in different types and performance; common ones are sheep foot, steel roller, pneumatic roller, plate compactor, and pedestrian roller. The questions further intended to determine the quality control measures on construction and maintenance operations of gravel roads.

i. Availability rate of construction plants

The question of the availability rate of construction plant revealed the following results: 16 (50%) respondents said it is low, while 10 (31.3%) respondents said it is medium, and two (6.2%) said it is high. ‘Low’ means one plant per seven contractors, ‘medium’ one plant per four contractors and ‘high’ one plant per two contractors. Table 6 shows the availability rate of construction and maintenance plant.

Table 6: Availability rate of construction and maintenance plant

Availability rate	Frequency of respondents	Percentage (%)
Low	16	50.0
Medium	10	31.3
High	2	6.2
No response	4	12.5
Total	32	100

From Table 6 it can be noted that the low rate of availability of maintenance plant jeopardizes the timely execution of the construction or maintenance exercises. According to Anastasopoulos, Mannering and Haddock (2009:8) the timely application of the appropriate maintenance treatment preserves the gravel road network and extends design life. In this regard, therefore, inadequate supply of maintenance plant is among the major hindrance for timely maintenance and preservation of gravel roads which needs to be addressed.

ii. Grading methodology

On grading methodology adopted during the grading exercise of gravel roads, it is noted from Table 7 that 28 (87.5%) respondents indicated that they are using self-propelled graders, three (9.4%) mentioned that they use both self-propelled and dragged equipment. However, they conceded that dragged equipment gave unsatisfactory results. Only one (3.1%) respondent indicated that they are using dragged equipment.

Table 7: Types of grading methodology adopted during the grading exercise of gravel roads and its frequency

Use of grading equipment	Frequency of respondents	Percentage (%)
Self-propelled	28	87.5
Dragged	1	3.1
Self-propelled and dragged	3	9.4
Total	32	100

iii. Labour-based maintenance operation

According to Beenhakker et al (1987:305), the advantages of labour-based construction include: the amount of employment created per unit of investment (potentially large); economic conditions in rural areas are improved due to the construction workers` wages; and new individual skills are created. The disadvantages of labour-based construction include but not limited to: increased initial costs until labour-based experience is developed;and necessity of retraining supervisory engineers, training para-professionals or sub-professionals in low technology methods.

Labour-based gravel road maintenance operations involve breaking down various components of gravel road maintenance into small and simple activities that are easily carried out manually. Such activities are: vegetation control, earth work and gravelling (Tembo and Blockhuis 2004).

On labour intensive maintenance method vis-à-vis equipment based method, 26 (81.3%) respondents concur that the labour intensive maintenance method is a minor option, whereas six (18.7%) respondents were of view that it is of medium priority. None of the respondents gave the method high priority. Table 8 indicates how labour intensive maintenance method is being perceived by respondents.

Table 8: The level of acceptance of labour intensive maintenance methods

Level of acceptance of labour intensive method	Frequency of respondents	Percentage (%)
Low	26	81.3
Medium	6	18.7
Total	32	100.0

In rural areas, the major maintenance method being employed is the mixed one which involves both equipment and labour based methods. Twenty six (80%) of respondents used both methods, while six (20%) respondents indicated that even in the rural areas, equipment based methods are being used for maintaining gravel roads.

iv. Grading schedules

Most gravel roads require that grading be scheduled at regular time intervals in order to remove corrugations, restore transverse profile, and bring back to the carriageway profile the gravel materials that have been swept to the sides by the action of traffic (Ellis, 1979:5). Furthermore, the rate of gravel roads deterioration gives little warning of what is to come (Harral and Asif 1988:4), hence maintenance scheduling is of utmost important. On the question regarding scheduling of maintenance activities on gravel roads, 25(78.1%) respondents reported that they conduct maintenance immediately at the end of the wet season, and the rationale behind such scheduling is as follows: a) to prevent maintenance works to be interfered with by the rain, which cannot be programmed, b) it is the source of moisture for compaction in dry areas, and to rectify defects, which were developed during the rainy season, c) intervention to restore and improve road conditions at the end of the rainy season yield good results, d) to restore the surface profile and clean drainage structures, e) to rectify distress caused by washout and rain, f) the nature of soil, which is predominantly clay, dictates that maintenance be done at the end of the rainy season, g) it is easy to notice defects, and h) the soil possesses moisture content, which is somehow near optimum moisture content.

However, there were some different viewpoints amongst respondents where one (3.1%) respondent said that they conducted maintenance at the beginning of the wet season, and four (12.5%) respondents said that they conducted maintenance twice a year, both at the end of the dry and wet season.

Reading from the response above, it is evident that the schedule for collecting data on road conditions, if the data has to be reliable, should be set between the periods not scheduled for maintenance activities. Such scheduling is effective if the results shall be used to determine the intensity of maintenance. However, experience indicates that determining the intensity of maintenance activity does not mean that maintenance activity is actually carried out.

8 Conclusions and recommendations

In conclusion regarding the answers and viewpoints expressed by respondents arising from the questionnaire, it is reasonable to mention that:

- There is a big variety in terms of experience, education and number of personnel running PMS. These variations do not allow the comfort of having a uniform format of PMS thorough out the country. Each TANROADS region office and district council should be tasked to have a unique MMS or PMS to reflect its capacity.
- The distribution of staff with less than three years, three to five years and more than five years' experience does not display any definite pattern to give room for transfer of knowledge and skills from those with more experience to those staffs with less experience, which needs to be addressed.
- Although there are only a few responses regarding areas which experience unique climatic condition, this should be taken cautiously as the world is currently facing a climate-change phenomenon. Road organization should constantly study the environment in which they are working so as to be the first to note any changes from normal. This alertness will give them room to take appropriate measures to maintain and improve further the performance of gravel road networks under their management.
- It was noted from the responses received that the average length of gravel road under the judiciary of each engineer, regardless of the road organization which one is coming from, is 158.4 km. Such length is quite long for one engineer to manage effectively bearing in mind the activities involved in the PMS and MMS. The manageable length recommended by this study is 100 km per engineer.

- None of respondent indicated that they collect local climatic condition data or conduct time-series performance studies. This should be addressed as time series quantification of the rate of gravel road deterioration is necessary in order to assess maintenance needs in economic terms and plan cost effective maintenance strategies.
- It is advantageous to perform maintenance activities on gravel roads after the rain season so as to get rid of all the distress caused by its effect and made worse by traffic loading and volume.

In the same regard, it can be recommended that:

- The pavement performance prediction models adopted or to be adopted for prediction of gravel road deterioration should reflect the capacity of the road organization in question to collect data on gravel roads, which are relevant to the model in question.
- There is a need for the government to establish materials laboratories or to encourage/motivate the private sector to run one for testing road building materials in each district.
- Data on climate should be collected at particular locations preferably at ward or village level for this data to be effective in predicting climate's effects on the performance of gravel roads in those areas.
- The road organizations have to constantly study the political and economic environment in which they work. This knowledge will assist in developing, improving, influencing, and maintaining the appropriate performance of the gravel road networks under their management within their financial capacity.
- A programme of continuous training of engineers to master existing technology and incorporate new ones in existing PMS is a must for sustainability of gravel road infrastructure. Hence, funds for such exercises should be made available.
- The policy leading to the allocation of insufficient funds for gravel road conservation is not sustainable in the long term, and certainly does not permit an optimisation of the cost-benefit relationship. Without an adequate gravel road conservation system, vehicle operating costs escalate, and the economy in general is damaged. Prolonged under maintenance eventually results in a net diminution of the gravel road network.
- Transparency in addressing the root causes of gravel road deterioration is a necessary condition for an optimal allocation of maintenance funds in any economy.

References

Anastasopoulos, P. C., Mannering, F. L. and Haddock, J. E. 2009. *Effectiveness and service lives/survival curves of various pavement rehabilitation treatments*. West Lafayette, Indiana: Indiana Department of Transportation and Purdue University.

Beenhakker, H. L., Carapetis, S., Crowther, L., and Hertel, S. 1987. *Rural transport services: A guide to their planning and implementation*. London: Intermediate technology publications.

Department of Transport, Republic of South Africa. 1989. Draft urban transport guidelines (UTG) 6: Maintenance management for large municipalities. Pretoria: Department of Transport-Committee of Urban Transport Authority.

Ellis, C. I. 1979. *Pavement engineering in developing countries.* Crowthorne: Transport and Road Research Laboratory.

Harral, C. and Faiz, A. 1988. *Road deterioration in developing countries: causes and remedies*. Washington D.C: The International Bank for Reconstruction and Development/The World Bank.

Henrrink, M., Hutter, I. and Bailey, A. 2011. *Qualitative research methods*. Los Angeles: Sage.

Holt, D. G. 1998. *A guide to successful dissertation study for students of the built environment.* 2nd ed. West midlands: The Built Environment Research Unit, University of Wolverhampton.

Huang, Y.H. 2012. *Pavement analysis and design*. 2nd ed. Upper Saddle River, New Jersey: Pearson Education International.

Kuennen, T. 2009. Manage your unpaved roads for best value, performance. *Road science, better roads* (online). Available:
www.americanbusinessmedia.com/images/abm/pdfs/events/neal_library/Better Roads—Class A lot 5.pdf (Accessed 06-August 2014).

Larsen, H. J. E., Hildebrand, G. and Macdonald, R. A. 2002. *Economic evaluation of pavement maintenance*. Denmark: Danish Road Institute.

Mwaipungu, R.R. and Allopi, D. 2012a. Review of sub-Sahara Africa gravel roads management system: Tanzania case study. In: Longhurst, J.W.S. and Brebbia, C.A. ed. *18th International conference on urban transport and the environment; urban transport and the environment in 21st century.* La Coruna, Spain. 11-12 May 2012. Southampton: WIT, 629-640.

Mwaipungu, R. R. and Allopi, D. 2012b. The use of gravel loss prediction models for effective management of gravel roads. In: *31st Annual Southern African Transport Conference*. CSIR, Pretoria, 9-12 July 2012. Pretoria: SATC.

Paige-Green, P. 1999. Materials for sealed low-volume roads. Transportation Research Record 1652: 163-173.

Paige-Green, P. 2007b. *South African highway technology practice: Unsealed and sealed low volume road technology in South Africa. TRB workshop 153*. (online). Available: www.nra.co.za/content/TRB2.pdf. Accessed 12 March 2014 (Accessed 12 March 2014).

Pearson, D. 2012. *Deterioration and maintenance of pavements.* London: Institute of Civil Engineering (ICE) (Thomas Telford).

Robinson, R. and Thagesen, B. 1996b. Training of staff. In: Thagesen, B. ed. *Highway and traffic engineering in developing countries*. London: E&FN Spon,
452-475.

Robinson, R., Danielson, U. and Snaith, M. 1998. *Road maintenance management: concepts and systems*. London: Macmillan Press.

Tembo, S. and Blockhuis, F. 2004. *Manual for supervision of labour based road rehabilitation work*. Harare. International Labour Office, Advisory, Support, Information Service and Training.

Whight, P.W., Lai, J.S., Parsonson, P.S. and Meyer, M. 1996. *Highway engineering*.6th ed. Singapore: John Wiley& Sons.