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Sustainable Gravel Road Construction and Maintenance in Serengeti National Park

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ABSTRACT:

All weather road networks in protected areas are important to facilitate management of wildlife, routine park operations and to facilitate tourist accessibility to the tourist’s attractions sites hence improving their satisfaction. However, road construction in protected areas should be sustainable in terms of availability of quality materials within economical haulage distance and the entire construction, operation and maintenance process should have less environmental impacts like habitat fragmentation and dust pollution. Several studies have been done in roads constructed in protected areas but most of them had concentrated on the ecological impacts of roads. Few studies have been done from the engineering perspective of sustainable construction and maintenance of roads in protected areas. Thus, the purpose of this study is to assess the sustainability and challenges of construction and maintenance of gravel roads in protected areas. To accomplish objectives of these study four types of data were collected in Serengeti National Park (SENAPA). The data collected were from soil material test in the existing borrow pits, traffic volume counting, document study and interview with fifty (50) road stakeholders and other key informants. The soil tests and traffic volume count results show that poor performance of the studied road sections can be contributed by the quality of soil material in the existing borrow pits under the current traffic volume. Furthermore, the interview results and the document study show that other factors were, insufficient budget for road operations, unreliable and insufficient number of road equipment and lack of field skills to road equipment operators. This study will contribute to the sustainable construction of road networks in protected areas through identifying possible challenges of road construction and maintenance and give the way forward for improvement.

Keywords:

1.Protected areas
2. Gravel roads
3. Sustainability
4.Construction
5.Maintenance

DEDICATION

Dear mama,

You have never attended classes in your life, but you never ceased to encourage me about the importance of education since when I started going to school up to now. I remember there was a time I was crying because I did not have school fees but you wiped away my tears and promised me that, I will never stop studying while you are alive. I humbly dedicate this work to you dear mama to show my heartily appreciation for your tireless encouragement throughout my life.

PART 1: THE MASTER THESIS PROJECT REPORT

PREFACE

This Master thesis was instituted during the spring of 2017 from January to June at the Norwegian University of Science and Technology (NTNU) under the department of Civil and Environmental Engineering. The thesis constitutes of 30 units for the fulfilment of Masters of Science in Project Management, under the root of Civil Engineering.

The work was backgrounded by the specialization project (TBA5331 Project Management) conducted during autumn from August to December and the data collected during the summer from June to August 2016. The aim of this study was to assess the sustainability and challenges of construction and maintenance of gravel roads in protected areas the case study area being Serengeti National Park (SENAPA).

I am grateful to acknowledge the European Union's Horizon 2020 research and innovation program under grant agreement No. 641918 (AfricanBioServices), under the Norwegian University of Science and Technology (NTNU) for the support I received during my Masters study. Many thanks to Professor Eivin Roskaft, the project coordinator from NTNU under the Department of Biology for his support and encouragement. Also to Eirik Skjetne from Norwegian Public Roads Administration (NPRA) for his tireless advice and encouragement to study my Masters in Norway.

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I would also to extend my appreciation to Tanzania National Parks (TANAPA) and Serengeti National Park for granting me two years' study leave and allowing me to collect data for this study. Special thanks to Chief Park Warden from Serengeti National Park Mr. William Mwakilema for his support and encouragement to pursue this Masters. Also to Mr Izumbe Msindai for his facilitation during data collection. Special thanks to Ms Rehema Kaitila park ecologist Manyara National Park for her moral support and encouragement during the whole time of my studies.

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SUMMARY

Management of protected areas like Serengeti National Park (SENAPA) can be smoothed by improved infrastructures. All-weather road networks are important not only for the facilitation of the daily routing management activities of these areas but also provides accessibility for the tourists to the attraction sites. However, road construction in protected areas should be sustainable in terms of availability of quality materials within economic haulage distance and the entire construction, operation and maintenance process should have less environmental impacts like habitat fragmentation and dust pollution. Despite of the importance of roads in protected areas, several studies have been conducted in these areas concerning roads, but most of them concentrated on the ecological impacts of roads. Few studies have been done from the engineering perspective of the sustainable construction and maintenance of gravel road in protected areas in Tanzania.

This paper aimed to assess the sustainability and challenges of the current practice of road construction and maintenance in the main roads of SENAPA. The ambition is that the findings from the study will help to improve the understanding of both the current situation of roads in terms of traffic volume and the quality of gravel materials in existing borrow pits (the main source of materials for road construction and maintenance).

Four types of data were collected in (SENAPA). The data collected were from soil material test in the existing borrow pits, traffic volume counting, document study and interview with fifty (50) road stakeholder. This was done during summer holiday from June to August 2016. Due to the types of data collected, the mixed approach was assumed appropriate for data analysis which is the combination of qualitative and quantitative approaches.

The thesis is comprised of two sections whereby the first section consists of the master thesis project report and the second part is the Article. The master thesis composed of five chapters, each of them dealing with different aspects of the study. Chapter one introduces the back ground of the study, the objectives and the research limitations. Chapter two explains the methodological approaches used in this study, with four sub-headings which are the general literature, the case study, the theoretical approaches and the data collection. Chapter three is the theoretical framework of the study. Chapter four presents the findings and discussions which were grouped in three subsections as per research questions, i) the current practice of gravel road construction and maintenance, ii) the advantages and disadvantages of the current practice and iii) the proposed improvement measures which will be taken to improve sustainability of gravel roads in the study. Lastly, chapter five presents the concussion with sub-sections as per research questions. i) the current practice of road construction and maintenance, ii) the strengths and weaknesses of the current practice and iii) the proposed improvement measures for sustainable roads in SENAPA.

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ACRONYMS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
BS	British Standard
CBR	California Bearing Ratio
CML	Central Material Laboratory
GC	Grading Coefficient
GM	Grading Modulus
LL	Liquid Limit
LS	Linear Shrinkage
MDD	Maximum Dry Density
MID	Ministry of Infrastructure Development (Tanzania)
MoW	Ministry of Works (Tanzania)
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	Plastic Limit
PMDM	Pavement Material and Design Manual
SABS	South Africa Bureau of Standards
SENAPA	Serengeti National Park
SL	Shrinkage Limit
SNRA	South Africa National Road Agency
SP	Shrinkage Product
SSRW	Standard Specification for Road Works
TAF	Traffic Adjustment Factor
TANAPA	Tanzania National Parks

1 INTRODUCTION

The first section of the paper introduces about the background and the objectives of the thesis. It also, exemplifies the limitations of the work.

1.1 Back Ground

All weather road networks in protected areas are important to facilitate management of wildlife, routine operations and to facilitate tourist accessibility to the attraction sites hence improving their satisfaction. Despite having a positive contribution to the existence of the protected areas and nature reserves roads are also widely recognized to have negative impacts such as increasing road kills, habitat fragmentation, dust pollution and introduction of invasive species (Laurance, Goosem et al. 2009). Moreover, roads can accelerate illegal activities like poaching (Fa, Ryan et al. 2005). Having both positive and negative impacts, there has been a general debate on which standards of the roads can potentially minimize the impacts in protected areas.

More than 75% percent of the road network in sub- Sahara Africa countries regardless their traffic volume are unsealed roads, mostly surfaced by gravel materials or natural earth materials (Overby and Pinard 2007). Moreover, about 93% of the road network in Tanzania are gravel or earth roads (Mwaipungu and Allopi 2012) and all roads in national parks in Tanzania are gravel or earth roads.

Mwaipungu and Allopi (2014) argued that gravel materials will continue to be considered as affordable and economical road construction material in most of sub-Saharan Africa countries. Other authors consider unsealed or gravelled roads as antiquities of the 19th century in developed countries. Nevertheless, in certain areas in developing countries and some rural areas in developed countries, gravel roads are part of the 21st century (Kuennen 2009). As found by Shearer and Scheetz (2011) some of the local agencies in developed countries are reverting to gravel roads in low volume traffic areas.

In addition to the facts mentioned, there are number of advantages of gravel roads if proper planning and management of construction and maintenance is enhanced (Mwaipungu and Allopi 2012).The construction and maintenance of gravel road is easier than sealed

roads, require less equipment and labouring experience, and there is less waste production during construction and maintenance of gravel roads. Moreover, gravel roads are relatively safer than sealed roads due to reduced speed of vehicles (Mwaipungu and Allopi 2014). Another advantage is that in many areas in most of sub-Saharan Africa countries there is abundance of gravel materials which were derived from natural weathering of surface rocks (Millard 1993). Also, gravel roads perform better in the climate of sub-Saharan countries than in countries whereby problems like damp, cold and frost have impact on the performance of gravel road. As concluded by Mwaipungu and Allopi (2014), environmental footprints can be controlled and gravel road performance can be enhanced if there is adequate funding, proper management and appropriate research.

During the literature study, initiating the research presented in this paper, it was observed that many studies done in protected areas concentrate on the ecological impacts of roads. Only very limited number of studies concerning the engineering perspective of road construction and maintenance have been conducted in these areas.

Protected areas or conserved areas in Tanzania are areas which receive protection due to their recognized natural, ecological, or cultural values (TANAPA-NPC 1994). The protected areas concerned in this paper are those areas designated as national parks in Tanzania. The main transportation systems in most of national parks in Tanzania are earth and gravel roads for the facilitation of patrol and management activities including tourism activities. For the case of Tanzania national parks these gravel roads are constructed and maintained by the use marginal gravel materials found within the national parks. Gravel materials are natural granular materials without any admixture of stabilizers. The challenge is sustainability of these materials in terms of quality, availability in short haulage distance from the source to the road construction or maintenance site.

1.2 Research Objectives

This paper aimed to assess the sustainability and challenges of the current practice of road construction and maintenance in the main roads of SENAPA. The ambition is that the findings from the study will help to improve the understanding of both the current situation of roads in terms of traffic volume and the quality of gravel materials in existing borrow pits

(the main source of materials for road construction and maintenance). It will provide information to the park management and the infrastructure department on better practices that will enhance improvement of current road conditions. In line with this, this paper addresses the following research questions;

1. What is the current practice of road construction and maintenance in Serengeti national park?
2. What are the advantages and disadvantages of the current practice for road construction and maintenance in Serengeti national park?
3. What are the possible improvement measures for a sustainable road construction and maintenance?

1.3 Research Limitations

This research will not go to the detailed design of gravel road structure but the concentration will be on the existing gravel material available in Serengeti National park in terms of its quality and haulage distance under the current traffic volume. Also, the challenges faced in road construction and maintenance in terms of availability of funds, equipment and qualified personnel for road construction and maintenance. Soil samples were collected on the existing excavated borrow pits (disturbed material samples), no samples were collected on the loose road surface or along road section. Furthermore, the discussion in this thesis is based on the specifications for materials for the wearing layer of the gravel roads. The traffic count was not done on the same day in all study road sections due to the limitation of resources.

2 METHODOLOGY

This section explains the methodological approach used in this study. This is the continuation of the of the specialization project conducted during the autumn of 2016. Therefore, the same approaches are used in this study. Moreover, this chapter will address the different approaches used to assess relevant information for literature review, the information of the study area and types of data collected in order to fulfil the objectives of this study.

2.1 General Literature

The literature review aims to provide conception on studies and theories relevant to acknowledge during executing research work. This includes studies conducted concerning gravel road construction and maintenance in general environment and protected areas, requirements for materials and the challenges. The first step was to select key words to be used which will generate relevant information about the subject. In order to find the most relevant articles, different combinations of these search words were used (e.g. “gravel roads” + “protected areas”).

Academic online search engines, libraries and institutional websites were used to search academic literature review materials. In this study NTNU library Oria and Google scholar were used. The materials searched were briefly evaluated on their relevance and reliability to the subject. Different criteria for filtering the data results from the search engines was used, considering articles which have topics same as the combination of words used for searching. The abstract of the study papers was also used as criteria to filter the search results to get more studies which are relevant to the topic. As stated by Cronin, Ryan et al. (2008) reading the abstract and briefly studying the source content, one can get information on what the study is about and decide which is more relevant. Finally, the references of the papers judged to be of particular relevance were used to get more information relevant to the study (citation chaining) (Cribbin 2011).

However, it was challenging to find relevant materials which suits the topic of gravel roads in protected areas. Most of studies about gravel roads in protected areas focused on ecological perspective than engineering perspective. Due to that gap, general studies and

guidance manuals for gravel roads were used in this study. The reason was that there is no big difference between the performance requirements for gravel roads in protected areas and the roads in the general environment, the difference may be the mitigation measures needed for prevention of environment degradation and traffic volume permitted in roads in protected areas.

2.2 Theoretical Approaches to the Study

Depending on the nature of the study, there are different approaches which are important to consider during planning research process. In the process of collection, analysis and interpretation of data, different approaches such as qualitative, quantitative, or mixed methods can be used to tackle the problem.

The quantitative approach; refers to those studies in which data collection and analysis can be handled numerically. As depicted by Hughes (2012), quantitative approach can be controlled through sampling and design. Therefore, precision can be measured quantitatively, also statistical techniques can be employed to allow sophisticated analyses. However, as explained by the same author, the approach has some limitations like it is difficult to control all the variables due to human complexity, it does not consider the ability of the researcher or the participants unique experience and ability of interpretation. Creswell (2014) exemplify that, it is an approach that enables generalization and replication of findings and makes it complex to bias opinions or alternative explanations.

The Qualitative approach; is the approach in which collection and analysis of data is chiefly based on non-numeric and it focuses on exploring and in-depth understanding of the field or the study case. As explained by Hughes (2012) this approach is interactive and take into account the participants or researchers experience and ability of interpretation. Moreover, data collected on this process is according to the researcher's settings and the analysis of data is inductively based on particulars to general themes while data interpretation is dependent on the researchers perspective and experience (Creswell 2014). However, this approach has limitations. It is difficult to use conventional standards of reliability and validity due to the origin and subjective nature, also the approach is based on

situations, contexts, events, conditions and interactions, therefore it is not easy to replicate or to generalise to wider context (Hughes 2012).

The Mixed Approach; This approach combines both quantitative and qualitative approaches. Due to the nature of data collected for the accomplishment of this study which are laboratory soil tests, traffic volume count, interviews and document study, mixed approach methodology was assumed to be appropriate. Some of the reasons why this approach was considered to be suitable for this study as exemplified by Bryman (2006) were:

i) The combined approach enables the researcher to bring together more comprehensive and in-depth understanding of the area of interest hence improve the completeness,

ii) Combined approaches enhance integrity of the findings,

iii) The use of qualitative data can help give more illustration and explanation of the quantitative data and

iv) The combined approach in one study can help to answer different research questions.

However, other studies argue that the combined approaches may result in unpredictable outcomes (Teddlie and Tashakkori 2003).

2.3 The Case Study

This section presents the general information about the study area. It gives the overview the location, the climate and the roads selected for the study.

2.3.1 Study Area

Serengeti National Park (SENAPA) is among of sixteen national parks which are managed by Tanzania National Parks (TANAPA). TANAPA is a government institution which is mandated to manage and regulate use of areas designated as National Parks in Tanzania. The core business of SENAPA and TANAPA as whole is conservation and sustainable tourism (TANAPA-CP 2008). To achieve that, the park is managed by safeguarding wildlife through regular patrols to combat poaching activities as well as monitoring sustainable tourism activities.

SENAPA was the first proclaimed national park in Tanzania (TANAPA 2012). The park coverage is 14,763km² within the Serengeti Ecosystem which covers a total area of 25,000km². It is the second largest national park in the country after Ruaha National Park (Sinclair and Arcese 1995). Moreover, SENAPA was ascribed as the World Heritage Site by UNESCO in 1981 (Sinclair and Arcese 1995) and is among of the world seven wonders (Kisingo, Rollins et al. 2016).

The location of Serengeti National Park is between 2° 19' 58''S and 34° 34' 0'' in north-eastern Tanzania. Serengeti is within the moderate and dry seasonal tropics whereby the mean annual rainfall is between 1,050mm in the northwest and 550mm in the southeast and the mean maximum temperatures are between 24° C to 27° C and the mean minimum temperatures are between 15° and 21° C (Sinclair, Mduma et al. 2000). The seasons of strong rain is between March to May and between November and December (Sinclair 1979). The underlined soils of most parts of the Serengeti national park is volcanic ash which was result of local volcano eruptions.

The main source revenue for protection and other operations for the management of SENAPA is from tourism activities. These sources of revenue are such as gate entrance fees for tourists and vehicles, landing fees for planes, concession fees from hotels and permanent tented camps, and camping fees from seasonal camp sites. Other sources are tourism attraction packages like game viewing, walking safari, balloon safaris and hostel and rest house charges.

In order to fulfil the core business of the park, good and passable road networks are important so as to facilitate anti-poaching patrol, tourist's traffic to and from SENAPA and routine operations within the park, refer Figure 1. Currently the park has about 1,726km of road stretch including major access roads, minor access roads, tourist game circuits out of which about 500km long is gravel road and 1,226km earth road. The management of roads in Serengeti national park which includes construction of new roads, water crossings and maintenance is done by infrastructure department which have a crew of 13 staffs comprised of Drivers, plant operators and artisans. The department have also road construction equipment like motor graders, wheel loaders, backhoe loaders, excavator, concrete mixers, low bed truck and dump trucks (SENAPA 2016).

2.3.2 Study Roads Selected

In this study, the main concentration was on the main entrance roads to the central Serengeti National Park. These roads are the roads which connect SENAPA to the cities like Arusha, Mwanza, Musoma and Mugumu. Naabi road of 67km length is in the South East, passes through Ngorongoro conservation area connects SENAPA with the main tourist city Arusha. Ndabaka road of 140km long is in the Western part connects SENAPA with Mwanza city and Ikoma road of 42km, is in the North West connects Mara region towns Musoma and Mugumu and then the Sirari boarder gate to Kenya. The lengths of the roads section given are referred from Seronera which is the centre to the borders of SENAPA as shown on Figure 1.

2.4 Data Collection

To accomplish objectives of this study four types of data were collected in Serengeti National Park. The data collected were from soil material test in the existing borrow pits, Traffic volume counting, office document study and interview with different road stakeholders. The office document study data were treated qualitatively while Soil test results, traffic count and interviews were treated quantitatively. This was done during the summer holiday from July to August 2016.

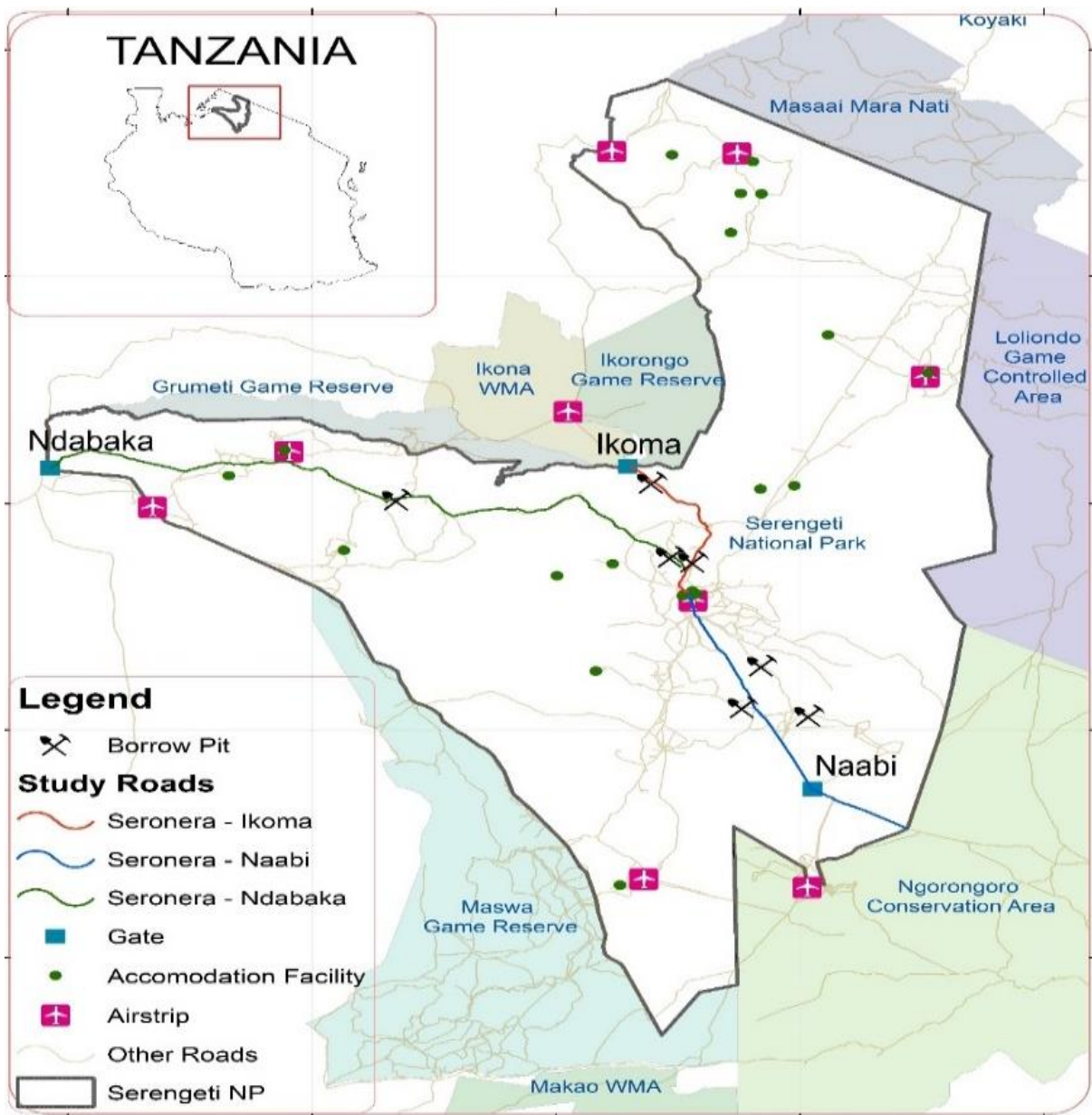


Figure 1: Map showing Serengeti road network, study roads, location of borrow pits, accommodation facilities and airstrips.

2.4.1 Soil Material Laboratory Tests

Information on the gravel material characteristics and classification facilitates the prediction on its performance. Such predictions are among the tools which can be used to find pollutions to engineering problems (McKinlay 1988).

In this study, disturbed soil samples were collected from existing borrow pits along the main roads of SENAPA. These borrow pits are the main sources of materials used for

road works. Three samples were collected from each borrow pit to obtain representative samples. The selection of borrow pits was based on different criteria. First criteria based on abundance and how frequently the materials from the sampled borrow pit are used. The information on the frequency use of the respective borrow pits was collected from the infrastructure department specifically the road construction and maintenance crew. The second criteria based on the perceived quality of the material on the borrow pit due to its past performance although there was no any information of laboratory tests done before. No samples collected on the road surface due to the assumption that the materials used for surfacing the roads are from the existing borrow pits. All soil laboratory tests were conducted at Arusha technical college (in Tanzania).

The aim of conducting soil laboratory tests was to assess the quality of the materials used for road construction and maintenance in the studied road sections. Laboratory tests to determine the characteristics of gravel materials in existing borrow pits were conducted according to procedures described by the Central Materials Laboratory (CML) of Tanzania (TZ-MoW 2000 p 2- 16). The procedures depicted in CML are based on the British Standards (BS). The soil tests conducted were soil classification which includes particle size distribution and Atterberg limits (BS 1377: Part 2: 1990 cited in TZ-MoW 2000 p 2 - 24), and soil strength which includes Compaction and California Bearing Ratio (CBR) three point (BS 1377: Part 4: 1990 cited in TZ-MoW 2000 p 36, 64).

2.4.2 Traffic Volume Count

The aim of traffic volume counts is to get information on the number of vehicles that pass on a specific section or point of a road way during a period of time (Wright, Dixon et al. 2004 p 126). As depicted by Garber and Hoel (2014), depending on the expected use of the traffic data, the count period can range from very short time 15 minutes to long time as much as one year and can further assigned into subclasses like vehicle classification, occupancy rates and directional movement. Usually traffic volume studies are conducted to determine certain vehicle volume characteristics. There are different types of volume measurement used due to the fact that traffic volume varies significantly. The relevant volume measurement used to average the traffic volume into single volume count are Average Annual Daily Traffic (AADT) and Average Daily Traffic (ADT).

The AADT can be defined as the average 24 hour collected every day in a year, in other words the sum of the number of vehicles passing at a certain point within a year divided by 365. Moreover, AADT data has different uses like assessment of economic feasibility of highway projects, development of major arterial street and freeway systems, traffic volume trend establishment, highway user revenue estimation and analysis and maintenance programs development and improvement.

ADT is defined as the average 24 hours counts, gathered over a number of days less than a year but greater than one whereby depending on the targeted use, this data can be measured in a duration of six months, a month, a week, and up to 2 days or define season (Mwaipungu 2015). The ADT data can be used in valuation of the existing traffic flow, development of highway activities and estimation of the current demand of traffic in a road section.

For this study traffic volume count were conducted in the main roads of Serengeti Naabi, Ikoma and Ndabaka to determine Average Daily Traffic (ADT), then Annually Average Daily Traffic (AADT). The traditional manual traffic count method was used to obtain number vehicles passing at the designated road section. This count for traffic volume was performed in different dates in different road sections, whereby count was done seven days in Naabi Road, three days for each Ikoma and Ndabaka road sections. These counts were carried out from 6:00 am to 07:00 pm, being the time when vehicles are normally permitted to move within the national park. Tally sheets were used for vehicle count and classification records.

The traffic volume count was conducted on the main roads because these roads are assumed to carry more traffic and are the one which needs frequent maintenance than other road sections. Also, it was assumed that, having the traffic data for the main roads can be used as baseline for decision making for the other roads. Manual count method of traffic count was used because it is the simplest way and affordable method.

Due to the constraints of time and transportation facilities traffic counts were conducted 12 hours for each road, whereby for Naabi road count was conducted seven (7) days and three (3) days each for Ikoma and Ndabaka roads. This was done on different dates for each road section due to the mentioned constraints. As depicted in Tz-MID (2009 Vol.

I) short period traffic counts require Traffic Adjustment Factors (TAF) to convert hourly, daily, or weekly data to ADT and AADT. For example, counts made for 12 hours should be converted to 24 hours by using hourly TAF in order to capture traffics which uses the road section during the night period. This is not the case for Tanzania National Parks, whereby the time limit for traffic movement in the national park is at 6:00 pm, therefore the TAF for hourly conversion not applicable. Also for Naabi road since the counts were conducted in seven (7) days consecutively, the daily TAF in a week were not applicable only the Monthly (seasonal) adjustment factor in a year (M) were applicable. For the other road sections, Daily adjustment factor in a week (D) and Monthly (seasonal) adjustment factor in a year (M) were applied. By referring the (Tz-MID 2009 Vol. I) section 3.11.6, the following formulae were used for calculation of ADT and AADT. Where V is the traffic volume at the specific location.

$$ADT = V \times D \dots\dots\dots (1)$$

$$AADT = ADT \times M \dots\dots\dots (2)$$

2.4.3 Interview to Stakeholders

Interviews are the vital source of information for research studies (Yin 2014). Moreover, interviews enhance in-depth understanding of the phenomena during a study, and it allows the interviewee to explain and elaborate their experiences and views on the case (Aasrum 2016). The aim of conducting interview was to increase the value of the information and creating deeper understanding of the case in hand (Holme and Solvang 1991). Furthermore, interviews give the researcher an opportunity to ask supplementary questions to improve understanding compared to questionnaires. Also, prior to the interview process researcher can explain and elaborate the aim of the study and make the interviewee more comfortable to answer the questions. Interviews can be either structured, unstructured, or semi-structured.

Structured Interviews: are defined as “verbally administered questionnaire” (Gill, Stewart et al. 2008). They offer very little room for follow up questions to explore responses for more depth and detail and does not use prompts. However, as depicted by the same author, the advantages of the structured interview can be quick administration process but can have disadvantage of not being useful if depth information is needed.

Unstructured interview: as defined by Legard, Keegan et al. (2003) is “a conversation with a purpose” which warrants the research more room for collection of in-depth information. Moreover, the same author exemplified that the main advantage of the unstructured interview is flexibility whereby the researcher and the interviewees have more freedom to create a context of conversation and create a comfortable environment to give information. However, the disadvantage of unstructured interview as argued by Gill, Stewart et al. (2008), is that it can be chaotic with little structure or planning because it does not reflect to any defined theories or idea and are conducted with little or no organization.

Semi-structured interview: is the medium between the structured and unstructured interviews. It has comprised with key questions which defines the areas of exploration and provides the researcher with flexibility to pursue an idea of respondent in detail (Gill, Stewart et al. 2008).

In this study, 50 semi-structured focus interviews (Yin 2014 & Wahyuni 2012) were carried out based on interview guide. The duration for each interview was 15 to 20 minutes. The interviewees were interviewed on-site in SENAPA. The interviewees were 13 TANAPA employees who manages, constructs and maintain the roads, 28 Tour driver/guides who are the main users of the roads and 9 Hotel managers who are the beneficiaries of the road. The interview conversations were face to face and were not recorded to increase the freedom and comfortability to informants to give information, instead field notes were taken.

However, the disadvantage of writing the responses from the interviewees instead of recording is that, the researcher may not take note of all information and can slow the interview process because of writing. But this was considered as suitable procedure to avoid interviewees to restrain some information or to be afraid of the recording procedure. During the interview questions were asked in the same order as in the interview guide. The important information was noted down and the respondents were given freedom of asking some questions and giving more information and advices they have.

Interviews have several disadvantages which need to be considered. The informants always give the information of what they just remember. Some of the informants are reluctant to give information and others gives the good news and hide the bad one. Further, positive elements get more attention than negative elements. Another drawback of

interviews is that, responses depends on the way the questions are posed. Sometimes the researcher may fail to be neutral during interview which may lead to the interviewees to give answers which they think will favour the researcher. Moreover, the way the questions are asked may vary from interview to interview. Despite the mentioned drawbacks, interviews were considered suitable to this study due to the following reasons. Firstly, as a complement to other sets of data, laboratory tests and traffic count. Secondly, to avoid biasness the interviewed stakeholders were mixed, TANAPA staffs from the administration side, tour guide/drivers and the hotel managers from the road user's side. Thirdly, the interview questions were formulated to contribute to answer the research questions.

2.4.4 Document study

Document study was the fourth type of data collected. Different documents such as budget books, annual reports, contracts, reports for employees, road equipment and operation reports were studied. In addition, different road design, construction and maintenance manuals and soil laboratory test manuals collected from other institutions like Arusha Technical College (ATC) in Tanzania and Tanzania Roads Agency (Tanroads) were also studied.

The aim of document study was to increase understanding and to obtain information of organization's past and current practice of road construction and maintenance. The document study process was used as the preparatory for the other data collection process. As depicted by Thagaard (2009), the document study can be used as preparation activity for data collection even for other methods of data collection. Also, the guidance for laboratory soil tests and traffic counts was obtained from document studies. As ascertained by (Tellis 1997) document study can also be used to verify data collected by other method.

However, there is some weakness of document study. It is time consuming process, and it is sometimes difficult to get all the needed documents at the same time. Some other documents are difficult to access due to its confidentiality. Another weakness is that, it depends on the willingness of the person in charge at the office to assist the researcher to get all necessary documents needed.

3 THEORETICAL FRAMEWORK.

Gravel roads can provide the intended transportation services economically and satisfactorily if proper construction and maintenance practices are used. Novelty and long-term strategic planning can keep road user satisfied with low operation cost as possible (van Zyl, Fourie et al. 2007). Therefore, roads with good satisfaction to the user can be achieved through maintenance to the acceptable level under the increasing traffic volumes and environmental needs at the same time decreasing the budgets and consumption of the suitable available materials. Moreover, the construction and maintenance of gravel roads can be easier, requiring less equipment and probably lower operator skills hence lower costs and less contribution to global warming (Mwaipungu and Allopi 2014). The same author stressed more that, damages to gravel roads are assumed to be easy and less expensive to correct than paved roads.

3.1 Sustainability of Gravel Roads

The sustainability of gravel roads depends on factors such as availability of quality gravel materials in economical haulage distance, water for compaction, and application of appropriate technologies in their design, construction and maintenance. Ferry (1998) suggested that sustainability of gravel roads can be ensured if appropriate techniques and proper technology are used during design, construction, and maintenance. But the question will remain which type of technology and technique will have less impact to the protected environment in terms of degradation of environment due to excavated gravel materials, dust pollution and erosion? Mwaipungu and Allopi (2014) suggested that, sustainability of gravel roads will largely depend on the suitability of the locally formulated manuals and standards of specification for road construction.

The word Sustainability generally can be defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland 1987). In this paper, the word sustainability means the abundance or the continual availability of gravel material with good quality within economical haulage distance while not destructing or severely disturbing the ecology and the nature of the protected environment. Also, sustainability of gravel roads in terms of durability of roads

with minimum maintenance routines. The definition by (Fowler and Fowler 1963.), “to keep going continuously” can probably suit the meaning in this paper. Will the current practice of sourcing gravel material within the national park be sustainable under the increasing demand of opening of new roads and the increasing number of traffic? This is the challenge which is required to be addressed for the sustainability of roads in SENAPA. As depicted by Mwaipungu (2015), gravel materials are non-renewable earth materials. These materials are rapidly depleted in many countries (Overby and Pinard 2007). Fine particles of gravel are lost as dust during gravel road operation and also during raining loose finer and courser particles are washed out by water and cause erosion (Mwaipungu and Allopi 2014). This can be minimized by the use of proper road design, construction and maintenance techniques and introducing local gravel loss prediction model which will be used as check-up for the quality performance of this techniques (Mwaipungu 2015).

3.2 Traffic Requirement for Gravel Roads

Gravel roads are low volume roads in rural environment having traffic volume less than 500 vehicles per day (Behrens 1999). The Tanzania Road Manuals defines gravel road pavements as the road design which have Annual Average Daily Traffic (AADT) less than 300 at the time of construction (TZ-MoW 1999). Also, Harral and Faiz (1988: 2) suggested that, gravel road can provide a good service under traffic volume ranging from 150 to 400 vehicles per day. On other hand; traffic volume regardless the type of traffic and loading are used as the criteria for decision making in the management of roads. As supported by Shuler (2007), traffic volume can be used as the simplest criteria for decision making. The same author explains that as the Average Daily Traffic (ADT) reaches 350 the cost for maintenance of gravel roads becomes uneconomical therefore, decision for paving or another technology should be considered.

Roads are designed and constructed to provide smooth or comfortable riding surface for vehicles at the same time to sustain the loads and traction effects caused by vehicles. If the volume of vehicles and its effects exceeds the capacity of the existing road structure, then problems can be revealed which pose to consideration of other type of road surface which can sustain the effects. For cost-effective decisions on construction and economical maintenance strategies of gravel roads, there is a great need for road engineers and planners

in a specific climate zone to understand the relationship between traffic volume, construction standards, deterioration rate and maintenance level (Ellis 1979).

3.3 Gravel Road Structure

Good performance of gravel road depends not only on traffic volume requirements but also on other factors such as the proper design of road cross section, quality of gravel materials, appropriate and proper use of equipment, proper application of material and skilled personnel (Skorseth, Selim et al. 2000).

The road structure which includes the subgrade and the gravel wearing course are important to be considered. Adherence to the requirement of this factors will increase the performance of the gravel road, riding quality and satisfaction to road users hence make the roads economically feasible. The road cross section of gravel roads includes the crown (camber), shoulder and the drainage structures (Skorseth, Selim et al. 2000). The same author stressed that the importance of this road cross section elements is to provide drainage of rain water from the road and to prevent water running on the surface of the road. The following is the brief explanation of these elements as shown on Figure 2.

- **Crown or cross fall:** For rapid flow of water from the road surface the road carriage surface, cross fall or crown is required to be properly designed and maintained throughout the service life of the road. To achieve this, function the Tanzania Ministry of Works Manual specified the cross fall of 4 -6 percent to be adequate for gravel road cross section (TZ-MoW 1999). However Skorseth, Selim et al. (2000) recommended the ideal cross slope for gravel road for better performance to be 4 percent. If the gravel road has no crown many problems will occur such as potholes and rutting. During the rainy season, water will not flow out of the road, the running water on the road surface will soften the gravel wearing course and cause rutting. Also, when vehicles pass on the water over the road surface small depressions will be formed which collects water and then lead to potholes. If the road crown is excessively high, can cause unsafe conditions and discomfort to drivers which result to accidents. Drivers tend to drive at the centre of the road due to high crown gravel roads. As concluded by Mwaipungu (2015), failure to repair flat camber gravel roads,

running rain water on the road surface will result to erosion, enhance gravel loss and significant decline in riding quality.

- **Road Shoulder:** On gravel road cross section, shoulder is the part which connects the road carriage way and the side ditch. Road shoulder is the supporting edge of the carriage way of the road. Other functions of the road shoulder are to provide safety space for drivers to gain control when forced out of the road and to drain water from the carriage way to the side ditch (Skorseth, Selim et al. 2000). In order road shoulder to perform its functions effectively, proper maintenance of its shape is important. The contact edge of the shoulder must be controlled and maintained to avoid low shoulder (drop-off) and high shoulder. Low shoulder or drop-off reduces the support of the edge of the carriage way and reduces the safety of the road. On other hand, high shoulders block the flow of water from the road surface which causes seepage of water to the subgrade and soften the whole road and weakens its stability. Another problem of high shoulder is that the running water erodes the surface gravel sometimes even the subgrade can be eroded which may lead to serious safety hazard. However, it is hard to eliminate completely high and low shoulder. Therefore, it is the responsibility of the road managers to work hard to maintain the proper shape of the shoulder. This can be achieved by the use of skilled operators and proper equipment which will reduce this defects to a minimum level and make the gravel road more sustainable and economical (Skorseth, Selim et al. 2000). The materials for shoulder should have the same quality as for the gravel wearing course (TZ-MoW 1999).
- **Road Ditch:** This is the main and common drainage structure for roads. Road ditches should be maintained to a good standard, gentle slope, free of debris and good shape and size to facilitate efficient flow of rain water and avoiding drainage problems on road surface. This can be easily achieved using proper equipment and skilled operators during the dry season or periods of low rain (Skorseth, Selim et al. 2000).

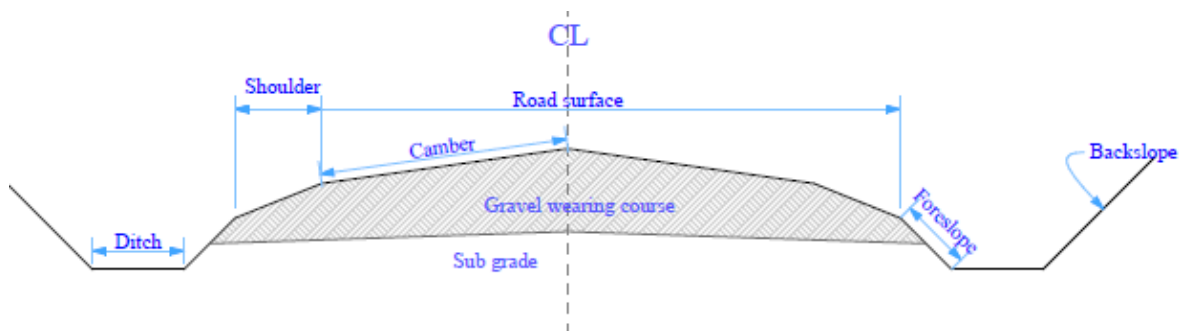


Figure 2: Elements of gravel roadway cross section

3.4 Gravel material requirements

The Quality of gravel materials is another factor which should be carefully considered for good performance gravel roads. Gravel is a combination of three types of materials of different sizes which are stone, sand and fines. Good gravel requires a certain percentage of stone to carry loads of vehicles especially during wet season, a percentage of sand sized particles to fill the voids between stones and give stability, and also a percent of plastic fines to combine together the stones and sand to make firm gravel surface to shade water (Skorseth, Selim et al. 2000). Proper gradation of gravel materials leads to good quality gravel. As ascertained by Mwaipungu (2015), factors which contribute to a good gravel are particle size distribution and cohesion which can have a range from very fine particle sizes up to about 40mm. Too high percentage of large particles (stones) will result in poor riding quality and the make the maintenance work difficult. On other side the fine particles should have good plasticity to provide bond with larger particles when dry but high plasticity is not recommended because will make the road slippery and impassable during wet season. In order to determine the quality of gravel, soil materials tests should be conducted in accordance with the locally available specification manuals (Mwaipungu and Allopi 2014). However, the knowledge of the past performance of the locally available materials on gravel road can be used as selection criteria of gravel material. As stated in the Tanzania Pavement Material and Design Manual (PMDM) the deviation from the provided standard can be done by experienced road engineer if necessary to take advantage of marginal gravel sources based on the proved past performance on gravel roads (TZ-MoW 1999).

Moreover, Tanzania road guidance manuals PMDM and SSRWs specify combination of parameters which should be satisfied during selection of gravel materials for

wearing layer and subgrade layer for gravel roads in Dry and moderate climate zones. Table 1 shows the requirement combination of parameters for wearing layer while Table 2 represent requirement combination of parameters for subgrade layer for gravel roads.

Table 1: Material requirements for gravel wearing source (Source PMDM table 11.1)

Properties	Material (Gravel) Class
CBR (%) at 95% MDD BS-Heavy Compaction on Dry or Moderate Climate Zone	Minimum 25 at OMC
% Passing the 37.5 mm Sieve	Minimum 95
Shrinkage Product (SP)	Minimum 120, Maximum 400
Grading Coefficient (GC)	Minimum 16, Maximum 34

Table 2: Material requirements for Subbase Layers of G25 (Source: PMDM, Table 7.3).

Material Properties	Material Class G25			
CBR [%] Wet or Moderate Climatic zones	Minimum 25 after 4 days' soak			
CBR [%] Dry Climatic zones	Minimum 25 at OMC BS-Heavy or minimum after 4 days soaking			
	General Requirement		Coral rock, Calcret or other Pedogenic Materials	
Atterberg Limits	Wet or Moderate Climate	Dry Climate	Wet Climate	Dry or Moderate Climate
max LL [%]	45	50	45	55
max PI [%]	16	20	18	24
max LS [%]	8	10	9	12
Minimum GM	1.2			

In general, construction and maintenance of gravel roads depends largely on the use of proper equipment, skilled and experienced personnel, and the use of good quality gravel materials. Good gravel road rehabilitation and maintenance is largely subject to two basic principles which are proper use of motor grader or other grading equipment and use of gravel materials of good quality (Skorseth, Selim et al. 2000). To achieve optimum economical construction and maintenance of gravel roads there is a great need of continuing study, development, and intensification of the knowledge of how various parameters of gravel roads interact.

4 FINDINGS AND DISCUSSION

This section presents the findings, the discussions and their implication to gravel roads. The findings were grouped in three subsections as per research questions, i) the current practice of gravel road construction and maintenance, ii) the advantages and disadvantages of the current practice and iii) the proposed measures which will be taken to improve the current practice and make gravel roads more sustainable. The main road discussed in this section are as shown on Figure 1.

4.1 Current Practice of Road Construction and Maintenance

The current practice of road construction and maintenance at the study area was assessed in terms of the quality of available gravel materials in the existing borrow pits, the existing traffic volume, the opinions of the road stakeholders and study of various documents. To fulfil this purpose the following sets of data were collected at the study area.

i) soil material laboratory tests were conducted to determine the quality of the available gravel materials in the existing borrow pits by the assessment of different parameters for soil quality analysis,

ii) traffic count to determine the existing volume of traffic in the main roads,

iii) interview to road stakeholders to get their opinions on the current condition of roads and

iv) document study to get information and improve understanding of the study area.

Following is the description, presentation and discussion of the findings based on the current practice of road construction and maintenance in SENAPA.

4.1.1 Soil Material Laboratory Tests

Most of Civil Engineering works are constructed on the soil or rock strata, at the same time soil and rock are the raw materials for construction works (Mwaipungu 2015). In most of civil and building engineering constructions, soil physical characteristics plays a vital role. In addition, soil is the result of accumulation of different factors, processes and it exist in many varieties. The soil material characteristics are largely depending on its weathering process at different stages of formation, the properties of the parent rock from

which they were derived and the weathering process of the parent rock. According to Mwaipungu (2015), the metamorphism and weathering process over geological time to some of rock materials resulted into the countless variate of soils existing today. Additionally, there are other factors on which variation of soil material depends on, such as wetting and drying, means of soil deposition, transportation method which brought the soil to its current location, drainage and its history of loading (McKinlay 1988). Furthermore, the same author concluded that the physical and mechanical characteristic of soils including gravel materials (product derived from soil) are cyclical and probably can differ within a short distance.

Road engineers required to be guided by soil test results when locating, designing and constructing roads (O'Flaherty 2002). The soil tests are required to be properly conducted and the data obtained should be examined wisely, for optimum and realistic test results. Tests on construction materials are important because the results will guide engineers to make scientific design and economic utilization of materials during design and construction of roads (Khanna and Justo 1982). It is also necessary to classify soil into groups of similar physical properties due to its wide variety of types. As depicted by Khanna and Justo (1982 p 1- 14) soil can be classified by simple laboratory tests like grain size analysis and consistency limits and indices.

The following is the description soil tests conducted and the results as indicated in respective tables including brief discussion as per specifications recommended for gravel wearing course materials given by different studies and gravel road guidance manuals.

Soil Particle Size Analysis: This is the measurement of size distribution of individual particles of given soil sample. According to (Sargious 1975), the relative proportions of different grain sizes of soil sample can be determined by soil particle size analysis. However, as depicted by McCarthy David (2007), soil behaviour can be affected to some degree by factors such as particle size and shape. In general, it is expected that soil materials which have same particle size distribution curve will have similar engineering physical properties. It is possible to classify coarse-grained soil material and estimate their engineering properties based on particle size distribution curve but prediction of soil behaviour by this method should be done cautiously (Scott 1980 p. 9). This is because

laboratory based soil particle size distribution curves does not give the arrangement, particle shape and packing density of the in-situ soil (Mwaipungu 2015).

The use of soil sieve analysis results is not only for the compliance under the given specification requirement for soil particle size distribution but also can be suitable for development of empirical relationship of gravel material performance (AASHTO 2009: T27-2). However, there are other studies which do not agree on the use of particle size distribution results on empirical relationship for the performance of gravel material but in general further studies can permit this practice. This was supported by O'Flaherty (2002) that, particle size distribution data are mostly valuable for soil classification determination, but for the empirical relationship of gravel material performance is not recommended unless studies are conducted to proof the application.

The presentation of particle size distribution data can be done in two formats, table and graph format. The table format is the format in which the total percentage of particles of a sample that passes a given sieve size are recorded while in the graphical format the relationship of the sieve or particle size versus the percentage passing the given sieve are plotted.

In this study, the results for soil particle size distribution were used for soil visual classifications and as parameters to assess the performance relationship of gravel materials used for road construction and maintenance in SENAPA. This was based on the specification requirement given by Standard Specifications for Road Works (SSRW) and Pavement Materials and Design Manual (PMDM) and other manuals. Therefore, Table format for data presentation was used as shown on Table 3 which shows the results for soil visual description. Also, Table 4 shows the sieve analysis results of materials passing sieves 63mm, 37.5mm, 19mm, 2mm, 0.425mm and 0.075mm. These sieve sizes were selected because the materials passing on these sieve sizes are used for the derivation of other parameters for soil behaviour characterization. Some of these parameters which are the preference of this study are Grading Coefficient (GC), Grading Modulus (GM) and Atterberg Limits.

Table 3: Summary of soil visual description

Road Name	Borrow Pit Name	Sample Number	Visual Soil Description
NAABI ROAD	Kilima Fisi Borrow Pit	1	Dark Greyish Silt GRAVEL
		2	Dark Greyish Silt GRAVEL
		3	Dark Greyish Silt GRAVEL
	Matiti Borrow Pit	1	Darkish Quartzite Silty GRAVEL
		2	Darkish Gray Volcanic Silt GRAVEL
		3	Dark Brownish Quartzite Silty GRAVEL
	Sumay Borrow Pit	1	Darkish Quartzite Silty GRAVEL
		2	Darkish Quartzite Silty GRAVEL
		3	Darkish Quartzite Silty GRAVEL
IKOMA ROAD	Ikoma Borrow Pit	1	Dark Grayish Volcanic Silt GRAVEL
		2	Dark Grayish Volcanic Silt GRAVEL
		3	Dark Grayish Volcanic Silt GRAVEL
	Mokasi Borrow Pit	1	Darkish Silty GRAVEL
		2	Darkish Silty GRAVEL
		3	Darkish Silty GRAVEL
NDABAKA ROAD	Belabela Borrow Pit	1	Reddish Volcanic Silty GRAVEL
		2	Reddish Volcanic Silty GRAVEL
		3	Reddish Volcanic Silty GRAVEL
	Nyaruswiga Borrow Pit	1	Dark Brownish Quartzite Silty GRAVEL
		2	Dark Brownish Quartzite Silty GRAVEL
		3	Dark Brownish Quartzite Silty GRAVEL

Grading Coefficient (GC): Is among of the parameters derived from particle size distribution results. GC is used as an indicator for the performance characteristic for gravel materials. As specified on the Tanzania Manuals (TZ-MoW 1999 p 11.3) and (TZ-MoW 2000 p3-24) the recommended GC value for marginal gravel materials can range from 16- 34 inclusive.

Based on the recommended range for GC, results show that only nine samples out of twenty-one which is about 42.9 % are within the recommended range of GC and twelve samples which is about 57.1% is out of the limit. All the samples which were out of the recommended limit were above the upper limit, no samples with GC values below the lower limit. Only Ikoma borrow pit, from which all its samples fall within the limit. Moreover, all samples of Nyaruswiga borrow pit falls outside the upper limit and the remaining borrow pits one or two samples fall outside the limit and vice versa as shown on Table 4.

Grading Modulus (GM): Is a simple method for the assessment of properties of the soil and gravel materials. According to (SABS 1996 P 2) the value for grading modulus of

gravel materials with low fine fraction will be greater than 1, while for gravel materials with higher fine fraction will have grading modulus value less than 0.8. In addition, materials with Grading Modulus greater than 2 denotes coarsely graded gravel with relatively good quality and materials with GM less than 2 indicates fine size gravel with poor quality for road construction uses (SNRA 2009).

Laboratory test results as presented on Table 4 show that seventeen samples which is about 81% have GM value greater or equal to two and four samples about 19% have GM value less than two. All samples of four borrow pits Matiti, Sumay, Mokasi and Belabela have GM greater than two, while two samples out of three from Kilima Fisi and Nyaruswiga borrow pits have GM value greater than two and one sample have value less than two but greater than one. The results for Ikoma borrow pit shows that two samples have GM value less than two and one sample have value greater than two. Under the recommended specification given above all samples have low fine fraction and four out of seven borrow pits have course graded materials which are relatively good for gravel road construction.

Table 4: Summary of Soil Particle size distribution, Grading Modulus (GM) and Grading Coefficient (GC) for soil samples from existing borrow pits in selected roads.

Road Name	Borrow Pit Name	Sample Number	Particle size distribution (% passing)						GM	GC
			63 mm	37.5 mm	19 mm	2 mm	0.425 mm	0.075 mm		
NAABI ROAD	Kilima Fisi Borrow Pit	1	100	86.0	69.7	37.0	20.4	14.9	2.3	31.6
		2	100	92.1	74.8	34.1	22.2	18.1	2.3	32.6
		3	100	100	87.2	47.4	35.7	25.5	1.9	39.6
	Matiti Borrow Pit	1	100	100	84.9	36.3	27.7	22.4	2.1	37.2
		2	100	89.2	74.9	40.5	24.7	15.0	2.2	32.8
		3	100	100	91.2	39.0	22.5	16.6	2.2	45.8
	Sumay Borrow Pit	1	100	100	79.2	32.6	22.8	19.3	2.3	34.3
		2	100	100	96.1	34.7	24.4	20.6	2.2	40.9
		3	100	100	85.0	39.9	25.8	20.2	2.1	37.8
IKOMA ROAD	Ikoma Borrow Pit	1	100	92.3	78.8	44.9	36.0	30.4	1.9	31.1
		2	100	100	86.3	44.7	35.3	30.2	1.9	33.8
		3	100	95.5	80.6	31.4	24.3	20.3	2.2	28.8
	Mokasi Borrow Pit	1	100	92.5	60.8	26.1	18.0	13.5	2.4	24.8
		2	100	93.4	84.2	44.1	31.2	20.7	2.0	34.3
		3	100	91.5	80.2	43.9	28.5	21.0	2.1	34.1
NDABAKA ROAD	Belabela Borrow Pit	1	100	96.3	82.1	14.1	9.4	7.4	2.7	23.4
		2	100	75.9	65.3	9.2	7.2	6.1	2.8	17.4
		3	100	89.9	78.8	30.1	17.7	11.8	2.4	34.2
	Nyaruswiga Borrow Pit	1	100	100	81.6	49.2	35.9	29.5	1.9	38.1
		2	100	100	86.1	37.0	21.5	17.3	2.2	40.8
		3	100	100	82.9	36.3	22.5	19.4	2.2	43.0

Atterberg Limits or Consistency: Are the tests conducted to measure the plasticity of the soil materials. O’Flaherty (2002) denoted that soil consistency test can demonstrate the soil flow resistance properties. As defined by Albert Atterberg the Swedish Scientist, there are six consistency limits of fine grained soils which are, the upper limit of viscous flow, the liquid limit, the sticky limit, the cohesion limit, the plastic limit and the Shrinkage limit (Mwaipungu 2015). The most used Atterberg limits for soil and road engineers and for this study are Liquid limit (LL), Plastic Limit (PL) and Shrinkage Limit (SL).

From the plastic limit and liquid limit results, the value for plasticity index can therefore be computed. The range of moisture content over which soil material is at plastic state is defined as the Plasticity Index (PI), or Numerically PI is the arithmetic difference between Liquid and Plastic Limits (Garber and Hoel 2014). As explained by O’Flaherty (2002), PI results can be used to predict the strength of gravel material. Furthermore, gravel materials with PI less than 6 are not suitable to be used as wearing material for gravel roads because of insufficient plasticity for that purpose (Naidoo and Purchase 2001). LL and PI can be the best option in prediction of the quality of gravel material by excluding granular materials to a certain extent (O’Flaherty 2002). Consideration of the formation and weathering process of the material in question is important as can affect the results. As supported by Paige-Green (1989) there is significant variation of the plasticity of gravel material of the same type of soil due to condition and stage of weathering.

Shrinkage Product (SP): Is another parameter for Atterberg limits which can be defined as the product of the shrinkage limit and the percentage of materials passing sieve size 0.425mm (Maxwell and Lay 2009). The recommended value of SP for road surfacing gravel material ranges from 120- 400, but the ideal value of maximum 270 is desirable to reduce the dust problems in built up areas (TZ-MoW 1999 p 11.3). However as depicted by Mwaipungu (2015), materials of high SP can be slippery during operation of the road and materials with low SP can lead to ravel and corrugation problems as shown on Figure 3. Table 5 presents the results of the Atterberg Limits of soil samples collected from existing borrow pits along main roads in SENAPA.

The results of Atterberg limits can be discussed as follows. As presented on Table 5, results show that all soil samples have PI value greater than 6 which implies that, the

materials are suitable for wearing course for gravel roads under PI specification (Naidoo and Purchase 2001).

On the side of Shrinkage Product parameter, results show that, eighteen samples which is about 85.7% have SP value which falls within the recommended value from 120-400, and only three samples about 14.3% falls below the lower range. Materials samples from five borrow pits namely Matiti, Sumay, Ikoma, Mokasi and Nyaruswiga which is about 71% falls within the recommended range for SP which implies that these materials can be suitable for gravel road construction and will perform well during road operation as shown on Figure 3. However, Kilima Fisi and Belabela borrow pit results show that only one sample from each borrow pit falls within the recommended range, two samples from each borrow pit falls below the lower limit, this implies that ravelling and corrugation problems can result during road operation if materials from this borrow pits used for gravel road construction. On other hand, only eleven samples which are about 52.4% meets the requirement of maximum SP value of 270 to reduce dust problems. Under this limitation only Matiti borrow pit sample results qualify for SP specifications 270 value for dust reduction, but since the roads are in protected areas these specifications for dust control should adhere the requirements for protected areas.

Strength Tests: Test conducted for strength were Compaction tests to determine the Maximum Dry Density (MDD), Optimum Moisture Content (OMC) and California Bearing Ratio (CBR). Compaction test are conducted to study the relationship between the grading characteristics, degree of compaction, the maximum dry density and the optimum moisture content of soil materials. Therefore, materials which are poorly graded gives low density and well graded materials gives high density (Gidigas 1983). Among of the engineering properties of materials for gravel wearing course layer is sufficient strength to support the traffic volume and load without significant plastic deformation. California Bearing Ratio test results are used as key parameters to assess strength requirement for gravel wearing course which covers and protect the subgrade layer against the traffic load (TZ-MoW 1999). Also, as depicted by the same manuals, the compaction tests are used as a guidance to specify field compaction for gravel materials. As explained earlier, the study area falls under moderate and dry climate zones. The recommended CBR value for gravel wearing layer as specified

by PMDM for moderate and dry climate zones is minimum 25% at OMC but it can be lowered to 15% for minor roads (TZ-MoW 1999 p 11.3).

Table 5: Summary of Atterberg Limits (Liquid Limit, Plastic Limit, Plasticity Index, Linear Shrinkage, and Shrinkage Product) for soil samples from existing borrow pits in selected Roads.

Road Name	Borrow Pit Name	Sample Number	Atterberg Limits				
			Liquid Limit (LL) %	Plastic Limit (PL) %	Plasticity Index (PI) %	Linear Shrinkage (LS) %	Shrinkage Product (SP)
NAABI ROAD	Kilima Fisi Borrow Pit	1	47.4	30.95	16.45	4.29	87.52
		2	48.2	31.61	16.59	3.57	79.25
		3	47.0	26.57	20.43	10.71	382.35
	Matiti Borrow Pit	1	44.2	26.73	17.47	8.57	237.39
		2	37.0	23.83	13.17	7.14	176.38
		3	36.4	23.83	12.57	7.14	160.65
	Sumay Borrow Pit	1	46.2	29.41	16.79	11.43	260.60
		2	41.4	24.73	16.67	12.86	313.78
		3	40.4	28.12	12.28	9.29	239.68
IKOMA ROAD	Ikoma Borrow Pit	1	33.60	16.39	17.21	7.86	282.96
		2	34.98	17.38	17.60	8.57	302.52
		3	37.85	18.44	19.41	10.0	243.00
	Mokasi Borrow Pit	1	89.0	21.05	67.95	11.43	205.74
		2	38.8	23.30	15.50	7.86	245.23
		3	36.8	21.14	15.66	10.71	305.24
NDABAKA ROAD	Belabela Borrow Pit	1	41.3	19.13	22.17	12.86	120.88
		2	44.5	24.15	20.35	11.43	82.30
		3	46.9	24.5	22.75	12.14	214.88
	Nyaruswiga Borrow Pit	1	38.40	24.45	13.95	9.29	333.51
		2	43.6	21.97	21.63	10.00	215.00
		3	55.80	29.63	26.17	14.29	321.53

We can discuss the strength test findings from the existing gravel borrow pits as follows; the gravel material class according to the CBR value from each sample ranges from G7 to G80. Since the study borrow pit materials are used for the construction and maintenance of the main roads in Serengeti National Park the minimum recommended CBR value for wearing layer and the subgrade or combined wearing layer and subgrade is 25% which is equivalent to gravel class G25 (TZ-MoW 1999 p 11.3). Sample materials from Matiti and Belabela borrow pits satisfies this requirement. Samples from other borrow pits have mixed CBR values as indicated on Table 6. Contrary to the perceived believe that

Nyaruswiga borrow pit materials are the best materials for road and airstrip maintenance, results show that this borrow pit is the one with the lowest value for CBR.

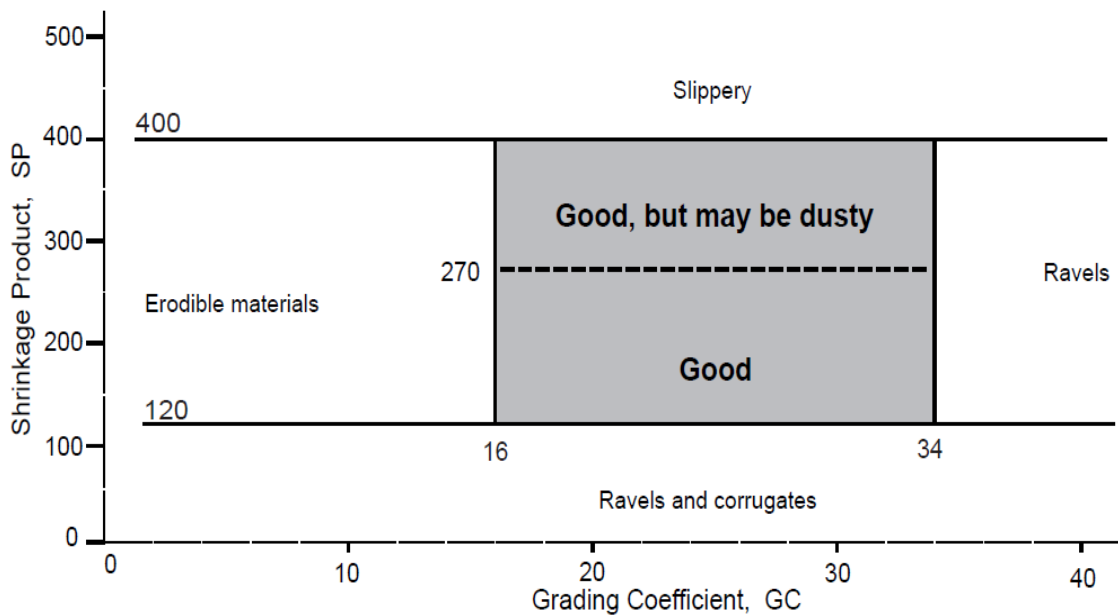
Proper gradation and mixing of materials during excavation and loading can improve the strength of the material. Although CBR is not the only criteria for gravel material, there is great need of proper study and assessment of the material sources by laboratory tests prior selection and excavation of borrow pits.

Table 6: Summary of Strength Tests (Optimum Moisture Content (OMC), Maximum Dry Density (MDD), California Bearing Ratio (CBR) and Soil Class for soil samples from existing borrow pits in selected Roads.

Road Name	Borrow Pit Name	Sample No.	Heavy Compaction		Three Point CBR Values (%) at different Compaction Energy			Gravel Class
			OMC (%)	MDD (gm/cm ³)	4.5kg x 5 layers x 62 Blows	4.5kg x 5 layers x 30 Blows	2.5kg x 3 layers x 62 Blows	
NAABI ROAD	Kilima Fisi Borrow Pit	1	14.8	1.870	39	26	20	G25
		2	14.0	1.909	19	9	7	G15
		3	18.2	1.753	27	24	14	G25
	Matiti Borrow Pit	1	12.0	1.968	27	21	13	G25
		2	17.4	1.790	49	38	13	G45
		3	10.5	2.000	81	48	29	G80
	Sumay Borrow Pit	1	11.6	2.004	27	18	11	G25
		2	9.6	2.018	22	11	9	G15
		3	12.2	1.916	46	37	24	G45
IKOMA ROAD	Ikoma Borrow Pit	1	12.8	1.780	17	15	8	G15
		2	12.0	1.936	33	28	3	G25
		3	10.8	2.015	24	16	7	G15
	Mokasi Borrow Pit	1	13.0	2.064	20	17	15	G15
		2	12.2	2.075	29	17	13	G25
		3	11.8	2.065	21	18	17	G15
NDABAKA ROAD	Belabela Borrow Pit	1	14.4	2.028	48	39	20	G45
		2	12.1	2.245	80	36	23	G80
		3	18.2	1.722	53	18	18	G45
	Nyaruswiga Pit	1	14.00	1.940	25	17	11	G25
		2	14.5	1.983	12	10	9	G7
		3	17.6	1.865	22	11	4	G15

To summarize the discussion on the section of laboratory soil materials tests, findings show that gravel materials for road construction and maintenance require variety of specification criteria before use. Combination of different factors of soil test requirements improves the prediction of the quality and performance of gravel materials. As specified by PMDM shown on Figure 3 the performance of gravel material depends on the correlation between SP and GC. As indicated on the mentioned figure, these parameters depend on the particle size distribution whereby excessive coarse materials will lead to poor grading and

shaping of the road during construction and maintenance practices. Also, corrugations and ravelling problems are the result of low value of SP less than 120 and slippery condition during wet season will be the result of SP value higher than the upper limit.



Key: SP= (Linear Shrinkage x (% passing 0.425 mm));

GC= [(% passing 28 mm) – (% passing 0.425 mm)] X (% passing 5 mm) / 100

Figure 3: Performance Specification for gravel wearing course (Source: PMDM, Figure 11.1)

Some of the existing borrow pits in SENAPA qualify under this specification and other did not meet the requirements. As explained earlier the material samples tested were collected from existing excavated borrow pits, more efforts like proper mixing of materials during excavation is required.

4.1.2 Traffic Volume Count

The second type of data collected in this study in order to assess the current practice of road construction and maintenance in Serengeti National Park was traffic volume count. Traffic volume data on different road sections are important for different uses like road design, planning and administrative purposes. For the case of gravel roads, the traffic data are required for the determination and specification of the road layer thickness and the decision making to set limitation of different road technology due to the volume level. In order to predict the performance of gravel material, the knowledge of the interaction between traffic and the gravel wearing course is important (Mwaipungu 2015). As mentioned in

theoretical framework, the Tanzanian PMDM sets the limitation for full engineered gravel roads and minor roads as 300 and 50 AADT respectively.

Table 7: Summary of traffic volume count results in selected Road sections.

Vehicle Categories	Road Section						Total all Roads	
	Naabi		Ikoma		Ndabaka		ADT	AADT
	ADT	AADT	ADT	AADT	ADT	AADT		
Light Passenger (Cars)	387	426	557	612	122	134	1066	1172
Goods Trucks < 20 tones	38	35	40	37	10	10	88	82
Heavy Passenger (Busses)	3	3	6	6	0	0	9	9
Total	428	464	603	655	132	144	1163	1263

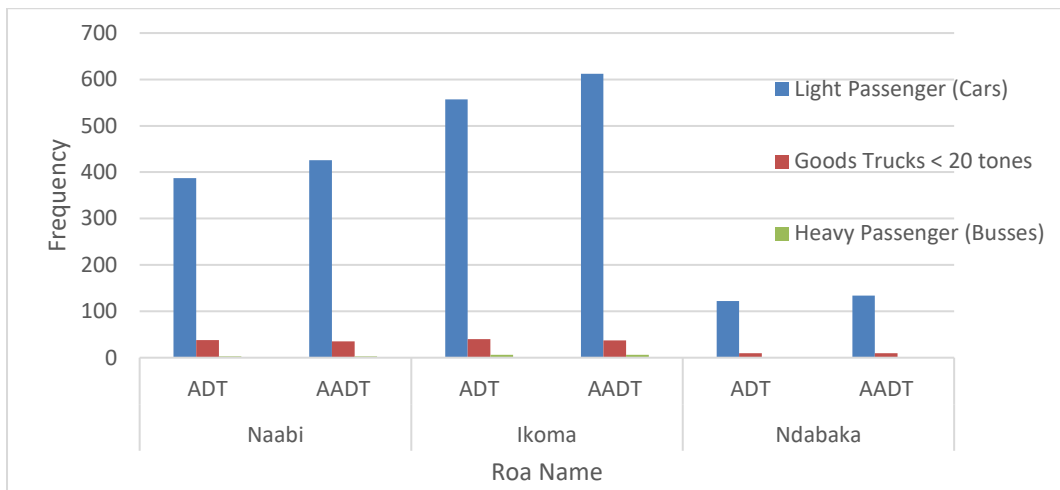


Figure 4: Graphical presentation of Traffic results.

Previous by using permits at entrance gates and because Naabi road connects to the main entrance gate from Arusha which is the main tourist city in Tanzania, it was assumed that the traffic volume of this road is higher than other roads. However, contrarily results show that the Ikoma road section have higher traffic volume than other sections as shown on Table 7 and Figure 4. The reason for this may be due to the Seronera Airstrip and the location of accommodation facilities in the side of Ikoma road. Therefore, it is good practice to conduct physical traffic count in other road sections instead of using data from entrance gates which can mislead the results.



Figure 5: Light passenger tourist cars which are the highest traffic using roads in SENAPA (Photo: Tarimo, M J.)

As shown on Table 7 and Figure 4, the AADT for Naabi and Ikoma roads is 464 and 655 respectively which is higher than the recommended AADT for gravel roads shown on Figure 6 provided by the Tanzania PMDM. Only Ndabaka road qualifies under the recommended AADT value. This may be among of the factors which contributes to the current poor condition of roads in the study area. When the traffic volume of a certain road section is higher than the recommended level, the frequency of maintenance increases due to deterioration caused under traffic. At this juncture, other alternative technology of improvement of the gravel material or paving should be considered. As depicted by Shuler (2007), traffic volume can be an indicator for decision on paving the gravel road. However, one can argue from the results that since 93% of traffic using the roads of SENAPA are light weight passenger cars which have weight less than 1.5 tones as shown on Figure 4 and Figure 5, the deteriorating factor for roads in this area can be due to traction of cars and not load. As explained by Pinard and Greening (2004), the performance of road pavements depends largely on the vehicle load associated stresses. Moreover, as depicted by Shuler (2007), the performance of gravel roads depends on traffic volume and type. The same author exemplifies that the type of traffic should is an important factor to be considered. For example, the impact of 500ADT which is merely passenger cars and lights tracks can be equivalent to the

impact of 250ADT traffic volume which is composed with light and medium size trucks (Shuler 2007).

Therefore, improvement of the material properties and use of proper engineering techniques can lead to better performance of the roads under the current traffic volume before the decision of paving the roads.

	AADT ²⁾					
	< 20		20 - 100		100 - 300	
S15 ¹⁾	150 mm GW		150 mm GW		150 mm GW	
S7 ¹⁾	150 mm GW		150 mm GW 100 mm G15 ¹⁾		150 mm GW 150 mm G15 ¹⁾	
S3 ¹⁾	Dry / Moderate climatic zones	Wet climatic zones	Dry / Moderate climatic zones	Wet climatic zones	Dry / Moderate climatic zones	Wet climatic zones
	mm 150 GW 150 G7 ¹⁾	mm 150 GW 300 G7 ¹⁾	mm 150 GW 100 G15 ¹⁾ 150 G7 ¹⁾	mm 150 GW 200 G15 ¹⁾ 200 G7 ¹⁾	mm 150 GW 150 G15 ¹⁾ 150 G7 ¹⁾	mm 150 GW 200 G15 ¹⁾ 300 G7 ¹⁾

Key: (1) Classification of subgrade classes S3, S7 and S15 and requirement for G7 and G15 materials as provided by PMDM Pg. 5.6- 5.7. (2) Maximum 50% heavy vehicles are assumed.

Figure 6: Wearing course and improved subgrade for major gravel road (Source

4.1.3 Interview to road stakeholders

Interview to road stakeholders was the third type of data collected to answer the research question, “the current practice of road construction and maintenance in SENAPA”.

This section was comprised of seven questions with the following theme; (i) The source of gravel materials (ii) The contact person if something goes wrong with roads (iii) The responsibility for road construction and maintenance in SENAPA (iv) The quality of available gravel material (v) The availability and reliability of road equipment (vi) The Staff knowledge for road construction and maintenance and (vii) Adequacy of the budget provided for road works. The questions were asked to the interviewees based on their group of interests. Some of questions were directed to all interviewee groups and some to two or one group as explained in the findings and discussion.

- **The sources of gravel material.**

The construction and maintenance of gravel roads can be economical if the sources of this materials are available from short distances. The objective of this question was to get information about where are the sources of gravel materials in the study area. This question was directed to all stakeholders. The result shows that 39 (78%) responded that the gravel materials are sourced from within the national park and 11 (22%) do not have idea where the materials come from. Referring to Figure 7, we can see that TANAPA staff respondents have information about the source of material, while other categories of respondents few of them do not have the information. Regardless of the quality of materials we can conclude from the results that the sources of materials are from inside the national park which can reduce the haulage distance.



Figure 7: Percentage contribution of respondents on the sources of materials.

- **The contact person/ department if something goes wrong with the roads.**

Serengeti National Park have diversified tourism attractions sites, this leads to the need of accessibility to the important parts of the park, thus make SENAPA to have a long stretch of road networks. In the course of moving from one place to another by using road networks some road problems such as road accidents and deformation of road section or crossing facilities like bridges and culverts are inevitable. When these problems happen, there is need to have someone or system in place to receive the information so as the immediate measures to the reported problem can be taken including rescue or repair of the deformed sections. This question was directed to all stakeholders and the objective was to

assess if the road stakeholders knows where to report when there is problem concerning roads during their normal use of roads.

The findings show that, about 13 (26%) of respondents do not know where to report while others knows but with different reporting places such as entrance and exit gates 6 (12%), infrastructure department or to park engineer 8 (16%) and tourism warden or to chief park warden 23 (46 %). Considering the percentage contribution per respondent groups as presented on Figure 8, results shows that hotel managers have information where to report, and about 78% of them reports to the tourism wardens.

The reason can be the hotel managers have closer relationship and frequent communication with the tourism warden due to the nature of their day to day operations. Surprisingly, results indicate that, even some of TANAPA staff do not know where specifically to report when there are problems concerning roads. Therefore, there is a great need of dissemination of the information to road stakeholders about the responsible personnel or department to enhance fast response to problems.

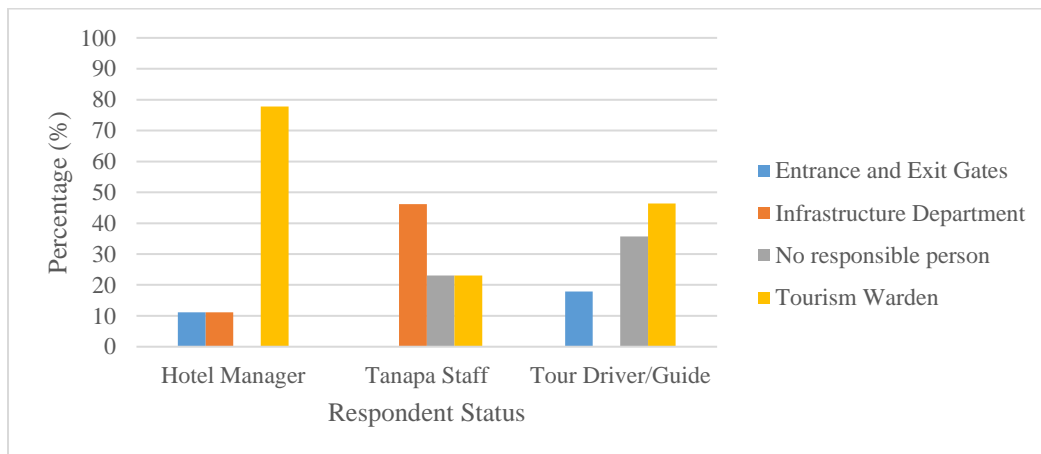


Figure 8: Percentage contribution of respondents showing where to report when there is problem with roads.

- **The responsibility of road construction and maintenance in SENAPA.**

The aim of the question was to assess if the road stakeholders have the information on who has the responsibility of construction and maintenance of roads in Serengeti National Park. The responses on this question was that 48 (96%) have information that the responsibility of road construction and maintenance is under TANAPA authority through

her designated department under park management. Only 2 (4%) responded they do not have an idea who has the responsibility. The reason can be it is easy for the road stakeholders to see the roads crew during their normal operations of road construction and maintenance using equipment registered and stamped with TANAPA stickers.

- **The quality of the available gravel materials.**

The quality of gravel materials used for road construction can be assessed by the laboratory tests or by visual assessment based on the performance during the operation. However, visual assessment based on performance can give misleading information because the performance of road depends not only on the quality of materials but on many other factors like proper use of engineering techniques for application of gravel materials, climatic conditions of the area and traffic volume just to mention few. This question was asked to TANAPA staff and the aim was to get information on the quality of gravel materials available based on the past performance on roads. The response on this question was that 46% of respondents replied the materials have good quality and about 54% responded the gravel materials have poor quality.

This is due to the performance of the roads after maintenance, whereby some road sections deteriorate fast after maintenance. Other respondents during interviews argued the materials to be collected from other areas outside the national park. Also, the results support the findings of laboratory tests conducted on the existing borrow pits in the study area which as explained on the section of soil laboratory tests some of the samples from the borrow pits did not qualify for gravel road construction. The quality of gravel material can to some extent be assessed by the performance of the gravel road during its operations as shown on these results.

- **The availability and reliability of road equipment.**

Proper use of road equipment in all stages of construction such as from material preparation, transportation, application, and construction have great impact on the final product and performance of the gravel roads. Not only proper use of equipment but also the reliability of the equipment improves the efficiency of road construction activities.

TANAPA staff were interviewed on this question, and the objective was to evaluate if there is sufficient and reliable equipment for road construction and maintenance in SENAPA.

The results show that 77% of respondents replied the equipment for road construction and maintenance are not reliable and sufficient, only 23% responded the equipment are reliable and sufficient. An inadequate number of equipment for road construction and maintenance can lead to inefficient in road construction and maintenance practices and hence poor performance of roads.

These results support the results of the previous question on the quality of available material whereby poor-quality materials cannot be the only factor which leads to poor performance of roads but also the insufficient and non-reliability of equipment can also contribute to poor performance.

- **Staff technical knowledge for road construction and maintenance.**

Among of the contributory factors for good performance of gravel road is the technical knowledge of the road crew. This includes the technical knowledge in selection of materials from borrow pits and the application of material on site. Furthermore, skilled and well-trained operators of road equipment play a big role on the performance of gravel materials and gravel roads in spreading of materials, construction of proper drainage for the road section by maintaining the road camber and other drainage features like side ditches and mitre drains. This question was directed to all interviewees, aimed to get opinions from the stakeholders on the skills of the road crew on construction and maintenance of roads. Results show that 30 (60%) of respondents said the road construction and maintenance crew have the required technical knowledge while 18 (36%) responded that the crew do not have the required knowledge and only 2 (4%) responded the do not have idea.

Since, TANAPA is a government organization it is not easy to recruit employees who do not have the required qualifications. However, the road crew may have the required skills and the technical knowledge but not used effectively because of lack of reliable working facilities like equipment. Also, another argument can be, you may have the personnel who generally have the required qualifications but they lack the practical field skills. To improve this proper training on actual field practices by experienced practitioners is important.

- **Adequacy of the budget provided for road works**

Availability of sufficient funds for maintenance of gravel roads contribute significantly to the good performance results. For smooth construction and maintenance operations like selection of materials, transportation, and application of the materials on the road sections, provision of sufficient budgets is crucial. Adequacy of funds increases predictability of road performance and smoothens the planning and management of road activities. This question was asked to TANAPA staff whereby the objective was to get opinions if there are sufficient funds for road construction and maintenance operations. Results show that, about 93% responded that the budget is not sufficient while only 7% responded the budget is sufficient. This may lead to unpredictability of road performance and the difficulties in management of road activities.

4.1.4 Document study

Document study was the fourth set of data collected from the study area. The information about the resources for road construction and maintenance were collected through document study. The document studied were infrastructure department annual reports, road budgets, employee and equipment reports for a period of ten years from financial 2006/2007 to 2015/2016 as shown on Table 8 and Table 9 .

Table 8: Summary of approved budget, number of employees and road length in a period of 10 years

S/N	Financial Year	Approved Budget (USD)	Employees	Total Road Length (KM)
1	2006-2007	133,087	22	991
2	2007-2008	440,128	22	991
3	2008-2009	555,469	22	1000
4	2009-2010	555,469	20	1200
5	2010-2011	555,469	20	1200
6	2011-2012	555,469	18	1295
7	2012-2013	555,469	13	1577
8	2013-2014	650,554	13	1577
9	2014-2015	773,870	18	1726
10	2015-2016	674,970	18	1726

The results show that, there was increase of the road length from 991 km in the financial 2006/2007 to 1726 km in the year 2015/2016. However, the budget for road construction and maintenance was not increasing as roads length increases. From the

financial year 2014/2015 to 2015/2016 the budget dropped, something which reduces predictability. Also, the number of permanent employees for the department was decreasing from 22 to 13 at that period of ten years (see Table 8).

On the side of equipment, the results show that the department lack full set of gravel road equipment (haulage, excavation, loading, grading, watering and compaction). However, the few existing equipment are old and do not receive proper services and maintenance, hence frequent break downs and poor performance. Moreover, the department do not have compactor machine for compaction and water bowser truck for watering as shown on Table 9. Also, sources for water during dry season is a big challenge in SENAPA.

Table 9: Types and number of equipment in SENAPA for the period of 10 years

S/N	Financial Year	Trucks	Motor Grader	Wheel Loader	Water Bowser	Back hoe Loader	Bulldozer	Low bed	Excavator	Supervision Car
1	2006-2007	8	6	2	3	2	2	1	0	1
2	2007-2008	8	6	2	3	2	3	1	0	1
3	2008-2009	8	6	2	3	2	3	1	0	1
4	2009-2010	12	6	2	3	2	3	0	0	2
5	2010-2011	12	6	2	3	2	3	0	0	2
6	2011-2012	12	4	2	0	2	3	0	0	2
7	2012-2013	10	4	2	0	2	3	0	0	2
8	2013-2014	8	4	2	0	2	2	0	0	2
9	2014-2015	8	4	2	0	2	2	0	0	2
10	2015-2016	8	4	2	0	2	2	1	1	2

In summary we can say that, insufficient resources for road construction and maintenance makes it difficult to establish and follow-up long-term plans in the study area. The interview results and the document studies reveals there is increase of road length while the resources such as budget, man power and equipment are declining. If this trend continues improvements cannot be expected, even if the available gravel materials meet the required standards.

Current Road Condition

The data collection for this study conducted from June to August 2016, which is the dry season and it is also the high season for tourists in the study area. The general condition of roads during this time was not promising. Naabi road which is in the savanna plains had corrugations, potholes, dust and ravelled more than Ikoma and Ndabaka roads although there was a motor grader trying to cut the corrugations. Other problems of the study road were that, the road level was below the ground surface, poor crown and side ditches. Also, the roads have poor drainage structure like culverts and mitre drains to remove water away from the roads during rainy season.

As ascertained by Kuennen (2009), good drainage is critical in gravel roads than paved roads hence shoulders, ditches and mitre drains should be properly maintained. As explained by Skorseth, Selim et al. (2000), the primary causes of corrugations can be lack of moisture, driving habit and the quality of gravel materials. Other causes can be driving speed of motor grader during grading and lack of crown. It is not easy to remove completely corrugations from gravel roads especially during dry season but can be reduced using proper equipment and skilled operators for road construction and maintenance, maintaining proper road structure and drainage systems and use of good quality gravel materials.

4.2 The Advantages and Disadvantages of the Current Practice.

The advantages and disadvantages of the current practice of road construction and maintenance in SENAPA was assessed in terms of the available materials as per soil test results, the current traffic volume and the results from stakeholder opinions on the current practice.

4.2.1 Advantages/ Disadvantages with the Available Gravel Materials

- **Advantages:** Gravel materials are naturally occurring materials. Availability of this materials in short haulage distances can significantly reduce the cost of road construction and maintenance. In the case of SENAPA gravel materials are excavated within the notational park. The soil test results as presented on tables 4, 5 and 6 shows that the available materials from the selected existing borrow pits have

revealed that some of the parameters qualify for gravel roads construction and maintenance and others did not qualify. The borrow pits from which the materials are suitable for gravel road construction and maintenance are advantageous to the organization because of the shortened haulage distance hence costs can be reduced to some extent. Another advantage from the soil test results show that there was no borrow pit which all its samples fail under all specified soil test requirements. Therefore, the improvement of the materials properties like proper mixing and adherence to the engineering techniques can lead to good performance of the materials.

- **Disadvantages:** From the soil test results, there are some borrow pits which most of the parameters did not qualify for gravel roads. Currently the materials are used without soil tests. Moreover, the engineering practices for road construction such as watering and compaction of the materials are not properly adhered. This can be the reason of poor performance of the studied road sections. Also, the roads do not last long after construction or maintenance which increases the frequency of maintenance and hence increases costs. Frequent maintenance means more excavation of the materials for road activities which can result to depletion of this non-renewable materials hence more destruction of the nature of the protected area.

4.2.2 Advantages/ Disadvantages with Traffic Volume

- **Advantages:** The traffic count results as presented on Table 7 and Figure 4 show that, Naadi and Ikoma roads have AADT higher than the recommended traffic level for gravel roads, only Ndabaka road qualifies under the specified requirement. Figure 4 show that more than 90% of the traffic in the study area are light passenger cars which have weight less than 1.5 tones. The advantage of this traffic can be the roads are deformed under vehicle traction forces rather than vehicle load stresses. The concentration will be required on the surfacing material quality than the structure of the road. Another advantage is that, this traffic is mainly for tourism activities, therefore there is a possibility of introduction of alternative routes of road which passes through tourist attraction points aiming to reduce the density of traffic on the main roads.

- **Disadvantages:** Under the current traffic volume, as explained earlier high traffic leads to frequent deformation of the roads which increases maintenance costs. Currently, there is no watering and compaction during maintenance of roads, this leads to high dust especially during dry season. High dust can destruct vision to drivers and animals which may lead to accidents and road kills. Another disadvantage due to the current traffic volume in the protected area can cause disturbances to animals especially if the traffic concentrates at single road section.

4.2.3 Interview Results on Advantages and Disadvantages of the Current Practice.

On this section discussion, will base on four interview questions to the road stakeholders with the following theme; (i) Advantages/ disadvantages with the availability of materials, (ii) Advantages/disadvantages with who to contact if something is wrong with roads, (iii) Advantages/disadvantages with the current condition of roads in the study area and (iv) Advantages/disadvantages with the operation costs. The questions of this section were asked to all stakeholders.

i. Advantages/disadvantages with the availability of materials.

Advantages: The response as indicated on Table 10 was that, 25 (50%) responded the availability of materials within the national park reduces the cost of maintenance, while 22 (44%) of respondents do not have idea if there is advantage and 3 (6%) replied there is advantage whereby the left-over pits after excavation of materials can be used as storage of water for animals in dry season.

This implies that, if the available materials within the park are of the required quality the construction and maintenance costs can be reduced significantly as explained on the results from laboratory tests. The idea that the left over borrow pits can be used as rain water storage for animals may be advantageous to the infrastructure department as the water stored can be used for road works (watering for compaction and dust suppression). Availability of water is among of factor limiting life in Serengeti ecosystem as Serengeti is in dry/moderate climatic zone (Gereta 2004 & Sinclair and Arcese 1995). Currently, as shown in the

document study, the infrastructure department do not have water bowser truck for road works, but also the availability of water is a great challenge.

However, the use of the leftover pits or the introduction of water holes in the ecosystem should be implemented cautiously as this can be contrary to conservation practices. If the excavated pits are used as water storage for animals, the disadvantage to conservation can be that, animal distribution over the area will be disturbed (Traill 2004), and illegal hunting can be increased on the area because of the concentration of animals on one area. The excavated pits should be recovered after depletion of materials at that area to try to recover the nature of the environment.

Table 10: Advantages with the availability materials

Responses	Hotel Manager	Tanapa Staff	Tour Driver/Guide	Grand Total
Cost reduction	7	12	6	25
Left over pits can be used as water catchments for animals			3	3
No Idea	2	1	19	22
Grand Total	9	13	28	50

Disadvantages: On the side of disadvantages of the availability of materials some of interviewees as presented on Table 11, about 20 (40%) replied that excavation of gravel materials from within the protected area destructs the environment, while 20 (40%) do not have idea whether the practice have any disadvantage and 10 (20%) responded due to the quality of the materials the current practice increases cost.

The results can be discussed that excessive excavation of materials within the national park without proper control and mitigation measures can destroy the natural environment as well as the ecology of the area which will be against the conservation procedures. These results also support the argument that gravel materials are non-renewable, frequency of excavation can be reduced by use of proper engineering practices to make them more sustainable when applied on roads.

Table 11: Disadvantages with the availability materials.

Responses	Hotel Manager	Tanapa Staff	Tour Driver/Guide	Grand Total
Destruction of environment	5	3	12	20
High costs		5	5	10
No Idea	4	5	11	20
Grand Total	9	13	28	50

ii. Advantages and Disadvantages with who to contact if something is wrong with roads.

Advantages: The results show that, about 30 (60%) replied there is advantage because problems can be solved at time and 20 (40%) they do not know if there is advantage. The contribution of each group shows that more than 76% of the Hotel managers and TANAPA staffs responded there is advantage but only 46% of the Tour Driver/Guide group responded there is advantage as presented on Table 12.

These results can give indication that the perceived advantages can be just theoretical but in reality, they are not because the tour driver/guide group are the one who are always on field and are the large number of road stakeholders. Information on the system or the specific person who is responsible for road problems reduces the delays on reaction and the required rescue can be facilitated.

Table 12: Advantages with who to contact is something is wrong with roads.

Responses	Hotel Manager	Tanapa Staff	Tour Driver/Guide	Grand Total
Fast reaction to problems	7	10	13	30(60%)
No idea	2	3	15	20(40%)
Grand Total	9	13	28	50

Disadvantages: Responses on this question shows that 27 (54%) replied they do not have idea on disadvantages while 23(46%) replied the problems will not solved on time as presented on Table 13. On the other hand, the contribution as per group response confirms the previous question on advantages whereby, more than 61% of Hotel managers and TANAPA staffs do not have idea if there are disadvantages while the tour driver/guide group only 42% do not have idea and the rest of this group replied the problems will not solved on time.

Table 13: Disadvantages with who to contact is something is wrong with roads.

	Hotel Manager	Tanapa Staff	Tour Driver/Guide	Grand Total
No idea	7	8	12	27(54%)
Problems not attended Promptly	2	5	16	23(46%)
Grand Total	9	13	28	50

iii. Advantages and Disadvantages with current road condition in the study area.

Advantages: On the current condition of the roads in the study area only 5(10%) responded there is advantage which is enhancement of conservation while 45(90%) do not have idea if there is advantage on the current road condition.

Disadvantages: All the respondents replied the current condition of road have disadvantages such as road accidents, frequent breakdowns of cars, complaints from tourists, high maintenance costs of roads and cars and delays to the destination points.

These results imply that, due to the current condition roads in the study area disadvantages outweigh the advantages. The studied roads during the dry season have corrugations, potholes, and dust. Due to corrugations drivers tend to drive at high speed with the reason that, high speed reduces vibrations to the car which reduces deformation. These high speeds increase dust which reduces the vision to drivers and animals which results in accidents and road kills.

iv. The Advantages and Disadvantages with the operation costs

Advantages: Results show that, 100% of stakeholders did not have idea if there is advantage on operation costs.

Disadvantages: On the side of disadvantages with the operation costs 100% of respondents replied that, the operation cost is high both to road users and to TANAPA. As explained on the advantages and disadvantages with the current condition of roads in the study area, these results confirm that due to poor performance of roads the operation costs to road users will be high. This can be due to high consumption of spare parts for repair of cars after breakdowns. The condition also causes delays to the destination points which can cause dissatisfaction to the tourists and road users in general.

4.3 Proposed Improvement Measures

In this section, some of the proposed improvement measures are discussed based on the data results and authors observations during data collection from the study area.

The importance of laboratory soil tests should be emphasised before the use of gravel materials for road works. This will enable the department to know the properties of the gravel

materials in the existing borrow pits and where necessary blending of materials can be done to improve the quality. On the side of traffic volume, the possibility of introduction of alternative roads which will be solely used by tourist cars should be considered. This will reduce the traffic density on the main roads which can reduce dust and the fast deterioration of the roads with high traffic.

Moreover, there is a need for the increment of funds and man power for road operations in terms of budgets, equipment and recruitment of skilled employees. In line with that, introduction of road management systems is important for the management and planning of road works. Reliable sources of water are a big challenge in SENAPA, excavation of shallow water holes for storage of rain water should be taken into consideration. The stored water can be used for road works and for animals as well.

On the other hand, respondents from the SENAPA replied that the existing materials have the required quality but the problem is the techniques of application of materials on site in terms of equipment, compaction, watering and the staff experience. Surprisingly, some of the tour driver/guides who are the main users of the roads mentioned that, some of the tourists enjoy the nature of the existing roads which blends with the environment. They actually do not want higher standards (paved) roads, that may reduce satisfaction to the tourists. Moreover, the suggestion from the park ecologist was that, upgrading of roads to paving will not blend with the natural environment and may lead to road kills due to high speeds of cars. Furthermore, integrated studies on engineering and ecological perspective to be conducted to come up with good practices for sustainable gravel road construction and maintenance with less cost and less impacts to the environment.

5 CONCLUSIONS

This paper set out to answer i) the current practice of road construction and maintenance, ii) the strengths and weaknesses of the current practice and iii) the proposed improvement measures for sustainable roads in SENAPA. The conclusion will base on these research questions.

5.1 The current Practice of Gravel Road Construction and Maintenance in SENAPA

The results of soil tests show that the gravel material in the existing borrow pits does not qualify in all parameters as specified by the standard manuals in Tanzania PMDM and SSRW, but still they can be used for gravel road construction and maintenance. On the other hand, traffic volume count results reveal the number of vehicles in the studied main roads Naabi and Ikoma is higher than the recommended standard for gravel roads except for Ndabaka road, but the impact to the roads is due to traction rather than load stress defects. However, the current poor performance of the studied roads in SENAPA may be mainly caused first by lack of resources for road construction and maintenance as revealed by interview and document study results. Secondly by the impacts from higher traffic volume and the failures shown in the soil tests.

5.2 Advantages/Disadvantage of the Current Practice of Gravel Road Construction and Maintenance

Availability of gravel materials within the national park can be an advantage to the organization because the haulage distance will be reduced which can result in low construction and maintenance cost. However, currently, the performance of studied roads was not promising. Causes of poor performance such as corrugations, potholes, and dust may lead to disadvantages. These disadvantages are such as road accidents, frequent breakdowns of cars, complaints from tourists, high operation costs both to the road users, beneficiaries and the organization and also delays to the destination points. Another disadvantage is that due to corrugations, drivers tend to drive at high speed with the reason that, high speed reduces vibrations to the car which reduces deformation. These high speeds

increase dust which reduces the vision to drivers and animals hence accidents and road kills can be the outcome.

5.3 The Proposed Improvement Measures for Sustainable Gravel Roads

To improve the current condition and make the roads more sustainable and economical, the following are the proposed measures based on the study results.

- Integrated studies on engineering and ecological perspectives to be conducted to come up with good practices in terms of the use of marginally available gravel materials and water. This will minimize the impacts to the nature at the same time to have roads which are passable throughout the year. In line with this, due to the dryness of SENAPA, excavation of shallow waterholes should be taken into consideration. Surface runoff storage can be used during the dry season for road works, dust suppression and for animals as well.
- To enforce the importance of laboratory soil tests for gravel materials before excavation of borrow pits and the use of materials for road works. In this regard, we can avoid excavation of pits with poor materials which will not last long and reduce the environmental impacts. Also, after laboratory tests the gravel materials can be blended to improve the soil properties and hence the availability of marginal materials in economical haulage distance can be achieved.
- The organization to invest on road resources such as recruitment of enough, skilled and experienced staff for road construction and maintenance, full set of gravel road equipment (material excavation, hauling, spreading and grading, watering and compaction) and allocation of sufficient budget for road operations.
- To find the possibility of introduction of scenic roads which will be used only by tourist cars to reduce traffic on the main roads. This will increase satisfaction to the tourist due to less dust compared to the main roads with high speed and traffic.
- The road department could introduce and implement a strategic road construction and maintenance management systems. This will help the department to document the road length and condition of each section (condition survey), to have preventive maintenance strategies, to determine needs and prioritization for each road section.

In line with the above improvement measures, some of the contributory factors for good road performance in SENAPA can be presented using fishbone diagram as shown on Figure 9. Fishbone diagram also known as Ishikawa diagram are causal diagrams created by a Japanese scientist Kaoru Ishikawa which indicates the causes of a specific event.

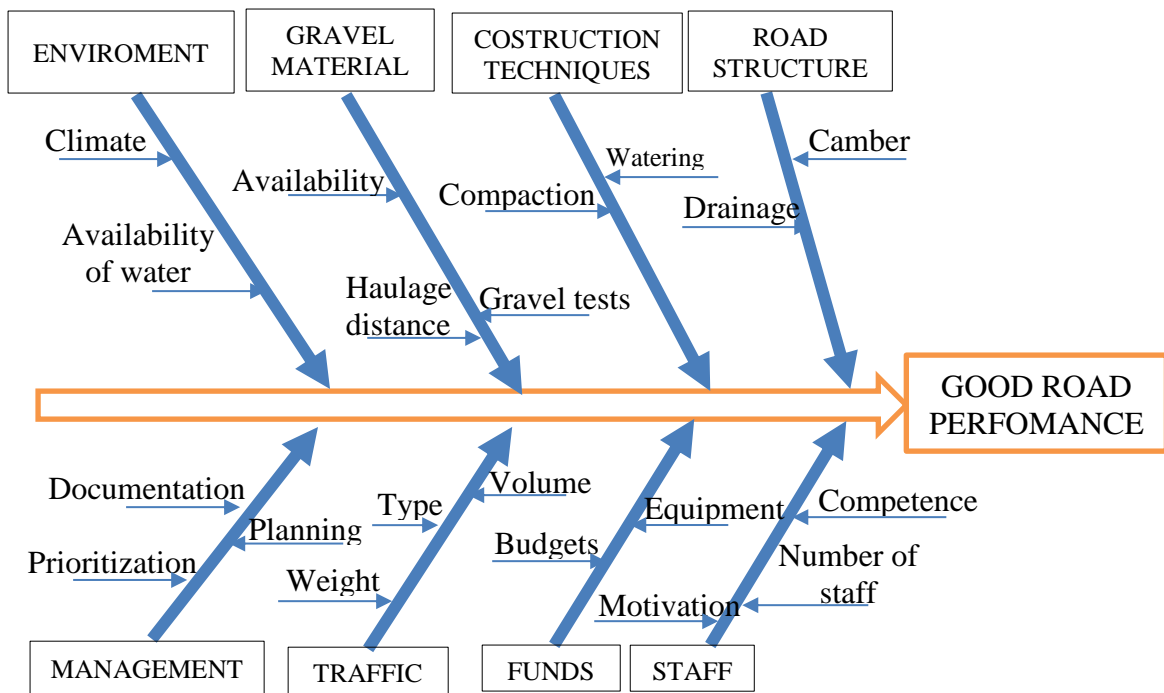


Figure 9: Fishbon Diagram showing contributory factors for good road performance

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PART 2: THE ACADEMIC ARTICLE

Sustainable Gravel Road Construction and Maintenance in Serengeti National Park

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Abstract

All weather road networks in protected areas are important to facilitate management of wildlife, routine park operations and to facilitate tourist accessibility to the attractions sites and hence improving their satisfaction. However, road construction in protected areas should be sustainable in terms of availability of quality materials within economic haulage distance and the entire construction, operation and maintenance process should have less environmental impacts like habitat fragmentation and dust pollution. Several studies have been done in protected areas concerning roads but most of them had concentrated on the ecological impacts of roads. Few studies have been done from the engineering perspective of sustainable construction and maintenance of roads. Thus, the purpose of this study is to assess the sustainability and challenges of construction and maintenance of gravel roads in protected areas. To accomplish objectives of these study four types of data were collected in Serengeti National Park (SENAPA). The data collected were from soil material test in the existing borrow pits, traffic volume counting, document study and interview with fifty (50) road stakeholder. Results show that the current poor performance of the studied road sections may be due to lack of financial and human resources, quality gravel materials and existing traffic volume. This study will contribute to the sustainable construction of road networks in protected areas through identifying possible challenges of road construction and maintenance and give the way forward for improvement.

Keywords: Protected areas; Gravel roads; Sustainability; Construction; Maintenance.

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INTRODUCTION

All weather road networks in protected areas like Serengeti National Park (SENAPA) are important to facilitate management of wildlife, routine operations and tourist accessibility to attractions sites and hence improving their satisfaction. Despite having a positive contribution to the existence of the protected areas and nature reserves roads are also widely recognized to have negative impacts such as increasing road kills, habitat fragmentation, dust pollution and introduction of invasive species (Laurance, Goosem et al. 2009). Moreover, roads can accelerate illegal activities like poaching (Fa, Ryan et al. 2005). Having both positive and negative impacts, there has been a general debate on which standards of the roads can potentially minimize the impacts in protected areas.

More than 75% percent of the road network in sub- Sahara Africa countries regardless their traffic volume are unsealed roads, mostly surfaced by gravel materials or natural earth materials (Overby and Pinard 2007). Moreover, about 93% of the road network in Tanzania are gravel or earth roads (Mwaipungu and Allopi 2012) and all roads in national parks in Tanzania are gravel or earth roads. Mwaipungu and Allopi (2014) argued that gravel materials will continue to be considered as affordable and economical road construction material in most of sub-Saharan Africa countries. Other authors consider unsealed or graveled roads as antiquities of the 19th century in developed countries. Nevertheless, in certain areas in developing countries and some rural areas in developed countries, gravel roads are part of the 21st century (Kuennen 2009). As found by Shearer and Scheetz (2011) some of the local agencies in developed countries are reverting to gravel roads in low volume traffic areas.

During the literature study, initiating the research presented in this paper, it was observed that many studies done in protected areas concentrate on the ecological impacts of roads. Only very limited number of studies concerning the engineering perspective of road construction and maintenance have been conducted in these areas. SENAPA is among of sixteen national parks which are managed by Tanzania National Parks (TANAPA). It covers 14,763km², thus being the second largest national park in the country after Ruaha National Park. It was ascribed as the World Heritage Site by UNESCO in 1981 (Sinclair and Arcese 1995) and is among of the world seven wonders (Kisingo, Rollins et al. 2016). TANAPA is a government institution which is mandated to manage and regulate use of areas designated as National Parks in Tanzania. The core business of SENAPA and TANAPA as whole is conservation and sustainable tourism. To achieve this, the park is managed with the prime objective of safeguarding wildlife. This is done through regular patrols to combat poaching activities as well as monitoring sustainable tourism activities mostly facilitated by gravel road networks with a length of about 1,726km.

This paper aimed to assess the sustainability and challenges of the current practice of road construction and maintenance in the main roads of SENAPA. The ambition is that the findings from the study will help to improve the understanding of both the current situation of roads in terms of traffic volume and the quality of gravel materials in existing borrow pits (the main source of materials for road construction and maintenance). It will provide information to the park management and the infrastructure department on better practices that will enhance improvement of current road conditions. In line with this, this paper addresses the following research questions;

What is the current practice of road construction and maintenance in Serengeti National Park?

What are the advantages and disadvantages of the current practice for road construction and maintenance in Serengeti National Park?

What are the possible improvement measures for a sustainable road construction and maintenance?

This study concentrates on the assessment of the quality of the gravel material available in the existing borrow pits used for road construction and maintenance in the study area and not the detailed design of gravel road structure. Soil samples were collected on the existing excavated borrow pits (disturbed material samples), no samples collected on the loose road surface or along road section. The traffic count was not done on the same day in all study road sections due to the limitation of resources.

RESEARCH METHODOLOGY

The research reported on in this paper was based on different sets of data collection conducted in SENAPA during the high season from June to August. These included, soil material laboratory tests, traffic counts and a scoping literature study (Arksey and O'Malley 2005) prior to these. Also, 50 interviews with road stakeholders and a document study were carried out.

Academic search engines such as Scopus and Google Scholar, NTNU libraries (Oria) and institution websites were used to search relevant studies about gravel road construction and maintenance in protected areas (and non-protected areas within the tropical context). Search words included gravel roads, gravel material, construction, maintenance and protected areas. In order to find the most relevant articles, different combinations of these search words were used (e.g. "gravel roads" + "protected areas"). Finally, the references of the papers judged to be of particular relevance were used to get more information relevant to the study (citation chaining) (Cribbin 2011).

Information on the gravel material characteristics and classification facilitates the prediction of its performance. Such predictions is among the tools which can be used to find solutions to engineering problems (McKinlay 1988). In this study, disturbed soil samples were collected from existing borrow pits along the main roads of SENAPA. These borrow pits are the main sources of materials used for road works. Three samples were collected from each borrow pit to obtain representative samples. The aim of conducting soil laboratory tests was to assess the quality of the materials used for road works in the studied road sections. Laboratory tests to determine the characteristics of gravel materials were conducted according to procedures described by the Central Materials Laboratory (CML) of Tanzania (TZ-MoW 2000 p 2- 16). The procedures depicted in CML are based on the British Standards (BS). The soil tests conducted were soil classification which includes particle size distribution and Atterberg limits (BS 1377: Part 2: 1990 cited in TZ-MoW 2000 p 2 - 24), and soil strength which includes Compaction and California Bearing Ratio (CBR) with the three point test (BS 1377: Part 4: 1990 cited in TZ-MoW 2000 p 36, 64).

The aim of traffic volume counts is to get information on the number of vehicles that pass on a specific section or point of a road way during a period of time (Wright, Dixon et al. 2004 p 126). In this study, traffic volume counts were conducted in the main roads of SENAPA Naabi, Ikoma and Ndabaka to determine Average Daily Traffic (ADT), then Annually Average Daily Traffic (AADT). The traditional manual traffic count method was used to obtain number vehicles passing at the designated road section. This count was performed at different dates in different road sections; seven days in Naabi road, three days for each of Ikoma and Ndabaka road sections. These counts were carried out from 6:00 am to 07:00 pm, being the time when vehicles are normally permitted to move within the national park. Tally sheets were used for vehicle count and classification records.

In this study, 50 semi-structured focus interviews (Yin 2014) (Wahyuni 2012) were carried out. The duration for each interview was 15 to 20 minutes. The interviewees were interviewed on-site in SENAPA. The interviewees were 13 TANAPA employees who manages, constructs and maintain the roads, 28 Tour driver/guides who are the main users of the roads and the Hotel managers who are the beneficiaries of the road. The interview conversations were face to face and were not recorded to increase the freedom and comfortability to informants to give information.

Document study was the fourth type of data collected. Different documents such as budget books, annual reports, contracts, reports for number of employees, road equipment and operation reports were studied. In addition, different road design, construction and maintenance manuals and soil laboratory test manuals collected from other institutions like Arusha Technical College (ATC) in Tanzania and Tanzania Roads Agency (Tanroads) were also studied.

The aim of document study was to increase understanding and to obtain information of organization's past and current practice of road construction and maintenance. Also, the guidance for laboratory soil tests and traffic counts was obtained from documents studies. As ascertained by Tellis (1997), document study can also be used to verify data collected by other method.

THEORETICAL FRAMEWORK

Gravel roads can provide the intended transportation services economically and satisfactorily if proper construction and maintenance practices are used. Novelty and long-term strategic planning can keep road user satisfied with low operation cost as possible (van Zyl, Fourie et al. 2007). Therefore, roads with good satisfaction to the user can be achieved through maintenance to the acceptable level under the increasing traffic volumes and environmental needs at the same time decreasing the budgets and consumption of the suitable available materials. Moreover, the construction and maintenance of gravel roads can be easier, requiring less equipment and probably lower operator skills hence lower costs and less contribution to global warming (Mwaipungu and Allopi 2014). The same author stressed more that, damages to gravel roads are assumed to be easy and less expensive to correct than paved roads.

The word sustainability generally can be defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland 1987). In this paper, the word sustainability means the abundance or the continual availability of gravel material with good quality within economical haulage distance while not destructing or severely disturbing the ecology and the nature of the protected environment. Also, sustainability of gravel roads in terms of durability of roads with minimum maintenance routines. The definition by (Fowler and Fowler 1963.), “to keep going continuously” can probably suit the meaning in this paper. Will the current practice of sourcing gravel material within the national park be sustainable under the increasing demand for opening of new roads and the increasing number of traffic? As depicted by Mwaipungu (2015), gravel materials are non-renewable earth materials. Fine particles of gravel are lost as dust during gravel road operation and also during raining loose finer and courser particles are washed out by water and cause erosion (Mwaipungu and Allopi 2014). This can be minimized by the use of proper road design, construction and maintenance techniques and introducing local gravel loss prediction model which will be used as checkup for the quality performance of this techniques (Mwaipungu 2015).

Gravel roads are low volume roads in rural environment having traffic volume less than 500 vehicles per day (Behrens 1999). The Tanzania Road Manuals defines gravel road pavements as the road design which has Annual Average Daily Traffic (AADT) less than 300 (TZ-MoW 1999). Also, Harral and Faiz (1988 p 2) proposed gravel road can provide a good service under traffic volume ranging from 150 to 400 vehicles per day. On other hand; traffic volume, regardless the type and loading, are used as the criteria for decision making in the management of roads. Furthermore, Shuler (2007) ascertained that traffic volume can be used as the simplest criteria for decision making. The same author explains that as the Average Daily Traffic (ADT) reaches 350 the cost for maintenance of gravel roads becomes uneconomical and the decision of paving or another technology should be considered.

For cost-effective decisions on construction and economical maintenance strategies of gravel roads, there is a great need for road engineers and planners in a specific climate zone to understand the relationship between traffic volume, construction standards, deterioration rate and maintenance level (Ellis 1979 p 5).

Good performance of gravel road depends not only on traffic volume requirements but also on other factors such as the proper design of road cross section, quality of gravel materials, appropriate and proper use of equipment, proper application of material and skilled personnel (Skorseth, Selim et al. 2000). The road structure which includes the subgrade and the gravel wearing course are important to be considered. Adherence to the requirement of this factors will increase the performance of the gravel road, riding quality and satisfaction to road users hence make the roads economically feasible. The cross section of gravel roads includes the crown (camber), shoulder and the drainage structures (Skorseth, Selim et al. 2000). The importance of this road cross section elements is to provide drainage of rain water from the road and to prevent water running on the road surface.

The Quality of gravel materials is another factor which should be carefully considered for good performance gravel roads. Gravel material is a combination of three types of materials of different sizes which are stone, sand and fines. Good gravel requires a certain percentage of stone to carry loads of vehicles especially during wet season, a percentage of sand sized particles to fill the voids between stones and give stability and a percent of plastic fines to combine together the stones and sand to make firm gravel surface to shade water (Skorseth, Selim et al. 2000). Proper gradation of gravel materials leads to good quality gravel. As ascertained by Mwaipungu (2015), factors which contribute to a good gravel are particle size distribution and cohesion which can have a range from very fine particle sizes up to about 40mm. Too high percentage of large particles (stones)

will result in poor riding quality and the make the maintenance work difficult. On other side, the fine particles should have a good plasticity to provide a bond with larger particles when dry but high plasticity is not recommended because will make the road slippery and impassable during the wet season. To determine the quality of gravel, soil materials tests should be conducted in accordance with the locally available specification manuals. However, the knowledge of the past performance of the locally available materials on gravel road can be used as selection criteria of gravel material. As stated in the Tanzania Pavement Material and Design Manual (PMDM) the deviation from the provided standard can be done by experienced road engineer if necessary to take advantage of marginal gravel sources based on the proved past performance on gravel roads (TZ-MoW 1999).

FINDINGS AND DISCUSSION

This section presents and discuss the results and findings of the data collected from the study area. The findings were grouped in three subsections as per research questions, which are the current practice of gravel road construction and maintenance, the advantages and disadvantages of the current practice and the proposed measures which will be taken to improve sustainability of gravel roads in the study area.

1.1. Current practice of road construction and maintenance.

The current practice of road construction and maintenance in the study area will be presented and discussed in terms of the quality of gravel materials, the current traffic volume and the current condition of roads. The presentation of findings and discussion will be referred to Figure 10, which shows the study area, the study roads and other information like location of accommodation facilities, borrow pits and the airstrips.

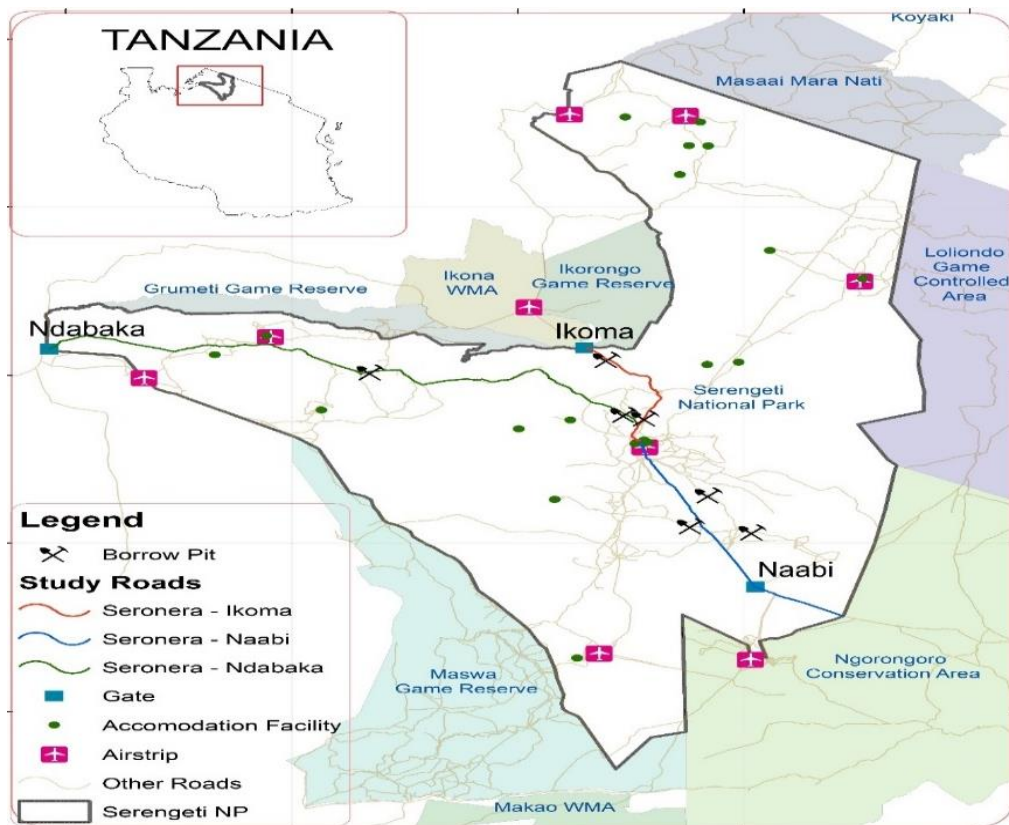


Figure 10: The map of Serengeti National Park showing the study roads, location of borrow pits, accommodation facilities and airstrips.

The quality and characteristics of soil material samples collected from the existing borrow pits were analysed in different parameters such as Soil particle size analysis and Strength tests. The specifications given by Tanzania guidance manuals, Standard Specifications for Road Works (SSRW) and Pavement Materials and Design Manual (PMDM) were used for the analysis of results. Under soil particle size analysis results show that, all borrow pit samples qualified under grading coefficient and grading modulus, all borrow pits have plasticity index value greater than 6 and more than 85% of all samples have recommended shrinkage product value within the range 120- 140. On the soil strength test only two borrow pits qualified under the specification of CBR of 25%, whereby other borrow pits some of samples did not qualify. Soil material tests results indicates that, some of the gravel materials of the existing borrow pits qualifies on the recommended specifications for gravel road construction. These results are contrary to the perceived believe that, materials especially from borrow pits near to Naabi road are of low quality. Therefore, enforcement on the importance of soil laboratory tests is crucial. Some of the few samples which results have poor quality can be improved by proper gradation of the material which can be obtained by mixing materials. Frempong and Tsidzi (1999) depicted that, inferior abundant available materials within the corridors of the existing roads can be blended to improve the soil properties which in turn will reduce the haulage distance.

The traffic counts were the second set of data collected to assess the current practice of gravel road construction and maintenance in SENAPA. In order to predict the performance of gravel material, the knowledge of the interaction between traffic and the gravel wearing course is important (Mwaipungu 2015). The results of traffic count show that, traffic volume was 464, 655 and 144 AADT for Naabi, Ikoma and Ndabaka road respectively. However, the results indicate that 93% of traffic volume is light weight cars which have axle load less than 1.5 tonnes. The recommended limit of traffic volume for gravel road is 300 AADT (TZ-MoW 1999). Ndabaka road qualifies under this limit. Naabi which was assumed to have more traffic than other roads, was found to have traffic volume less than Ikoma road. This shows the importance of physical traffic count instead of relying on data from gate entry permits. However, since 93% of traffic in SENAPA is light weight passenger cars, the impact of traffic on the road can be assumed as due to vehicle traction rather than vehicle load associated stresses. As depicted by Shuler (2007), the performance of gravel roads depends on traffic volume and type. The type of traffic is important factor to consider because, the impact of 500ADT which is merely passenger cars and lights trucks can be equivalent to the impact of 250ADT traffic volume which is composed with light and medium size trucks (Shuler 2007).

The data collection was done from June to August 2016, which is the dry season and it is also the high season for tourists in the study area. The general condition of roads during this time was not promising. Naabi road which is in the savanna plains had problems such as corrugations, potholes, dust and ravelled more than Ikoma and Ndabaka roads although there were motor grader trying to cut the corrugations. Also, the roads have poor drainage structure like culverts and mitre drains to remove water away from the roads during rainy season. As ascertained by Kuennen (2009), good drainage is critical in gravel roads than paved roads hence shoulders, ditches and mitre drain should be properly maintained. In addition, Skorseth, Selim et al. (2000), exemplifies that, the primary causes of corrugations can be lack of moisture, driving habit and the quality of gravel materials. Other causes can be driving speed of motor grader during grading and lack of crown. It is not easy to remove completely corrugations from gravel roads especially during the dry season but can be reduced using proper equipment and skilled operators for road construction and maintenance, proper road structure and drainage systems and the use of good quality gravel materials (Kuennen 2009).

The resources for road construction and maintenance.

On this section, the information about the resources for road construction and maintenance were collected through document study and interviews with road stakeholders. The document studied were infrastructure department annual reports, road budgets, employee and equipment reports for a period of ten years from financial 2006/2007 to 2015/2016 as shown on Table 14.

Table 14: Approved budget, employees, and road length for ten years' period

S/N	Financial Year	Approved Budget (USD)	Employees	Total Road Length (KM)
1	2006-2007	133,087	22	991
2	2007-2008	440,128	22	991
3	2008-2009	555,469	22	1000
4	2009-2010	555,469	20	1200
5	2010-2011	555,469	20	1200
6	2011-2012	555,469	18	1295
7	2012-2013	555,469	13	1577
8	2013-2014	650,554	13	1577
9	2014-2015	773,870	13	1726
10	2015-2016	674,970	13	1726

The results show that, there was increase of the road length from 991 km in the financial 2006/2007 to 1726 km in the year 2015/2016. However, the budget for road construction and maintenance was not increasing as roads length increases as indicated on Table 14. From the financial year 2014/2015 to 2015/2016 the budget dropped, something which reduces predictability. Also, the number of permanent employees for the department was decreasing from 22 to 13.

On the side of equipment, the results show that the department lack the full set of gravel road equipment (haulage, excavation, loading, grading, watering and compaction). However, the few existing equipment are old and do not receive proper services and maintenance, hence frequent break downs and poor performance. Moreover, the department do not have compactor machine for compaction and water bowser truck for watering. Also, sources for water during dry season is a big challenge in SENAPA.

The interview results on resources reveals the same problems as found in document study. There were three interview questions about resources. i) the availability of reliable road equipment, ii) the staff technical knowledge on road construction and maintenance and iii) the adequacy of the budget provided for road works. The responses show that the budget provided is not sufficient and the equipment are not enough and reliable. However, the technical knowledge of staff is sufficient but the number of staff is not adequate.

In summary we can say that, insufficient resources for road construction and maintenance makes it difficult to establish and follow-up long-term plans in the study area. The interview results and the document studies reveals there is increase of road length while the resources such as budget, man power and equipment are declining. If this trend continues improvements cannot be expected, even if the available gravel materials meet the required standards.

Proposed improvement measures

Among proposed improvement measures was that, more studies should be done on the existing materials to improve the quality. Respondents from the SENAPA replied that the existing materials have the required quality but the problem is the techniques of application of materials on site in terms of equipment, compaction, and watering, and the staff experience. Surprisingly, some of the tour driver/guides who are the main users of the roads mentioned that, some of the tourists enjoy the nature of the existing roads which blends with the environment. They actually did not want higher standards (paved) roads, that may reduce satisfaction to the tourists. Moreover, the suggestion from the park ecologist was that, upgrading of roads to paving will not blend with the natural environment and may lead to road kills due to high speeds of cars.

CONCLUSIONS

This paper set out to answer i) the current practice of road construction and maintenance, ii) the strengths and weaknesses of the current practice and iii) the proposed improvement measures for sustainable roads in SENAPA.

The results of soil tests show that the gravel material in the existing borrow pits does not qualify in all parameters as specified by the standard manuals in Tanzania PMDM and SSRW, but still they can be used for gravel road construction and maintenance. On the other hand, traffic volume count results reveal the number of vehicles in the studied main roads Naabi and Ikoma is higher than the recommended standard for gravel roads except for Ndabaka road, but the impact to the roads is due to traction rather than load stress effect. However, the current poor performance of the studied roads in SENAPA may be mainly caused first by lack of resources for road construction and maintenance as revealed by interview and document study results. Secondly by the impacts from higher traffic volume and the failures shown in the soil tests.

Availability of gravel materials within the national park can be an advantage to the organization because the haulage distance will be reduced which can result in low construction and maintenance cost. However, currently, the performance of studied roads was not promising. Causes of poor performance such as corrugations, potholes, and dust may lead to disadvantages. These disadvantages are such as road accidents, frequent breakdowns of cars, complaints from tourists, high operation costs both to the road users, beneficiaries and the organization and delays to the destination points. Another disadvantage is that due to corrugations, drivers tend to drive at high speed with the reason that, high speed reduces vibrations to the car which reduces deformation. These high speeds increase dust which reduces the vision of drivers and animals hence results in accidents and road kills.

To improve the current condition and make the roads more sustainable and economical, the following are the proposed measures based on the study results. Integrated studies on engineering and ecological perspectives to be conducted to come up with good practices in terms of the use of marginally available gravel materials and water. This will minimize the impacts to the nature at the same time to have roads which are passable throughout the year. In line with this, due to the dryness of SENAPA, excavation of shallow waterholes should be taken into consideration. Surface runoff storage can be used during the dry season for road works, dust suppression and for animals as well. To enforce the importance of laboratory soil tests for gravel materials before excavation of borrow pits and the use of materials for road works. In this regard, we can avoid excavation of pits with poor materials which will not last long and reduce the environmental impacts. Also, after laboratory tests the gravel materials can be blended to improve the soil properties and hence the availability of marginal materials in economical haulage distance can be achieved. The organization to invest on road resources such as recruitment of enough, skilled and experienced staff, purchase of the required gravel road equipment and allocation of sufficient budget for road operations. To find the possibility of introduction of scenic roads which will be used only by tourist cars to reduce traffic on the main roads. This will increase satisfaction to the tourist due to less dust compared to the main roads with high speed and traffic. The road department could introduce and implement a strategic road construction and maintenance management systems. This will help the department to document the road length and condition of each section (condition survey), to have preventive maintenance strategies, to determine needs and prioritization for each road section.

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INTERVIEW QUESTIONS

A. Personal information

1. Name of respondent.....
2. Current employer.....
3. Work experience.....

B. What is the current practice of road construction and maintenance in Serengeti national park?

1. Where do the materials come from?
2. Whom do you contact if something is wrong with the road?
3. Who do the repair and construction of roads?
4. What is the quality of available gravel materials?
5. Are there sufficient and reliable equipment for road construction and maintenance?
6. Is the staff technical knowledge sufficient to maintain the roads?
7. Is the current budget adequate to maintain the roads?

C. What are the advantages and disadvantages of the current practice for road construction and maintenance of roads in Serengeti national park?

1. Advantages/disadvantages with the availability of materials
2. Advantages/disadvantages with who to contact if something is wrong
3. Advantages/disadvantages with the current conditions of roads
4. Advantages/disadvantages with the operation costs

D. What are the possible improvement measures for road and construction maintenance?

1. Other road construction and maintenance materials
2. Other road construction technology