Tanzania Journal of Engineering and Technology 2023, **42(1)**: 158-169
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Websites: https://ajol.org/tjet; https://tjet.udsm.ac.tz

ISSN 1821-536X (**print**); ISSN 2619-8789 (**electronic**)
https://doi.org/10.52339/tjet.v42i2.814

Regular Research Manuscript

A Perspective into Development of Pavement Design Methods for Low Volume Roads: A Review

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ABSTRACT

The definition of low volume roads (LVRs) is not time static and it varies from place to place around the world. The importance of such roads for providing access, in connecting communities and link farms to markets is well appreciated worldwide. LVRs are credited as the direct source of social economic development in rural communities, growth, reduction of poverty and sustaining livelihood. Nevertheless, the LVR network is growing at an unsatisfactory rate especially in Sub-Saharan Africa. The slow rate in developing LVR network is attributed to the high cost of construction and maintenance. To the author's perspective, research has a significant role in lowering both maintenance and construction costs and in turn realise a growth in the network size and adequacy. To demonstrate the importance of research in road development, a comparison has been made between the current and the previous pavement design methods for LVRs in Tanzania. The improvement so far has been in the determination of subgrade strength using the Dynamic Cone Penetration (DCP) method instead of the less accurate and more demanding California Bering Ratio (CBR) method; a simpler approach in estimating design traffic load that is also less conservative; encouraging the use of local natural materials which could be marginal for construction instead of the conventional but expensive crushed rock; and improvement in layer design which result to less pavement thickness. While all these improvements enhance saving in pavement cost, it is argued that further development is possible through research especially in local materials and procedures.

ARTICLE INFO

First submitted: Oct. 25, 2022

Revised: Apr. 20, 2023

Accepted: Apr. 30, 2023

Published: June, 2023

Keywords: *low volume roads, pavement design, marginal materials, road development*

INTRODUCTION

Low Volume Roads (LVRs) form a significant part of any transportation system. They serve as access roads, connect communities and link farms to markets. LVRs are necessary to serve the public in rural areas, to improve the flow of goods and services, to help promote development, public health and education. From the outset of this review, it is imperative to define LVRs as there is a wide variation of definitions around the world. LVR definitions are normally based on one or two criteria; the number of annual average daily traffic (AADT) during the design life of the road and the expected traffic load in terms of Maximum Equivalent Standard Axials (MESA). In Ethiopia for instance, LVRs are defined as roads which are expected to carry an AADT of 300 motor vehicles per day over their design life while not exceeding 1.0 MESA in one direction (ERA, 2011). This definition also applies in Malawi (MTPW, 2013) and Tanzania (MoWTC, 2016). However, the previously established LVR guideline for the Southern African Development Community (SADC) region defines LVRs as those which typically carry less than 200 vehicles per day, including up to 20% commercial vehicles, and often include non-motorised traffic (SATCC, 2003). In his book, (Douglas, 2016) has adopted the definition of low volume roads to be those with traffic volumes of no more than 400 vehicles per day. In India, a road carrying up to 5.0 MESA is still categorised as a LVR (Bagui, 2012). Praticò *et al.* (2011) reported a broad classification of LVRs of mainly unpaved roads with AADT of less than 500 vehicles but also including certain paved roads. Behrens (1999) also defined LVRs in terms of 500 vehicles per day. According to Keller (2016), LVRs are those with an AADT of 1000 to 400 or less vehicles per day. In Zegeer *et al.* (1994) roads with traffic volume up to 2000 vehicles per day were termed as LVRs whereas Sirivitmaitrie *et al.* (2011) considered a range of up to 5000 vehicles per day in expressing LVRs. For European standards, the AADT of up to 1000 is the cut off point for LVRs (Falla *et al.*, 2017). The variation in defining parameters of LVRs would mean a variety in design approaches. Under such circumstances, design methodologies that have taken into consideration the local input parameters such as materials and climatic conditions should be more certain hence preferable.

The definition of LVRs is not static but rather aligns with increase in traffic volumes occurring in transportation network due to development. For instance, back in the 80's, the upper boundary for defining LVRs in the US was an AADT of 400 (Oglesby, 1985) compared to a more recent definition by Keller (2016) which accommodates up to 1000 vehicles per day and may differ from state to state. Likewise, the Tanzania definition changed from the cut-off point of 200 vehicles per day with up to 20% commercial vehicles as per SATCC (2003) to the current definition of up to 300 vehicles per day and not more than 1.0 MESA as defined by MoWTC (2016). Some of these roads have very low general traffic but rather serve special purpose as carrying farm to market trucks or forestry products. These might have low traffic but relatively heavy and therefore their design should consider these facts, example (Hauser *et al.*, 2018). This variety of classifications together with the fact that design philosophy LVRs is based more on the roads' response to environmental factors suggest that unique solutions to pavement designs will have best results compared to generic ones. Considering such circumstances, it can be suggested that the best way to find solutions to challenges or just advance in LVRs design would be by conducting research at country or regions level rather than relying on global solutions.

Besides differences in their classification, there is a general agreement about the importance of LVRs around the world mainly attributed to the service they offer but as well their number. LVRs are credited as the direct source of social economic development in rural communities, growth, reduction of poverty and sustaining livelihood (Praticò *et al.* 2011; Sirivitmaitrie *et al.* 2011; Behrens 1999;

Faiz 2012). However, these benefits are normally difficult to quantify. In both the developed and developing world, the network of LVRs takes a larger share of the total length of the road network. In the US for example, LVRs are estimated to cover 60% of the road network (Praticò *et al.* 2011) and by late 1990s, Behrens (1999) reported that LVRs represented more than 54% of the annual roads' investment program for their development and rehabilitation. Paige-Green (1999) informed that South Africa has an enormous road network classified as light trafficked. Likewise, Dell'Acqua and Russo (2011) documented that Low volume roads of typically AADT less than 1000 vehicles per day take a large chunk of the rural roadway network in Italy. In Tanzania, LVRs take more than 75% of the road network and is the backbone to social and economic progress for more than 80% of the country's population living in rural areas (MoWTC, 2016). Therefore, the development of LVRs is crucial to the development of the country.

METHODS AND MATERIALS

In the context of this paper, road development means improvement of design tools, material testing equipment, procedures and outputs, improvement in the serviceability of the roads in the existing network, increase of the network size and overall reduction in road construction/maintenance costs. This study aims at reviewing the progress made especially in pavement design of LVRs and try to point out the implication of the progress especially for Tanzania. The objective of any pavement design is to provide an economical structure in terms of thickness and material that can withstand the expected traffic loading over a specified time without deteriorating below a specified level of service. Nearly all pavement design methods consist of assessing the strength of the subgrade, determining the design traffic loading, selecting materials for the pavement layers and determining the pavement layers thicknesses. The SADC guideline (SATCC, 2003) assessed and presented design methods commonly used for the region. The manual listed appropriate methods for design of LVRs, one of these was the Tanzania Pavement and Materials Design Manual (MoW, 1999). An appropriate design method is that based on experience and fundamental theory of structural and material behaviour that develop over time. This means the MoW (1999) method was most relevant for design of LVRs in Tanzania and therefore development of LVRs design methods will be discussed based on the MoW (1999) versus the more recent MoWTC (2016) method. The discussion is related to the four stages of pavement design listed above.

Assessment of Subgrade Strength

Except for rehabilitation and overlays design, the MoW (1999) pavement design method recommends subgrade strength in terms of the California Bearing Ratio values (CBR). The manual clearly state that other methods may be used to evaluate the subgrade strength but should be correlated with CBR and approved by the Ministry before application. In the laboratory, CBR values are recommended to be evaluated at three density levels or more and must be soaked for four days before testing. Three CBR classes are defined in the method which may be interpreted as low, medium and high. The CBR is one of the oldest soil testing methods that emerged in the 1940's (Hauser *et al.*, 2018). It is also simple, economical and very popular. Nearly all matured pavement design methods require subgrade strength in terms of CBR. However, when it comes to determination of structural function of a pavement layer, comprehensive tests are more suitable (Falla *et al.*, 2017).

One drawback of applying CBR method is that it tends to overdesign pavements due to the presentation of the soaked CBR as the prevailing subgrade condition all the time (Rolt and Pinard, 2016). Still its simplicity and popularity favors it in the market especially considering that agencies dealing with LVRs tend to rely on design input requirements that are readily available due to limited resources, lack of information, time and budget to perform other advanced tests (Warith *et al.*, 2015).

The MoWTC (2016) LVRs pavement design method however insists on the use of the Dynamic Cone Penetrometer (DCP) as the method for determining insitu strength of the subgrade. This method has many advantages over the CBR method including it being cheaper and much faster. Many DCP tests can be performed over a very short time which improves reliability of the design by having enough data for analysis. Moreover, in the DCP test, the material is tested in an undisturbed state, whereas the CBR test is carried out on a disturbed sample, which must then be remoulded in the laboratory; hence the possibility of introducing a number of sources of errors (Rolt and Pinard, 2017). The application of DCP in subgrade strength determination has brought about the DCP design method which has demonstrated a potential to save pavement cost (Chibwe and Musenero, 2019). It is through long term research that the DCP has finally come to be one of the reliable tools in pavement design.

Determination of Traffic Loading

In the MoW (1999) procedure for determination of traffic loading, the following steps are usually applied:

(a) Perform traffic counting in both directions of the road;
(b) Axle load survey in both directions;
(c) Determination of vehicle equivalent factors;
(d) Determination of proportion of standard axles classified as heavy;
(e) Applying traffic growth and lane distribution;
(f) Add construction traffic;
(g) Determine the design traffic loading and;
(h) Classify into one of the seven available traffic load classes.

The procedure for LVRs manual is similar to the MoW (1999) except for some specific cases here and there. For instance, the MoWTC design traffic estimation procedure recognizes the difficulty in conducting axial load surveys for some of the low volume roads. Therefore, it has a provision of using the AADT from traffic counts, where records are taken to indicate whether the medium and heavy vehicles that have been counted are full, empty or partial. There is a provision of vehicle equivalent factors to facilitate the forecasting of traffic loading instead of the commonly applied power law which generally tend to exaggerate the traffic loading (SATCC, 2003).

Another element of concern is the estimation of traffic growth in low volume roads. The general trend of LVRs especially near townships is that when a once classified LVR is paved, the volume of traffic tends to increase and sometimes beyond the limit identified for their class. Apronti *et al.* (2016) identified important variables for predicting the volume of LVRs to be land use adjacent the road, road surface (unpaved or paved), population, number of households, access to highway, per capital income and density of housing units. There is also a room for improving the traffic volume forecasting by doing local studies that try to identify the common patterns of traffic variations relative to social and economic conditions that are country or regional specific.

Selection of Construction Materials

Selection of road construction materials start early in the design stage where a desk study is undertaken to assemble existing information about the subgrade and construction materials. Later during design, samples are taken from the identified sources, tested and compared to standards. Materials that pass the requirements per standards will be used as desired while those which fail the tests will either be rejected or improved to meet standards. Composite manufactured materials such as bituminous mixes will require individual ingredients to pass the relevant tests to be applied in producing the desired mix. An exceptional philosophical feature of the current LVR design method is to maximise the use naturally occurring unprocessed materials (MoWTC, 2016) contrary to the MoW (1999) approach that seem to limit their use in favour of the more expensive crushed rocks. Furthermore, the current LVR manual recognises that the lightly trafficked roads do not necessarily require structural surfacing hence it has provision of a wide variety of bituminous seals and their combinations. There is also an option of using a variety of discrete materials such as fired clay bricks and stones.

The current move with regard to LVR design is to encourage the use of locally available materials which may not in totality satisfy the standards. Scarcity of good quality natural materials and long hauling distances are the major motives for promoting utilisation of locally available materials. Stabilisation is deemed a solution for upgrading the less qualified materials to good quality but sometimes just a simple blending may result to a qualified material for pavement construction (Lingwanda and Mnkeni, 2017; Chengula and Mnkeni, 2021). The relaxation of material quality in standards is also due to the discovery that the material control properties such as plasticity and grading do not correlate with the pavement failures most of the time (Rolt and Pinard, 2016). However, as discussed by Bagui (2012), too low qualifications prior to stabilisation may be a preparation for the road's high maintenance cost hence uneconomical solution. For instance, cement stabilised marginal materials are likely to fail prematurely due to shrinkage cracks as compared to high quality materials (Liebenberg and Visser, 2003). Therefore, too low prior qualifications should generally be avoided.

To refer to a practical example, the construction of Dar – Mlandizi road which took place in the late 90s is a prime example of how the application of natural existing materials has potential of great saving in pavement cost. According to Onyango *et al.* (2007), the project was able to achieve a 20% cost saving as compared to if conventional design with thick asphalt layer were used. Similarly, it is through dedication to research that natural pozzolan was introduced as alternative to cement stabilizer for road construction around 2003 – 2004 in Tanzania.

Determination of Pavement Layers

Available empirical methods for determination of suitable pavement layers and their thicknesses require subgrade strength, traffic loading and climate information as inputs. Back in the 1990's some states of the US used a standard section (usually a double surface seal) over a granular layer of a specified thickness for all low volume roads. Later it was found that this practice resulted to inadequate pavement structures and the need for proper designs was established (Li *et al.* 2011). However, it is a common practice for LVRs to be built at a lower standard than their counterpart (Benmaamar, 2003). According to Falla *et al.* (2017), thin asphalt surfacing requires high quality material for bases therefore their failure might be due to inferior base materials. However, it is not anticipated for the pavement structure of a low volume road to be the same as that for a high-volume road mainly because of the primary difference in performance between LVRs and high-volume roads. While the former is much affected by weather elements, the later are affected much by traffic loading (SATCC, 2003). Studies have shown that a typical low volume pavement built of a granular base with a thin asphalt surfacing fails by deformation in form of rutting unlike high traffic volume roads where fatigue cracking is dominant (Singh and Sahoo, 2020).

Up to the year 2016, LVRs in Tanzania were designed using the Tanzania Pavement and Material Design Manual (MoW 1999) which does not explicitly cover LVRs. This means the LVRs were unnecessarily thicker than required hence overdesigned. Even so, it was shown by Wanyan *et al*. (2010) that provision of a thicker pavement layer does not guarantee prevention of failure. In flexible pavement systems, a high-volume road pavement may consist of three to four layers whereas a low volume road is generally anticipated to be a two layered pavement system (Singh and Sahoo, 2020). It has been demonstrated earlier that LVRs design using the Tanzania Pavement and Material Design manual (MoW, 1999) results to an exaggeration of the pavement thickness with a cost implication of twice as much as what is necessary (Mfinanga and Mwakyami, 2008). Since their observation was done long before the introduction of the current LVRs design manual, it is the interest of this review to compare the two design manuals and determine the difference between design outputs.

RESULTS AND DISCUSSIONS

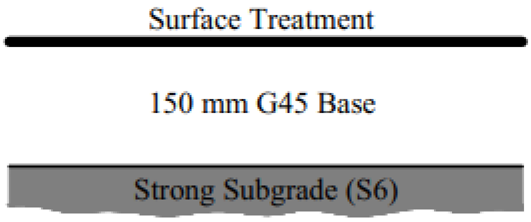
To demonstrate the differences in the two design catalogues, two design scenarios are considered as follows:

Best Case Scenario

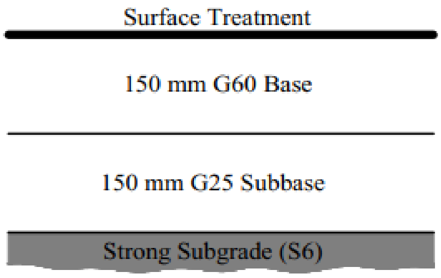
A typical LVR consists of a thin bituminous surface underlain by one or more layers of natural gravel. With the use of LVR design manual, a pavement in dry environment might consist of a 150 mm thick G45 base layer on top of a strong subgrade (S6) when the estimated traffic is low (less than 0.01 MESA). These conditions of dry environment, strong subgrade and low traffic are considered to be the best-case scenario to the designer. For comparison, when such a pavement had to be designed using the MoW (1999) method, the pavement would be provided with the following layers: 150 mm G60 base over a 150 mm G25 sub base. The two resulting designs are compared in Figure 1 where it can clearly be concluded without cost analysis that design (b) is more expensive than design (a) in terms of quality of specified materials and thickness. This shows the significance of using relevant guidelines for any design.

Worst Case Scenario

To the designer, the worst-case scenario would be the extremes of traffic loading accompanied by low strength subgrade and unfavourable weather. In this case the consideration is for a weak subgrade (S2), high traffic load (0.5 – 1.0 MESA) and wet conditions. Although the traffic loading is higher than the previously discussed case (best-case), it is still within the LVRs limits according to the standard. Design using LVR manual (MoWTC, 2016) result to provision of a 200 mm thick G80 base over a 175 mm thick G30 sub base over a 175 mm thick G15 capping layer. On the contrary, using the MoW (1999) manual the following layers are recommended: 150 mm thick CRS base over 200 mm thick G45 sub base over 150 mm thick G15 improved subgrade over a 300 mm thick G7 lower improved subgrade layer. These designs are compared in Figure 2 where it can be clearly concluded that design (b) is more expensive than design (a) due to pavement thickness and quality of the recommended materials.

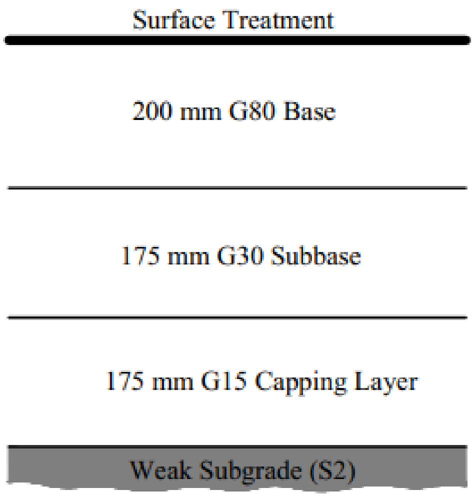


(a) Design by MoWTC (2016) manual

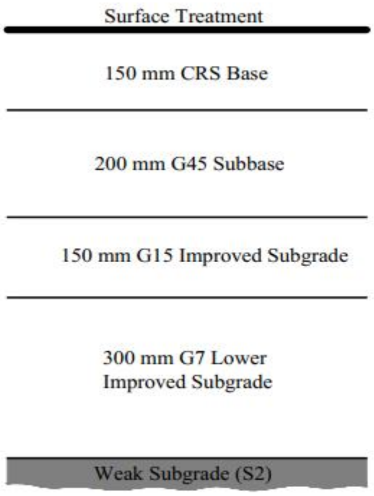


(b) Design by MoW (1999) manual

Figure 1: Comparison of pavement layers requirements in the best-case LVR scenario



(a) Design by MoWTC (2016) manual



(b) Design by MoW (1999) manual

Figure 2: Comparison of pavement layers requirements in the worst-case LVR scenario

where:

S2 means subgrade of soaked CBR 3 – 4%

S6 means subgrade of soaked CBR > 30%

G7 means natural gravel or soil of CBR ≥ 7%

G15 means natural gravel or soil of minimum CBR of 15%

G30 means natural gravel of minimum CBR of 30%

G45 means natural gravel of minimum CBR of 45%

G80 means natural gravel of minimum CBR of 80%

CRS means crushed stone obtained by crushing and screening of blasted rock, stones, boulders and oversize from natural gravel.

Further details of swell characteristics, gradation, maximum particle size and plasticity are also specified in the standards. Compaction efforts and CBR moisture conditions specifications should be checked against each specific manual.

With reference to the two arbitrary design scenarios, we have perceived a great serving in material and cost due to the difference in designs between MoW (1999) method and MoWTC (2016) method. However, it is the opinion of the author that these designs may further be refined to be more economical. For instance, the design in Figure 2(a) which is supposedly the best among the two still seems too thick. It is difficult to contemplate a low volume road which historically had only one bearing layer (the base) to have three layers totalling 550 mm. It is hereby proposed the consideration of analytical approaches coupled with the so far gained experience about the catalogue to research on the possibility of further reducing the pavement thickness.

In comparison, AASHTO design specifications were also meant for high traffic volume roads (Ruenkrairergsa, 1987). Back then, Oglesby (1985) recommended the geometric design of LVRs take a different approach to that of high-volume roads for economical purposes. In 2016 Tanzania finally had a manual that take care of LVRs and these efforts should be commended. In fact, the treatment between low and high-volume roads is expected to be different even at the appraisal stage. Normally the user benefit approach is suitable for roads of relatively high traffic volumes whereas the cost effectiveness approach is deemed more suitable for low volume roads (Benmaamar, 2003). This is mainly because LVRs demonstrate small magnitude of user benefits and their deterioration are rather due to environmental factors than traffic effects. Preferably, LVR design should be simple and less demanding in data requirement because these two might have a cost implication in case the agency will be required to hire experts to handle the complex activities.

Role of research in road development

About 15 years ago, it was reported that 93% of the 85,000 km road network in Tanzania were unpaved (Mfinanga and Mwakyami, 2008). Later in 2015, Kelly and Juma documented that 56,000 km of the network (which would make about 70% of the network) were still unpaved. Theoretically with this trend, one would predict to take more than 50 years to have the network fully developed. The slow rate of road improvement is mainly attributed to the high cost in road construction and maintenance, a situation that has been prevailing in most of the Sub-Saharan Africa. It has been documented earlier that Sub-Saharan Africa was the region with the least developed road networks, with the exception of a few counties like South Africa, Gambia and Mauritius (Faiz, 2012). Information like this means more efforts are needed to reduce the cost of construction and rehabilitation so that more kilometers can be developed per year. This can never be achieved without a dedication in research especially in aspects of road design and maintenance.

Being part of the SADC, Tanzania has benefitted from several donor funded projects in the region aiming at researching and preparing guidelines to handle major aspects of LVRs including design (Mfinanga and Mwakyami, 2008). Other than that, the number of published research on LVRs, materials and roads in general have been very low, hence a missed opportunity to improve the roads and lower the cost. For instance, the Tanzania LVR manual launched in 2016 has very few countries specific research linked to it. It is the opinion of the author that road research is a responsibility of the road agencies and the higher learning institutions because they both have the demanded expertism. One may argue that road agencies are likely to have a shortage of staff that are trained to conduct research, example Mwaipungu and Allopi, (2014). However, a good collaboration between higher learning institutions and road agencies is likely to bring about the positive changes in the road sector. For instance, where the agencies may take the role of communicating the challenges they face in practice, higher learning institutions may take the role of conducting the research and publishing the results. Some research activities like data collection might be shared between the agencies and the institutions. The agencies will implement the research recommendations and give feedback to the institutions who might be required to revise their earlier recommendations through further research. This way a sustainable cycle of road development will be achieved.

Development of roads in every sense of the term is highly dependent on research. For instance, early geometric design standards provided for narrower road lanes which prompted safety concerns in the modern world. Later in their research, Zegeer *et al.* (1994) demonstrated that accident rates on paved, low-volume roads are significantly reduced by provision of wider roadway width, improved roadside condition and flatter terrain among other factors. However, they warned that widening of lane width should be accompanied by provision of shoulders for effective reduction in accidents. This is something that practitioners would never guess without doing proper research.

The importance of research in roads development can never be overemphasised. For example, the knowledge growth in LVRs in the US is attributed to the establishment of the Transport Research Board (TRB) back in 1972 (Faiz, 2012). The board had a role in conducting, sponsoring and dissemination of research results through publications and organization of conferences. Furthermore, the American Association of State Highway and Transportation Officials (AASHTO) has had a long experience in road designing and publications of a variety of guides. To date, many countries rely of American research and standards in making decisions about their road sector. However, it was suggested by Magafu and Li (2010) that among the reasons for failure of LVRs in Tanzania is the use of design methods adopted from developed countries. Now that Tanzania has a country-specific LVRs design manual, professionals should be reminded that improvements of the design methods will be more relevant coming from research based in the local materials and procedures. Design approaches, especially for LVRs should simultaneously satisfy the criteria of simplicity, input availability and cost effectiveness (Karim *et al.*, 2015). Most LVR designs methods are empirical, specifying materials and their thickness based on country specific experience (Falla *et al.*, 2017). Changes in traffic volume, traffic loading and environmental conditions over time suggest the need of improving design procedures to analytical methods that will suit the new conditions. This is yet another reason to stress on road research in Tanzania. It was through extensive research that now lateritic materials are encouraged for application as road construction materials besides their less conformity to typical specifications (Paige-Green *et al.*, 2015). The relaxation of standards to allow uses of what are generally considered as marginal materials means an increased demand in material stabilisation hence a demand in research. It can also be thought as an opportunity to use unconventional stabilisers. Elsewhere in the world, research on using unconventional soil improvement materials is a current topic (Turkane and Chouksey, 2022).

The current Tanzania LVR design manual came to practice in 2016 (MoWTC, 2016) and is definitely one of the greatest achievements with regard to road development. Before that, the standard used for design of all roads in the country was the Pavement and Materials Design Manual (MoW, 1999). Among the great features of LVR manual is allowance to use locally available materials that may be marginal. Around the world, researchers agree that scarcity of high-quality building materials prompt the use of what was considered marginal materials in low volume roads. Not because these are of less importance but because the low traffic in numbers and loading means marginal materials are more likely to sustain the conditions more than in highly trafficked roads. Unlike manufactured materials, geotechnical materials tend to be unique and variable hence accompanied by significant uncertainties. This would mean that research results based on materials from a certain locality need to be verified before application of the same to a different location. Variation in traffic, weather, construction methodology only adds uncertainties to the equation. This will generally mean that more research is needed to allow application of results at specific localities. Locally based research is the best in solving specific challenges.

Research is also applicable in introducing new materials to the market. Normally the penetration to market of a new product such as a new stabilizing material tend to be difficult especially due to lack of specifications and quality supporting research (Campbell and Jones, 2011). Proper research with trial and control road sections, proper data collection and proper keeping of construction data and monitoring would almost guarantee the sustainability of the introduced material to the market so long as it has demonstrated performance and cost benefits.

CONCLUDING REMARKS

Pavement design for low volume roads has come a long way before the introduction of the current design manual in Tanzania which is specific to low volume roads. Although this review did not quantify in monitory terms the savings brought by using the current design approach, it has demonstrated that the previous design manual overdesigned low volume road pavements which had a negative impact to the cost. Moreover, the current approach has given allowance for use of local marginal materials, a move that has a positive impact to the cost and environment preservation. There is a room to further improve every stage of the pavement design process namely establishing the subgrade strength, determining design traffic loading, selection of materials and design of the actual pavement layers. However, emphasis should be put in researching local materials and procedures to ensure that improvement proposed are more relevant to the country.

To start with, road agencies should make it a mission to have a database of all managed roads including construction records, traffic, maintenance and condition information. The database should be well maintained by updating it regularly. Let practicing engineers contribute to development/improvement of the current design methods by collecting and documenting both their positive and negative experiences on the use of the design manuals. These may be shared with higher learning institutions for research purposes. Strategically engage training and research institutions to investigate the identified issues and challenges and let them bring the solutions back to practitioners. Research has a great potential to lower road construction and maintenance costs and eventually develop the road network at a faster pace.

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