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Evaluation of Sustainable Development for Low-Volume Roads in Sarawak

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ABSTRACT

The national socio-economic development programme prioritises rural development, and the state of Sarawak requires many rural roads to connect existing villages to the main roads. This programme can be achieved by upgrading existing non-standard access roads or constructing new access roads. The current challenges and issues related to the sustainable development of low-volume roads (LVRs) in the Malaysian state of Sarawak were investigated in this study. The key goals of the study were to understand the challenges of sustainable development in Low Volume Roads (LVRs) in Sarawak using expert interviews as well as surveys on experienced engineers. It aimed at clarifying what LVRs are, highlighting challenges to do with designing and planning them, and also discussing pavement design aspects. The data for the research was collected through interviews with experts in state Public Work Department (PWD) and consultants with more than 15 years' experience in road planning and construction. An online questionnaire was distributed and it targeted government agencies, consultants, contractors, with 52 respondents out of 200 possible. This helped to identify important problems associated with LVR development; it stressed that a proper knowledge of LVR design, planning difficulties and those specific concerning pavement designs is needed among professionals within Sarawak road building industry. Based on the findings, immediate need for actions was required to be taken by road agencies to investigate the development and appropriate design of LVRs also to record and gather historical data on current LVRs for further improvement.

Keywords: Low-volume roads; rural roads; sustainability; sustainable development

INTRODUCTION

Low-volume roads, commonly known as LVRs, have a lower investment priority than other road types, as traditional investment prioritises projects based on volume-driven benefit and effect indicators (NCHRP 2018). Nevertheless, LVRs can contribute significant value to the greater economy and society. These values include providing basic access to underprivileged communities, ensuring the connectivity of the industry to the global economy (particularly last-mile connectivity), and boosting economic growth opportunities. While major infrastructure investment should prioritise high-volume roads, LVRs should receive special consideration. LVRs are utilised infrequently in rural areas accessible to local access and collector highways. Moreover, the construction standard for low-volume paved roads fall below that of standard design.

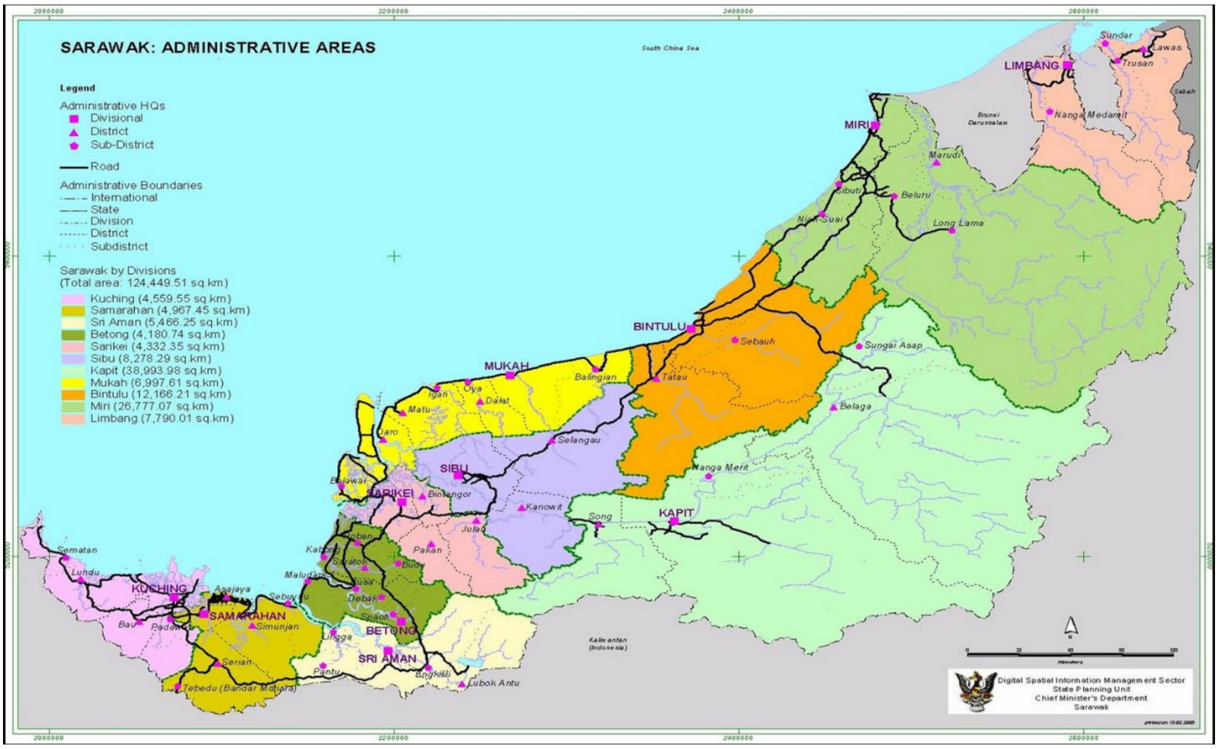


FIGURE 1. State map of Sarawak, Malaysia
Source: Sarawak State Planning Unit, Department of the Premier of Sarawak

Transportation agencies lack the funding to provide adequate serviceability than higher-volume highways when managing LVRs (Hafez et al. 2019). The available evidence substantiates the claims made by policymakers regarding the positive impact of rural road construction on both agricultural and non-agricultural economic growth, as well as its potential to alleviate poverty. However, the evaluation of the causal impacts of rural roads poses significant challenges, primarily attributable to the endogeneity issues associated with the placement of these roads. The correlation between the location of new roadways and the economic and political aspects of the surrounding area is generally attributed to the high costs and potential advantages associated with infrastructure investments (Blimpo et al. 2013; Brueckner, 2014; Lehne et al. 2018). Many agencies attempt to justify their maintenance investments in the present economy while maximising their limited LVR resources for optimal serviceability. Thus, increased production activity promotes truck loads exceeding the basic design specifications. Most LVRs are also constructed over an extended period, where no historical records of their maintenance and restoration are recorded. Many LVRs remain in poor conditions as the network lacks sufficient historical and performance data sets, including insufficient resources for traffic accumulation, operation, performance, and inventory data (Hafez et al. 2019). In recent years, expenditure and funding justifications for LVRs have been intrinsically weak, while expenditures on maintaining transport surfaces have declined (The Pew Charitable Trusts 2014; Hafez et al. 2019).

The Sarawak Socio-Economic Transformation Plan (SETP) prioritises road construction as one of its key components. Hence, the objective of developing an extensive road network in Sarawak by 2030 has been established. According to the Ministry of Works Malaysia (KKR), 1,424 kilometres (km) of federal roads and 29,626 km of state roads are recorded in the state of Sarawak (see Figure 1). Approximately 18,289 km of state roads are paved, 5,078 kilometres are gravel roads, and 6,259 km are earth roads (Buku Statistik 2018). Due to the large size and rugged terrain of the region, many settlements are still not connected by roads. The Ministry of Infrastructure and Communications of Sarawak presents that the state requires roughly 9,253 km of rural roads to connect existing communities to major roads. Furthermore, existing non-standard access roads should be improved, or new access roads should be constructed to build these roads.

The Sarawak Public Works Department, commonly known as Jabatan Kerja Raya Sarawak (JKRS), have divided existing villages into two groups. Category "A" villages have approximately 4,851 km of non-standard access roads connecting to existing major roadways, requiring improvement in this category. In contrast, villages Categorised as "B" are characterised by a lack of access roads that connect them to the preexisting main road network. The total length of access roads needed in this particular category is estimated to be approximately 4,402 kilometres. Given that the majority of village roads are commonly used for the transportation of individuals and goods by light vehicles, it is assumed that these roads adhere to the standards set by the Public Works Department (JKR) for R1 or R2 classifications.

When constructing roads that are well-engineered, it is imperative to ensure that the minimum criteria are satisfied while addressing any associated concerns. The roads in question should be designed and constructed in a manner that reflects and encompasses deliverables that are considered to be of utmost importance. One of the key outcomes comprises the potential for cost savings and time efficiency in transport, contingent upon the proper construction of roads with adequate and suitable resources. Specifically, roads that have been meticulously designed demonstrate a decrease in travel time and an enhancement in safety. Good planning can reduce the detrimental impact on society and the environment if these roads are to be developed and maintained at a low cost. Thus, the decisions taken during the design phases, construction, and maintenance affect the surrounding community and other industries, such as agriculture, water, public health, and education.

A unique set of difficulties and concerns is usually presented when developing and constructing LVRs. The constructed LVRs also encounter challenges and issues arising from certain criteria not being met or completely prioritised during the planning, development, and construction phases. These issues cause considerable challenges, which should be addressed to complete or overcome the obstacles. Due to the prevalence of these challenges, LVRs are becoming more difficult to maintain. Hence, this study provided solutions to the issues related to the management of LVRs. On the contrary, LVRs acquired various facets as numerous challenges and issues were associated, which were unique.

DEFINITION OF LVRS

Although no single approach to the LVR definition has been discovered, various volume thresholds are recorded (particularly to set design guidelines). Faiz (2012) analysed numerous low-volume design concepts employed in the United States, in which LVRs were typically characterised as roads based on average daily traffic of fewer than 500 vehicles. According to the frequently accepted definition of LVRs, the maximum daily number of permitted vehicles was 400 (AASHTO 2001). The study described LVRs as those transporting fewer than 1,000 vehicles per day (vpd). Additionally, LVRs were responsible for approximately two-thirds of all roads worldwide, equivalent to approximately 30 million km or 18 million miles (Faiz, 2016; Keller, 2016). Alternatively, rural roads in Spain were LVRs with an Average Daily Traffic (ADT) of less than 500 vpd annually (Gallego et al. 2008). In South Africa, rural roads recorded between 50 to 200 vpd on average (Pinard et al. 2003).

The road hierarchy guideline in Malaysia is categorised by function and capacity, contained in the "A Guide on Geometric Design of Roads" manual published by the Road Engineering Association of Malaysia (REAM). The LVRs are typically a Minor Road element classified as R2 and R1. This classification provides an expected traffic volume or ADT between 150 to 1,000 or less than 150 vehicles daily for R2 and R1 standards, respectively (REAM 2002). From the LVR traffic volume criteria, no generic LVR definition is abundantly clear, and its corresponding identification is only based on location, land use, terrain, traffic mix, and population (Douglas 2016). This assertion is maintained as no universally accepted definition of LVR is recorded. Another element of the LVR definition (AASHTO 2001) is the functional classification (or hierarchy) of routes. This strategy builds effective road management and maintenance practices while aligning engineering standards with road-related obligations (Giummarra 2003). On a higher-class road, mobility takes priority, while on a lower-class road, property access takes precedence. The function of a road, which is widely used by road authorities to classify roads into different functional classes (such as local roads), is reflected by the characteristic of the route (such as projected traffic volume) (Austroads, 2015a, Franzen & Thorpe 2020). This classification facilitates resource allocation (Giummarra 2003), in which LVRs are frequently connected with lower hierarchy roads. For example, local roads primarily offer access to households, farms, and businesses rather than to meet traffic demands (AASHTO 2001).

METHODOLOGY

This study investigated the current obstacles and concerns associated with the sustainable development of LVRs in Sarawak. The first stage involved interviews with 3 senior officers from the state Public Work Department (PWD) and 3 experts from consultant with more than 15 years of experience planning, designing, and managing road projects for the Public Work Department to determine the common issues associated with developing LVRs in Sarawak. Therefore, this study addresses three specific research questions as follows:

Q1: What was the common definition for LVRs?

Q2: What were designers' common issues and challenges in planning and designing LVRs?

Q3: What were the common issues related to the pavement design of LVRs?

This interview and inquiry served as the basis for a survey questionnaire distributed to practicing engineers and professionals from numerous local administrations around the state in road construction and design.

The second stage of this study involved disseminating questionnaires to local engineers with experience in LVRs. This information was crucial for analysing state-level practitioners' present concerns and challenges concerning LVRs. Subsequently, the online questionnaire was conducted using a proprietary platform, which provided several benefits, including speed, timeliness, flexibility, convenience, and ease of data entry and analysis. The questionnaire was voluntary, and confidentiality was guaranteed to alleviate the respondents' concerns. The objective of the first section of the questionnaire was to collect data regarding LVR experience, definition, and concept. In the second section, issues and challenges associated with the pavement design of LVRs in Sarawak were discussed. Approximately 200 questionnaires were distributed, and 52 replies were received (see Figure 2). The percentage of respondents and organisations participated comprised 12 (23%) from government agencies, 35 (67%) from consultants, and five (10%) from contractors. The following sections provide a synopsis of the key findings of this study.

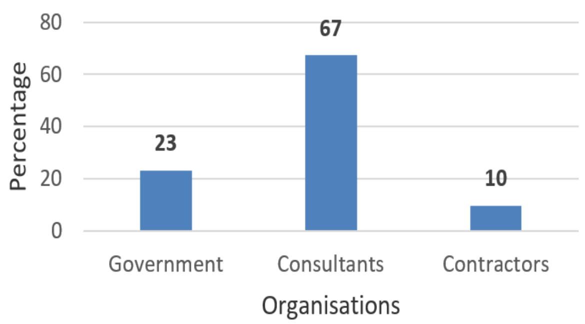


FIGURE 2. Percentage of respondents and organisations

RESULTS AND DISCUSSION

RESPONDENT PROFILE AND BACKGROUND

The analysis of respondents' backgrounds was conducted using results derived from Microsoft Excel, based on data collected from a total of 52 questionnaires received via an online Google survey. This formed the basis for data analysis in this study. Figure 3 presents a summary of the respondents' areas of specialization, revealing a diverse range of expertise within the sector. Notably, approximately 29% of the participants are engaged in road construction, while another 23% are involved in a broader scope of activities encompassing pavement, road planning and design, and civil engineering works. Other significant areas of specialization include Project Management/Coordination (13%), Civil Works/Laboratory and Field Testing of Construction Materials (12%), and Road/Highway Maintenance, with each of the remaining categories, such as Researchers, Academics, and Site Managers, constituting 5% of the respondent pool. Also, Figure 4 describes the respondents' years of experience within the field, demonstrating that 19% have between 1 and 5 years of experience, 42% possess 6 to 10 years, 25% have 11 to 15 years, and 13% boast more than 15 years of experience.

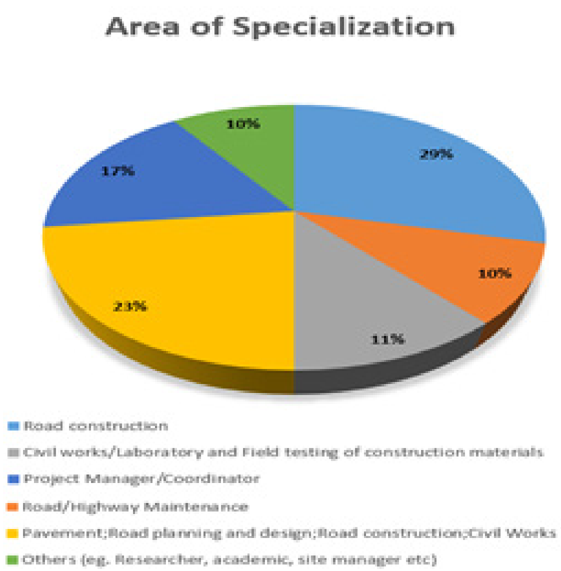


FIGURE 3. Respondents' area of specialization

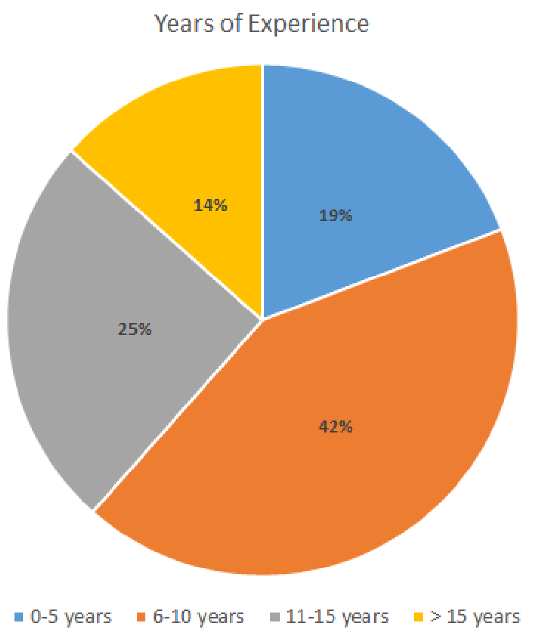


FIGURE 4. Respondents' years of experience

DEFINITION OF LOW-VOLUME PAVED ROAD

All respondents agreed that the LVR definition was derived from the REAM guidelines (REAM, 2002), which defined the ADT to be between 150 to 1,000 vehicle per day (vpd) for the R2 standard and less than 150 vpd for the R1 standard. While the guideline specified that the average ADT ranged from 150 to 1000 vpd, several respondents preferred a maximum of 500 vpd due to design considerations. Approximately 52% of respondents agreed that the upper limit should be 500 vpd to achieve a cost-effective design compared to the maximum ADT of 1,000 vpd (see Figure 5). Since actual traffic data were unavailable or typically difficult to obtain, terrain factors and remoteness of the location were applied for most LVR design estimations as a rule of thumb.

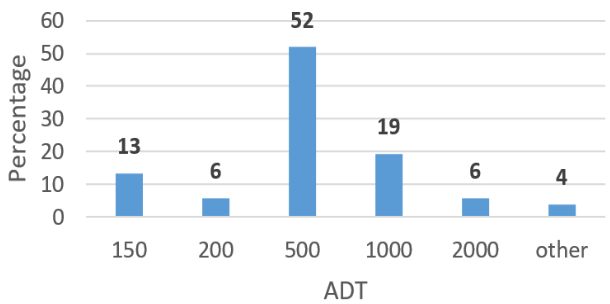
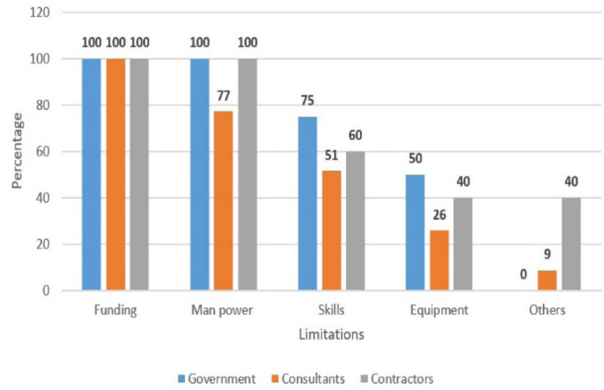


FIGURE 5. Upper limit of Average Daily Traffic (vehicles per day)



The questionnaires addressed the various truck loadings as an additional significant variable defining LVRs. Based on the findings, all respondents agreed that the Average Daily Truck Traffic (ADTT) should be considered with a maximum vehicle volume. Truck traffic was a critical load determining pavement performance over time, which should be included or considered when defining LVRs. Approximately 42% of respondents agreed that the maximum ADTT limit for paved LVR designs should be 30 vpd (see Figure 6). Few respondents recommended that there should be no limit for ADTT, while others suggested 150 vpd and truck size or weight should be considered when designing the network. Generally, most responses were based on REAM [13] and Arahan Teknik manuals (JKR, 1985; JKR, 1993; JKR, 2013). The Guidelines for the Design of Low Volume Rural Roads (LVRR), GL01.2015, were also implemented for LVRR designs by local engineers (JKR Sarawak, 2015).

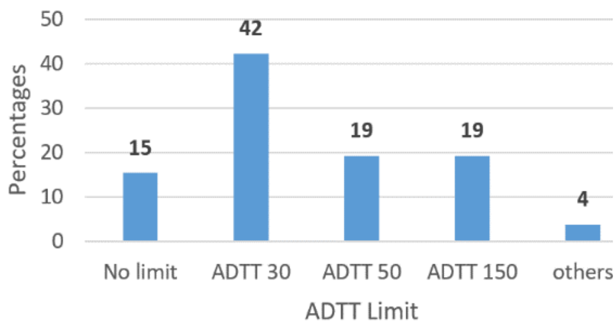


FIGURE 6. The upper limit of ADTT (vpd)

RESULTS FROM DATA COLLECTION AND QUESTIONNAIRE

The questionnaires included recommendations for prospective data collecting of LVR maintenance and design. These questions were developed to assist in determining the most critical data sources to manage at the network level. Figure 7 depicts the responses of three distinct data categories in each questionnaire: traffic counts, structural data, and pavement conditions. Most respondents believed the collected traffic counts data were critical as accurate traffic counts produced more precise LVR design and evaluation. The pavements deteriorated at different rates depending on major factors, such as traffic and truck volumes. On LVRs with minimal fluctuation in traffic volumes or patterns, traffic with reasonable accuracy could be anticipated. In contrast, counting real traffic volumes was discovered to be preferable in forecasting present and future traffic volumes using various methods.

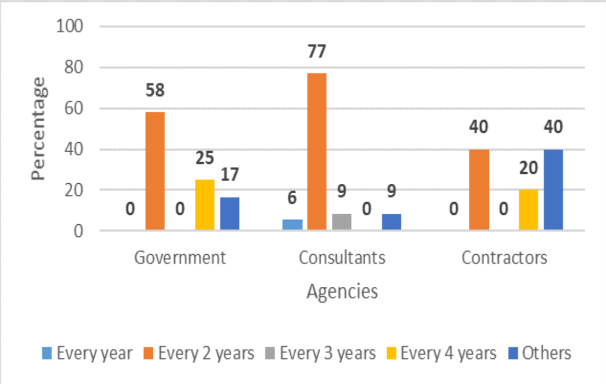


FIGURE 7. Recommended data collection type

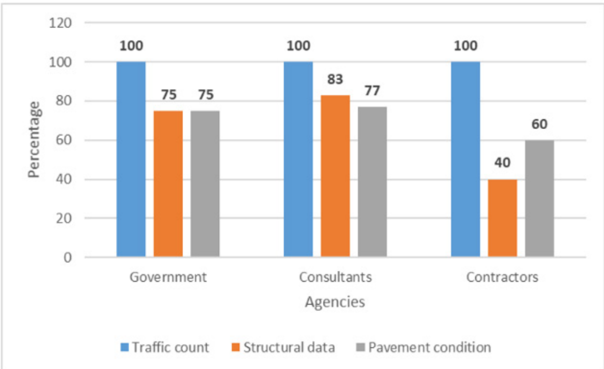


FIGURE 8. Data collection frequency

The questionnaires included questions to ascertain the technique and frequency of data collection. Since frequent data collection techniques included manual and automated methods, they were utilised independently or in combination. The LVR data collection frequency was widely recognised by agencies (see Figure 8). Although LVRs degrade slower than high-volume roads, most responders advocated data acquisition every two years.

According to a number of participants, the collection of data should be contingent upon the availability of resources and limited to what is necessary for specific purposes. The present study also garnered feedback concerning the challenges or constraints associated with the processes of data collection, wherein a majority of participants concurred that issues pertaining to funding and workforce scarcity were widespread within agencies (see Figure 9). Furthermore, a lack of expertise, equipment, and local specialists could impede efforts to collect accurate and current data for planning and maintenance purposes. The LVR improvements could allow users to conserve funds (typically described as user benefits) similarly to other roads. Particularly on LVRs, adequate functionality usually prevented lengthy detours and severe travel time losses, whereas poor road conditions significantly increased vehicle operating expenses.

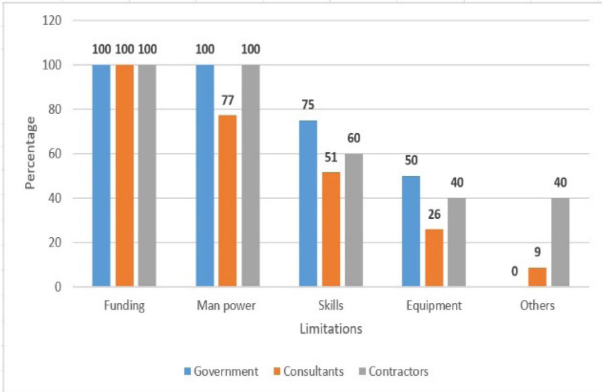


FIGURE 9. Data collection limitation

DEVELOPMENT AND SUSTAINABILITY OF LVRS

A widespread consensus was demonstrated in several studies, which well-maintained LVRs reduced travel costs, improved economic conditions in the corresponding areas, and enhanced road users' social welfare. Since LVRs facilitate access to markets, agricultural goods, and other items, they were deemed "crucial to rural development" (Faiz 2012). Access was vital for the movement of goods and the labour market, while roads provided access to labour, significantly contributing to higher revenues. While it is true that Low Volume Roads (LVRs) often proved advantageous for the most economically disadvantaged groups (Coghlan, 2000), it is important to note that their effectiveness heavily relied on the preservation of connectivity and the subsequent rise in wages (Faiz 2012). Frequently, the process of road project planning encompassed the implementation of a novel roadway or the enhancement or restoration of an already established road section, typically linked to a distinct construction activity. The state of Sarawak initiated the current LVR development programmes, supported by two major general components. These components included designing a new road and upgrading an existing road to a higher road class.

Certain respondents developed or upgraded the logging and plantation roads of private companies. Most respondents agreed that several issues should be addressed during this stage before constructing or upgrading roads. Among the common LVR planning concerns requiring clarification and consideration are as follows (see Figure 10):

1. Appropriate geometric criteria provide a relationship between construction costs and user advantages of roads. Generally, the higher the geometric standard, the costlier the construction, and the larger the benefits to road users.
2. Minimum design standard serving the road user and meeting the functional requirements of such facilities.
3. Identifying and avoiding regions caused by roads being built on an unstable or saturated hill slope, such as land landslides, peat areas, poor soils, extremely steep grades, or slope failure.
4. Impacts on area expansion, Native Customary Reserve (NCR) lands, and local communities or indigenous populations (influences beyond the Right-of-Way of the road).
5. There are a wide range of surface and road pavement alternatives available.
6. Appropriate utilisation of locally sourced materials in the design, construction, and surface of sustainable pavements.

The points represented the significant, irreversible, or difficult-to-mitigate concerns a road could have on a region. Once a road was constructed in an area, changes in long-term land use and unintended growth could be observed. Thus, these challenges in the planning phase of a road project should be addressed.

During the design life, identifying the most cost-effective pavement combination (in terms of layer thickness and material type) compatible with the soil foundation and the traffic performance is defined as pavement design. Therefore, the primary objective of road pavement structural design is to determine the material composition and thickness of the various layers required to support a specific traffic load. The local practitioners in Sarawak encountered five significant challenges in the LVR productions (see Figure 11). All respondents agreed that the traffic load predictions were the most concerning challenge. This outcome was because actual traffic data were typically unavailable or difficult to obtain. In addition, the high expenses of traffic volume studies were a factor in collecting precise data. The trend and discussion of the five challenges were presented in the following sections. Approximately 94% of respondents cited drainage as a major challenge and proper drainage in road construction was complicated. The issues caused by inadequate drainage were related to load capacity and road surface degradation. Soil with a high moisture content possessed a lower bearing capacity, promoting erosion, and reducing the lifespan of roads. In such circumstances, roads would require more maintenance than well-drained roads. Subsequently, further analyses were discussed in the following sections.

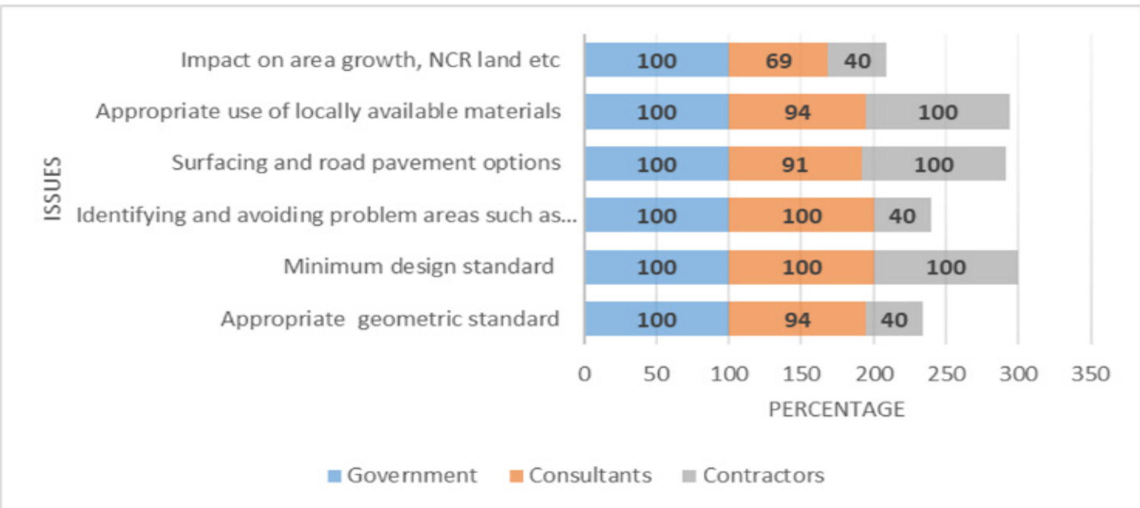


FIGURE 10. Common issues concerning LVR designs during the planning phase

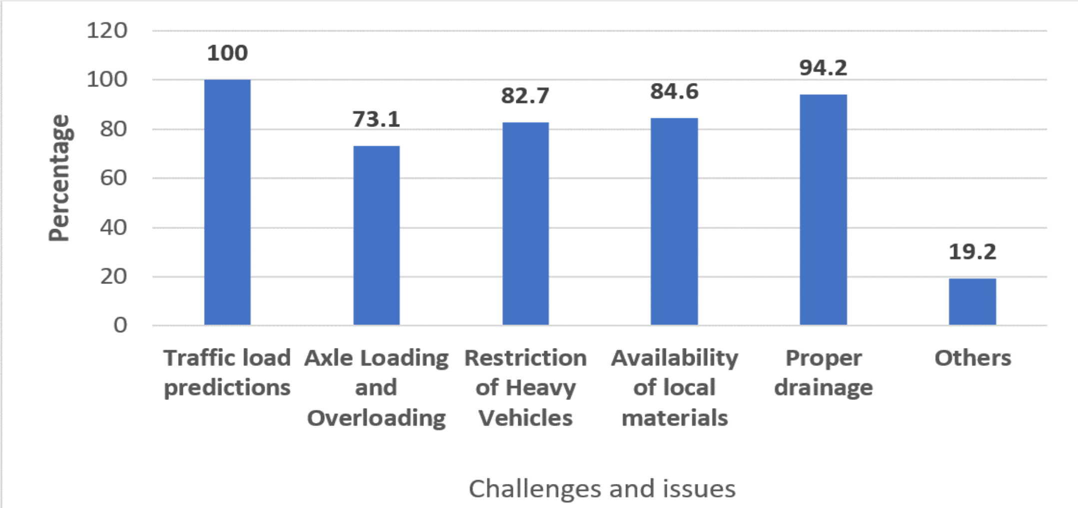


FIGURE 11. Challenges and issues concerning LVRs in Sarawak

TRAFFIC LOAD PREDICTIONS

When making a decision regarding the design of road pavement for a low-volume rural road in Sarawak, it is crucial to take into account the anticipated traffic loading that will be sustained throughout the lifespan of the pavement. The heightened level of complexity was observed during the process of constructing a new roadway in order to forecast the projected volume of traffic. The process of upgrading an existing road involves the collection of traffic data through traffic counts and the subsequent classification of observed traffic into categories based on vehicle weight, namely light or heavy vehicles. This method allows for the straightforward determination of traffic volumes. In order to achieve cost-effective designs, it is imperative to project traffic growth and assign accurate load equivalence factors.

Traditionally, the estimation of traffic patterns for a newly constructed road was based on the analysis of existing roads in the vicinity that catered to a similar population and number of communities. Typically, this estimation was deemed satisfactory in ascertaining the fundamental design parameters of a road pavement structure. While it was relatively easier to collect AADT data for higher functional classes, only a limited proportion of LVRs had access to reliable and precise data (Das and Tsapakis, 2020). According to the cited source (Darma et al. 2017), the incidence of traffic fatalities on rural roads was found to be greater in comparison to other types of routes. Therefore, the utilisation of LVRs in traffic estimation has the potential to enhance both planning and operational processes (Yang et.al, 2016). Moreover, it is worth noting that the presence of heavy traffic significantly contributes to the structural failure of pavements. Additionally, it is observed that as traffic volume rises, the rate of deterioration of pavement function also escalates (Aioub & Gabriel, 2023). The accurate determination of the traffic growth rate necessitated meticulous attention, and precise traffic volume counts were indispensable for a multitude of transportation analysis procedures. The collection of traffic data held significance due to the negative consequences associated with inaccurate traffic data, including excessive expenditure on the transport network and errors in future calculations pertaining to metrics such as vehicle kilometres travelled, congestion, and area growth development.

AXLE LOAD AND OVERLOADING

Minor rural roads integrated into the public network should accommodate axle loads similar to those intended for the rest of the road network. The overloading issues were equally relevant to the safety of small rural roads. Several examples of logging trucks or transport to and from quarries were recorded, where heavy vehicles caused major damage to rural roads over a short period (Bosso et al, 2018). When the maximum axle loads were exceeded, the traffic generated extensive damage to the road and its structures, reducing the life expectancy of the road pavement. Globally, truck overloading is a major issue (Chan, 2008; Jacob and Loo, 2008; Karin et al. 2014; Ghosn et al. 2015; Nichols et al. 2015; Bosso et al. 2018), negatively influencing pavement efficiency and bridge service life. Moreover, heavy trucks produce a negative effect on road safety. Overloaded vehicles respond to emergencies more slowly, increasing the likelihood of an accident and diminishing the service level of the route. Minor rural roads were also part of the public road network and should accommodate axle loads designed for the rest of the network.

The amount of pavement structure damage caused by various axle loads, expressed as the Equivalent Single Axle Load (ESAL), is a standard alternative design criterion. Based on the "Maximum Permissible Gross Vehicle and Axle Loads, RTA 1987, Weight Restriction Order 2003", the design should consider the legal limits on axle loads permitted on public road networks in Malaysia. This factor was critical to identify the potential number of heavy vehicles to determine the proper load-bearing capacity of the roads. In addition to traffic loads, road infrastructure was subjected to various weather and seasonal effects (rain, heat, freezing, and thawing). Considering roads were typically constructed with locally available materials, the structural design of road pavements was necessary for their service life (Kolisoja & Kalliainen, 2020).

RESTRICTION OF HEAVY VEHICLES

Since minor rural roads were designed for lower traffic intensity, the damaging overloading effect was more immediate. The pavements of highways and other major roads typically withstood loads longer than those of minor rural roads. Several studies indicated that regulations should be enforced effectively, as overloaded truck traffic increased when traffic control was reduced (Bosso et al. 2018). Overloaded trucks can also adversely affect road safety as follows:

1. Overloaded trucks were less stable, particularly in curves compromising driving and safety.
2. Braking distances were longer, reducing the capacity to handle emergencies.
3. Overloaded vehicles were underpowered, resulting in lower speeds on uphill slopes (Jacob and Feypell-de La Beaumelle, 2010, Bosso et. al. 2018).
4. Overloaded vehicles significantly affected the lifespan of the pavement structure and the potential rut depth.
5. Overloaded trucks decreased the service life of bridges. Numerous studies reported that higher total gross truck weight could increase bridge fatigue damage (up to 100%) (Aggarwal and Parameswaran, 2010, Bosso et al. 2018).

Major damages for rural communities relying on a single access road could directly affect the economic and social activities depending on these transport facilities. The re-establishment of transport links could take several months due to limited resources for repair works. Furthermore, residents were keen to protect their newly constructed road from excessive heavy vehicle abuse and damage. Commonly, barriers were erected to prevent heavy vehicles from entering the roads. Nonetheless, the efficacy of the solutions was dependent on the authorities' willingness to enforce axle load limitations. The trucks transporting construction materials to worksites frequently utilised the public road network. If axle load restrictions were not adhered to, the roads between the quarries and the construction site could be severely damaged. Therefore, road agencies were suggested to investigate specific contract clauses, restricting the material in each truck delivery and requiring the contractor to restore any damages incurred during the delivery.

AVAILABILITY OF LOCAL MATERIALS

The rising scarcity of quality quarried materials and natural gravel for road construction and maintenance was a major challenge facing road agencies, which depleted the available resources. Gravel quarry goods were shipped over longer distances, indicating higher costs for road building and maintenance. This issue was compounded by the move towards tougher environmental regulations and regulations on the operation of quarries and standards for land access. Therefore, this issue added more expenses and restricted the ability to develop new quarries by opening new gravel pits. In Malaysia, the standard practice used for any road construction was the Standard Specification for Road Work (SSRW) Section 4: Flexible Pavement (2008) provided by Jabatan Kerja Raya (JKR) Malaysia.

Numerous natural gravels were commonly prohibited as at least one stringent specification condition was not met. Since road construction required enormous quantities of materials, the reduction of transport distances substantially impacted the total cost of the project. Hence, project approaches and design methods should be developed to rely as much as possible on locally accessible resources. If local materials meeting the specifications are not available, the alternatives should include the following:

1. Import of suitable paving materials (nevertheless, these materials were costly and required long distances to import)
2. Improved locally available materials by adding stabilising agents, such as lime and cement (JKR Sarawak 2015)

Based on the alternatives, a general relaxation was vital in the requirements for low-volume rural roads. The need to better use locally occurring materials was internationally recognised while stimulating significant interest and studies (with those in Africa being the most comprehensive and extensively documented). Several examples were reported in multiple research studies on this issue (Gourley & Greening 1999; Morosiuk et al. 2000; Cook 2001; 2002).

PROPER DRAINAGE

The climate in Sarawak is categorised as Af type (Koppen 1916), which indicates Sarawak has a tropical rainy climate with temperatures above 18°C in the coldest month. Additionally, the region has no definite dry periods. In soil moisture and soil temperature regimes, they are categorised as perudic (sometimes peraquic) and isohyperthermic (Soil Survey Staff 2010). Consequently, road location, drainage, construction, and other operation areas are the most influential variables affecting water quality, flooding, and road expenses. Drainages entail regulating surface water and the proper flow of water beneath roads by using natural canals. On the contrary, road construction drainage is a challenging subject, and inadequate drainage-based issues are related to the bearing capacity of the road and its deterioration. High moisture content also decreases soil-bearing capacity, increasing the erosion rate and shortening road life (Ghavami et al. 2019). In road design and construction, the following drainage issues should be addressed:

1. Road surface drainage.
2. Flood management in ditches and pipe inlets or outlets.
3. Crossings of natural canals and streams.
4. Wet area crossings.
5. Subsurface drainage.
6. Collection and configuration of culverts, low-water crossings, and bridges.

Each side of rural roads typically possessed a surface water channel. This road construction was adequate for low levels of heavy commercial traffic. Conversely, the additional pressure (increased pavement loading) frequently overstressed the edge, producing a loss of edge support. This process was followed immediately by edge break and shear failure, significantly increasing maintenance costs. Trucks and trailers tracked along a wider traffic path on curves than other vehicles, necessitating a wider traffic lane than lighter vehicles and putting higher stress on the edges of the roads. Hence, successful road construction relied heavily on the drainage design of rural roads. A well-drained road with the proper water management features could acquire higher pavement strength, require less maintenance, and prevent erosion. Moreover, provision for adequate road drainage systems was important in road design. A road drainage system should meet certain primary criteria (based on hydrological and hydraulic analysis), emphasising the significance of producing reliable and prompt data.

CONCLUSION

This study aimed to assess the sustainable development concerning LVRs in Sarawak. The questionnaire data from government agencies, consultants, and contractors were successfully summarised. Thus, this study provided in-depth details on the challenges encountered while establishing LVRs in Sarawak. The questionnaire responses lead to the following conclusions:

1. Since actual traffic data were usually unavailable or difficult to obtain, the upper limit of 500 vpd for ADT was considered a rule of thumb for most LVR design estimations.
2. The variable loading of trucks (ADTT) was to be considered and should possess an upper limit on the volume of the vehicle.
3. Accurate traffic volume counts were essential to multiple transportation analysis processes. Projecting traffic growth and assigning precise load equivalence factors were necessary to achieve economical and sustainable designs.
4. The overloading of trucks was considered one of the main concerns in road transport. Therefore, the potential heavy goods vehicle amounts were important to be identified in determining the correct load-bearing capacity of the road.
5. The LVRs were designed for lower traffic intensity, and the damaging overloading effect was immediate. Proper heavy vehicle restrictions could reduce the detrimental impact of overloading, such as clause inclusions in the contracts limiting the quantities of material in each truck delivery and charging the contractor to repair any damages caused during the material delivery.
6. The scarcity of good materials for road construction required project approaches or design methods to be built, relying as much as possible on locally available resources.
7. Proper drainage was important to ensure a high-quality and long pavement life, as the water or rainfall accumulations in any structural layer of the pavement could cause issues. Water could accumulate underneath and weaken the pavement structure if not systematically removed.

The results indicated an urgent need for initiatives by road agencies to review the development and design suitability of LVRs alongside recording and gathering historical data on the existing LVRs. Consequently, the absence of these initiatives could impede the improvement of the existing LVRs.

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DECLARATION OF COMPETING INTEREST

None

REFERENCES

Aggarwal, V. & Parameswaran, L. 2010. Effect of overweight trucks on fatigue damage of a bridge. In: Vasant, M. (Ed.), Advances in Structural Engineering. Springer, Berlin, pp. 2483-2491.

Aioub, G.& Gabriel, A. 2023. Using Cement as Filler to Enhance Asphalt Mixes Performance in Hot Climate Regions. *Jurnal Kejuruteraan* 35(3) 2023: 747-753 https://doi.org/10.17576/jkukm-2023-35(3)-22

Austroads. 2015a. Guide to traffic management part 1: Introduction to traffic management (Publication no. AGTM01-15) (3rd ed.). Sydney: Austroads Ltd.

Blimpo, M. P., Harding, R. & Wantchekon, L. 2013. Public Investment in Rural Infrastructure: Some Political Economy Considerations. *Journal of African Economies*, 2013, 22 (AERC Supplement 2).

Bosso, M. et al. 2018. Use of regression trees to predict overweight trucks from historical weigh-in-motion data. *Journal of Traffic and Transportation Engineering* (English Edition), https://doi.org/10.1016/j.jtte.2018.07.004

Bosso, M., Vasconcelos, K., Beja, I.A., et al. 2016. Weigh-in-motion system to monitoring overloading in a Brazilian heavy traffic highway. In: 7th International Conference on Weigh-In-Motion (ICWIM7), Foz do Iguac¸u, 2016.

Brueckner, M. 2014. Infrastructure, Anocracy, and Economic Growth: Evidence from International Oil Price Shocks, 2014. Working paper

Burgess, Robin & Dave Donaldson. 2012. Railroads and the Demise of Famine in Colonial India, 2012. Working paper.

Chan, Y.C. 2008. Truck Overloading Study in Developing Countries and Strategies to Minimize its Impact (Master thesis). Queensland University of Technology, Brisbane.

Charman, J.H. 1988. Laterite in road pavements, special publication 47, Construction Industry Research and Information Association, London, UK.

Coghlan, G.T. 2000. Opportunities for low-volume roads. Transportation Research Board CD

Cook, J.R. & Gourley, C.S. 2002. A framework for the appropriate use of marginal materials, World Road Association (PIARC) technical committee C12 seminar, Mongolia, PIARC, Paris, France, 19 pp.

Cook, J.R., Bishop, E.C., Gourley, C.S. & Elsworth, N.E. 2001. Promoting the use of marginal materials, report prepared for the Department for International Development (DFID), TRL, Crowthorne, UK.

Das, S. & Tsapakis, I. 2020) Interpretable machine learning approach in estimating traffic volume on low-volume roadways. *International Journal of Transportation Science and Technology* 9: 76–88. https://doi.org/10.1016/j.ijtst.2019.09.004

Fekpe, E.S.K., Clayton, A.M. & Alfa, A.S. 1993. Aspects of performance of truck weigh stations. *Canadian Journal of Civil Engineering* 20(3): 380-385.

Franzen, T. & Thorpe, D. 2020. Sustainable development and management of low-volume road networks in Australia. Sustainable Ecological Engineering Design. Springer, Cham, 2020. 51-63

Gallego, E., Moya, M., Garcia, A. I. & Ayuga, F. 2008. Valuation of low volume roads in Spain. Part 1: methodology development, in press. https://doi:10.1016/j.biosystemseng.2008.06.009

Ghavami, M.S.M., Hosseini, M.S., Zavattieri P.D. & Haddock J.E. 2019. Flexible pavement drainage system effectiveness. *Construction and Building Materials* 218: 99-107, https://doi.org/10.1016/j.conbuildmat.2019.05.088

Giummarra, G. 2003. Establishment of a road classification system and geometric design and maintenance standards for low-volume roads. Transportation Research Record: *Journal of the Transportation Research Board* 1819: 132–140.

Ghosn, M., Fiorillo, G., Gayovyy, V., et al. 2015. Effects of Overweight Vehicles on New York State DOT Infrastructure. The City College of New York, New York.

Jacob, B. & Loo, H.V. 2008. Weigh-in-motion for enforcement in Europe. In: International Conference on Heavy Vehicles, Paris, 2008. John Wiley & Sons Ltd, New York.

Jacob, B. & Labry, D. 2002. Evaluation of the effects of heavy vehicles on bridges fatigue. In: 7th International Symposium of Heavy Vehicles Weights and Dimensions, Delft, 2002.

Jacob, B. & Feypell-de La Beaumelle, V. 2010. Improving truck safety: potential of weigh-in-motion technology. *IATSS Research* 34 (1): 9-15.

JKR Malaysia, Manual on Pavement Design, Arahan Teknik (Jalan) 5/85 (Pindaan 1/199), 1993. Public Work Department, Kuala Lumpur

JKR Malaysia, Manual for the Structural Design of Flexible Pavement (2013). ATJ5/85 (Pindaan 2013), 2013. Public Work Department, Kuala Lumpur

JKR Sarawak, Guideline for the Design of Low Volume Rural Roads, 2015. Public Work Department, Sarawak (JKR Sarawak GL01.2015)

Karin, M.R., Ibrahim, N.I., Saifizul, A.A., et al. 2014. Effectiveness of vehicle weight enforcement in a developing country using weigh in motion sorting system considering vehicle by-pass and enforcement capability. *IATSS Research* 37(2): 124-129.

Khan, R., Liew, M. & Ghazali, Z. 2014. Malaysian Construction Sector and Malaysia Vision 2020: Developed Nation Status. *Procedia-Social and Behavioural Sciences* 109: 507-13

Koen, V. 2012. Malaysia's Economic Success Story and Challenges Economics Department Working Papers (Paris: France Organisation for Economic Co-operation and Development)

Koppen W. 1916. Classification für Klimate, Temperature, Niederschlag and Jahreslauf. Paterm. Mitteil. 1916; 62:197–203.

Lawrance, C. & Toole, T. 1984. The location, selection and use of calcrete for bituminous road construction in Botswana, report 1122, Transport and Road Research Laboratory, Crowthorne, Berkshire, UK

Lehne, Jonathan, Jacob Shapiro & Oliver Vanden Eynde (2018). Building Connections: Political Corruption and Road Construction in India, Journal of Development Economics, 2018, 131, 62-78.

Lionjanga, A.V., Toole, T. & Newill, D. 1987a. 'The development of specifications for the use of low-grade calcretes in lightly trafficked roads in Botswana. *Transportation Research Record* 1106: 281-304.

Lionjanga, A.V., Toole, T. & Newill, D. 1987b. 'The use of calcrete in paved roads in Botswana', Soil mechanics and foundation engineering: Proceedings of the 9th regional conference for Africa, Lagos, Nigeria, Balkema, Rotterdam, The Netherlands.

Marwan Hafez, Khaled Ksaibati & Rebecca Atadero 2017. Developing a methodology to evaluate the effectiveness of pavement treatments applied to low-volume paved roads. *International Journal of Pavement Engineering* DOI: 10.1080/10298436.2017.1356174

Morosiuk, G., Toole, T., Gourley, C.S. & Hine, J.L. 2000. 'Whole life performance of low volume sealed roads in Southern Africa', TRL Annual Research Review 1999, pp. 25-32.

Nichols, A.P., Chou, C.S. & Dayan, S. 2015. Evaluation of the Percent of Overloaded Vehicles Receiving Proper Permits. West Virginia Department of Transportation, Marshall University, Huntinpton.

Paige-Green, P. 1996. Recommendations on the use of marginal base course materials in low volume roads in South Africa, research report RR 91/201, Department of Transport, Pretoria, South Africa.

Pinard, M. I., Ellis, S. D., Eriksson, C.-H., Johansen, R., Toole, T., Berger, R., Gumbie, M. E., Lotter, H. J. S., & Quimby, A. R. 2003. Guideline on Low-Volume Sealed Roads, Southern African Development Community, Botswana. https://www.ssatp.org/sites/ssatp/files/pdfs/Toolkits/LVSR-Guideline-FullText[1]_0.pdf.

Public Work Department. 2008. Standard specification for road works-section 4: flexible pavement. JKR/SPJ/2008-S4, Kuala Lumpur: Malaysia.

Rys, D., Judycki, J. & Jaskula, P. 2015. Analysis of effect of overloaded vehicles on fatigue life of flexible pavements based on weigh in motion (WIM) data. *International Journal of Pavement Engineering* https://doi.org/10.1080/10298436.2015.1019493

Soil Survey Staff. Keys to Soil Taxonomy 11th edition. 2010 (USDA-SCS, Washington, D.C.).