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Evaluation of Mobile Lidar Technology Use in Management of Road Furniture Inventory in Kenya: A Case Study of Kenha Highways in Nairobi City County

Karbolo Benedict Sulati, Dr. Mungathia Tulatia, Dr. Isaac Fundi
Sustainable Materials Research and Technology Centre (SMARTEC),
Jomo Kenyatta University of Agriculture and Technology, Nairobi,
Kenya. P.O. Box 62000-00200 Nairobi, Kenya.

ABSTRACT: **Vandalism of road furniture in Kenya roads has been alarming over the years. For instance, KeNHA reported that 150 out of 200 signage placed in the period between July to September 2022 had been vandalized posing danger to the motorists who ply along the Nairobi –Narok busy highway. However, there has been a challenge on how this data is collected and analyzed to give a clear picture of the road assets management. The manual methods of road assets data collection used does not guarantee accuracy, are time consuming and output requires manipulation to achieve recording quality. The manipulations of data collected using manual methods does not give a fair value of road assets hence poor budgeting practices by the road agencies. Therefore, the main objective of the study was to evaluate mobile LIDAR technology use in management of road furniture inventory. The research was conducted in various KeNHA highways in Nairobi City County. The study adopted a correlational survey design. Data for this study was obtained through site visit and extraction form the set Mobile LIDAR. The cloud points in sensor's coordinate system were advanced to Universal Transverse Mercator (UTM) which presents measurements in meters. Descriptive statistics was used to explain the features of data collected. Further comparison of the study findings and the existing literature was conducted to ascertain the level of accuracy. The findings revealed that the accuracy level of data collection using mobile LiDAR was high at 86.6 % accuracy rate. The false hit and false miss percentages were 7.8 % and 5.6 % respectively. The interpretation of the high level of hits was that KeNHA had reasonably ensured maintenance of road assets in various highways in Nairobi City County despite the cited cases of vandalism. The study concluded that automation of roads asset management practices using the Mobile LiDAR technology presents an opportunity to improve reliability, validity and timeliness of inventory data for effective decision making, budgeting and planning purposes.**

Keywords: **Mobile LiDAR, Point Clouds, Road Furniture Inventory, Road Asset Management, Annual Road Condition and Inventory Survey (ARCIS)**

1.0 INTRODUCTION

Infrastructure projects, among them roads, have a crucial role within societies of converging the economic development need and most importantly to change the citizens' quality of life (Matu et al., 2020). Rapidly increasing population and urbanization in large cities have directed the attention of researchers to the importance of traffic services including timely road asset maintenance, updated road information, road safety, and comprehensive management (Riveiro *et al*, 2015). These services highlight the need for a variety of specialized software for road design, expansion, and asset inventory to achieve accurate, comprehensive and systematic road management and efficient road maintenance (Wang *et al.,* 2017*)*.

Civil engineering infrastructure projects undergo three main phases during their lifetime: first phase is planning and design, second phase is construction which involves execution or implementation and the third stage involves monitoring the project and maintenance. The monitoring and maintenance phase takes the longest period of all the three stages as well as highest cost. These civil engineering projects are expected to be operational during their design life period. However, impairment and wear are unavoidable on these projects. High cost of maintenance or

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replacement of the road assets are also incurred. To take control of the process of maintenance and improvements, it is necessary to have a register of the assets and inventories in a suitable format. Traditional manual data collection and survey methods have been commonly adopted for asset inventory data collection. Even though the traditional methods provide accurate results, they are time consuming and require a lot of manpower. This has led to use and adoption of technology advanced techniques.
Road Asset Management (RAM) also known as the infrastructure asset management is a strategic and systematic process of operating, maintaining and improving physical assets on the roads. The aim of RAM is focused on both engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation and replacements to sustain a desired state of good repair over the lifecycle of the road assets at minimum practicable costs (Greenwood et al., 2012). Road assets that include traffic signs and signals, light poles, guardrails, and culverts, are essential components of transportation networks. According to Song, He, and Liu (2018), inventory is essential to asset management and roadway maintenance. To prioritize rebuilding, state Departments of Transportation (DOTs) and local transportation agencies require current inventory data to determine the state of the road networks under their authority and repairs on the roads.

Road asset management represents a systematic process of maintaining, upgrading and operating assets, combining engineering principles with sound business practice and economic rationale, and providing tools to facilitate a more organized and flexible approach to making the decisions necessary to achieve the public's expectations (OECD, 2001). Road asset management is consequently about managing road agency resources more like a business. There is therefore need for road agency managers to develop a common language with budget holders, hence giving them the critical ability to demonstrate the implications of investment options (Mutai & Obura, 2018). This business-like approach of road asset management requires estimation of the value of infrastructure assets, as this value is a significant factor in determining priorities for future investment in road assets (New York State Department of Transportation, 1998). The valuation process, with its emphasis on economics or finance, represents a shift in thinking from the traditional engineering approach to transport program development.

The modern advancement in RAM has realized adoption of digital maps and Geographic Information System (GIS) technologies. This has enhanced the efficiency of asset and inventory management in road project across the world. Several instruments like Global Positioning System (GPS) and inventory databases (aerial imageries, terrestrial photographs and laser point clouds) have been used in the management. The field of remote sensing technologies for road information inventory is rapidly evolving. With traffic speeds, the ability to obtain three-dimensional (3D) data of large-area roadways with survey-grade accuracy is opening up effective and efficient new ways for road inventory data. Latest developments make these technologies accessible and reasonably priced in sensor electronics and data handling. Image-based and laser-based mobile mapping systems are the two main remote-sensing technologies that are commonly utilized in road information inventories (Toth 2009). According to JICA Annual Report (2020) on Data Collection Survey on Road Asset Management Platform Technical Support, it was noted that the challenges facing road asset management in various developing countries, Kenya included, is lack of proper data collection techniques. According to the report the manual methods used for road assets data collection did not guarantee accuracy, they are time consuming while the output requires some editing to achieve recording quality. Further, the results are influenced by the subjectivity and experience of the raters (Bianchini et al, 2010; Mutai & Obura, 2018). The editing of data collected using manual methods does not give a fair value of road assets hence poor budgeting practices by the road agencies. This may cause over budgeting leading to waste of public resources or under budgeting which does not solve the problem and risk at hand.

According to Mutai and Obura (2018), road assets management as a practice in road maintenance has a significant contribution to the performance of road agencies in Kenya. The Road Agencies in Kenya, which include Kenya National Highways Authority (KeNHA), Kenya Rural Roads Authority (KeRRA) and Kenya Urban Roads Authority (KURA), usually undertake Annual Road Inventory and Condition Surveys (ARICS) on the existing road network as a way of obtaining data to be used for informed decision making on the appropriate maintenance interventions to be undertaken. There are seven (7) major highways, covering approximately 200 kilometers, built and maintained by KeNHA in Nairobi City County which include; Uhuru Highway, Waiyaki Way, Thika Super Highway, Mombasa Road, Southern Bypass ,Western Bypass Highway. High traffic volume and snarl-ups have been experienced along these highways due to increasing population within the Nairobi Metropolitan overtime. It is estimated that more than 10,000 assorted road furniture units were installed along these highways during the

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construction period. Ideally, the road furniture assets are expected to last for a design period of nearly 20 years under scheduled maintenance regimes. However, vandalism of road furniture on these roads has been on the rise in the recent past. For instance, it was reported that 150 out of 200 signages placed along Nairobi-Narok Road over the period between July to September 2022 had been vandalized. Such vandalism poses danger and compromises safety of road users while increasing road maintenance cost (KeNHA Annual Report, 2023). According to the Auditor General report (2020) on installation and maintenance of road furniture in Kenya, the assessment of road furniture on various sampled roads exposed that several warning and informatory signs were missing at crucial locations. The report further revealed that that, there were 50 vandalized road signs, 40 vandalized guardrails and 14 vandalized bridge rails on the 22 KeNHA roads inspected.

Despite the well-known challenges facing road asset management, the road agencies in Kenya lack a vigorous and reliable information about the true cost of holding and maintaining the assets, or the size of maintenance and investment backlogs. They also lack the detailed information required to derive down the cost bases and improve service delivery. In this regard, efficient road asset management incorporating adoption of current technology should play a critical role in tackling this problem hence the need for this study. Consequently, the study aimed to evaluate mobile LIDAR technology use in management of road furniture inventory along KENHA highways within Nairobi City County.

2.0 MOBILE LIDAR TECHNOLOGY USE IN ROAD ASSETS MANAGEMENT

Peter & Andreas (2021) defines Light Detection and Ranging (LiDAR) technology as a remote sensing measuring technique that uses light in form of pulsed laser to measure ranges to the Earth. The information obtained therein forms 3-Dimensional (3D) data about the earth's surface and its characteristics, often referred to as point clouds. Modern LiDAR systems are fully integrated sensor platforms, typically comprising one or more laser scanners, digital cameras of different spectral ranges, inertial measurement units coupled with global navigation satellite system receivers (Peter & Andreas, 2021). According to Nathan et al (2021), there are four popular platforms for producing point clouds, namely; Aircraft and Unmanned Aerial Vehicle (UAV); Mobile LiDAR mounted on moving vehicles including road, rail and water; handheld Terrestrial LiDAR normally mounted on a tripod; and short-range LiDAR using Simultaneous Localization and Mapping (SLAM) technology used for capturing data within indoor spaces.

Mobile LiDAR is an important technology that has major implications on the way in which geospatial data is collected, exploited, managed and maintained by transportation agencies (Olsen, M. J., 2013). Mobile LiDAR system (MLS) is gaining popularity in three-dimensional (3D) mapping applications along various road corridors (Yadav et al., 2013), because of the extreme ease it provides in capturing comprehensive high resolution 3D topographic data at highway speed (Yadav et al., 2016). As Road Agencies transition from 2D workflows to 3D model-based design and asset management, the ability to make efficient use of mobile LiDAR will only increase. With a mobile LiDAR system, mapping engineers can drive on a highway, rural road and railroad, or along the shoreline of a river or lake as the system captures trees, bridges, streetlights, buildings, power lines and other street-scene small objects (cracks and road markings) in the form of 3D point clouds. In addition, the acquired 3D point clouds provide accurate 3D geospatial information of roadways. The collected data are a totally immersive 3D view of the objects and surroundings (Rybka 2011).

According to Glennie (2009), mobile LiDAR technology has mainly attracted transportation related applications since year 2003. This has majorly been associated with its extreme ease in capturing comprehensive high resolution 3D topographic data at highway speed (Yadav et al., 2017). With a mobile LiDAR system, road agencies engineers can drive any category of roads from urban centers to even remote areas capturing features along the roads such as trees, bridges, buildings, streetlights, power lines, and other minor items found in street scenes (such as cracks and road markings) shown as 3D point clouds. Furthermore, precise 3D geospatial data of roads is provided by the obtained 3D point clouds. (Rybka 2011). LiDAR is more autonomous, effective, and precise when compared to other remote sensing technologies. Moreover, since laser scanning is largely sunshine independent, it can operate in both day and nighttime conditions. (Moselhi et. al., 2020).

Morales et al., (2021) performed a study on machine learning methodology to predict alerts and maintenance interventions in roads. To prevent future failures, this contribution focuses on forecasting maintenance alerts in highways and choosing the most suitable form of treatments. While the approach described can be used for various non-pavement road linear assets, the goal was matched with that of Pavement Maintenance Decision Support Systems (PMDSS). To design a strategy based on evaluating the four most advanced Machine Learning (ML)

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approaches, it was necessary to compile the key findings. Using information from the historical inventory of inspections and maintenance interventions, machine learning techniques such as Decision Trees (DT), K-Nearest Neighborhood (KNN), Support Vector Machines (SVM), and Artificial Neural Networks (ANN) are employed (Morales et al., 2021). Both supervised and unsupervised model training are embodied in the correlation process. The maintenance projections are displayed and contrasted across multiple segments that align with the actual maintenance interventions carried out on an operational road network within a designated geographic area. Li *et al.,* (2019) conducted research on segmentation of road furniture using mobile laser scanning data. In the preliminaries of the study, they first detected road furniture from unorganized mobile laser scanning point clouds. The next stage was conducted by detecting road furniture when decomposed into poles and attachments (traffic signs). While interpreting the results, they extract a set of structures using a knowledge-driven approach to categorize the attachments. Additionally, they employed four types of machine learning classifiers that are reflective which include; random Forest, Support Vector Machine, utilizing the Gaussian Mixture Model and Naïve Bayes, investigate the best approach. The spatial relationships between poles and their attachments, as well as the unary aspects of attachments, are the intended features. Final results revealed that the random forest classifier over performed the other methods, where the overall accuracy acquired was over 80% in Enschede test site and over 90% in both Saunalahti epochs. The findings of two epochs in the same area verified a high reliability of the framework. This was a clear prove that the approach uses training data from one epoch to test data from another, achieving good transferability and a high rated degree of accuracy.
Shtayat *et al.,* (2020) did a review of monitoring systems of pavement condition in paved and unpaved roads. The review indicated that the rising number of vehicles on roadways expedites the urge to increase efforts in implementing monitoring systems that look after road pavement conditions. This rising in number of vehicles on roadways also cause more damages and distresses on road pavement. Road pavement conditions should be accurately evaluated to identify the severity of pavement damages and types of pavement distress. Therefore, monitoring systems are considered a significant step of maintenance processes. Paved roads and unpaved roads require regular maintenance to provide for and preserve users' usability, accessibility, and safety. Transport agents and researches would spend a lot of time and money in inspecting some sections of the roadway surface; that inspection would then be followed by results recording and data analysis to diagnose the type of treatment required. These monitoring systems have been developed using various methods that include smart technologies and prepared equipment. Many related studies evaluate road pavement degradation and distress, while others focus on identifying the best maintenance monitoring approach in terms of time and cost. This paper set out to explore different monitoring techniques used to evaluate road pavement surface condition. Also, this study introduces dynamic and static monitoring systems used in both paved and unpaved roads to identify the severity of pavement degradations. Further, types of pavement distress on road surfaces and also this study explains the used equipment in the previous monitoring studies.

In a study by Ragnoli, *et al.,* (2018) on pavement distress detection methods, it was found out that the road pavement conditions affect safety and comfort, traffic and travel times, vehicles operating cost, and emission levels. In order to optimize the road pavement management and guarantee satisfactory mobility conditions for all road users, the Pavement Management System (PMS) is an effective tool for the road manager. An effective PMS requires the availability of pavement distress data, the possibility of data maintenance and updating, in order to evaluate the best maintenance program. In the last decade, many researches have been focused on pavement distress detection, using a huge variety of technological solutions for both data collection and information extraction and qualification. This paper presents a literature review of data collection systems and processing approach aimed at the pavement condition evaluation. Both commercial solutions and research approaches have been included. The main goal is to draw a framework of the actual existing solutions, considering them from a different point of view in order to identify the most suitable for further research and technical improvement, while also considering the automated and semi-automated emerging technologies. An important attempt is to evaluate the aptness of the data collection and extraction to the type of distress, considering the distress detection, classification, and quantification phases of the procedure.
Gonzalez-Gomez, *et al.*, (2021) did an assessment of intersection conflicts between riders and pedestrians using a GIS-based framework and portable LiDAR. An algorithm for the automatic detection of zebra crossings from mobile LiDAR data was developed and tested to be applied for road management purposes. The performance of the algorithm was evaluated over several mobile LiDAR strips accounting for a total of 30 zebra crossings. That test showed a completeness of 83%. Non-detected marks mainly come from painting deterioration of the zebra crossing

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or by occlusions in the point cloud produced by other vehicles on the road. Yadav *at el.*, (2017) did an extraction of road surface from mobile LiDAR data of complex road environment. The proposed method was constructed using unstructured MLS data as input and does not require any other additional data. The method revealed the acceptance performance for complex roadways having road section with raised curb and also without raised curb, and has potential to be employed for such road environments, which are not uncommon.

3.0 METHODOLOGY

The study adopted a correlational survey design. The correlation research design is a tool that enables measurements of two or more variables at about more or the same time and provide suitable ground for the analysis of the relationship between the variables (Kothari, 2012). Guided by the Krejcie & Morgan (1970) sample size table, data collection targeted road furniture inventory installed over a distance of 132 out of 200 Kilometres covered by all the seven (7) KeNHA highways serving the Nairobi City County. The key road assets which were of interest for this research included sidewalks, medians, guardrails, fencing, concrete structures, lighting, landscape areas, striping, crosswalks, raised pavement markers and other highway signs. Additionally, the features for these assets are also populated. The typical database structure for such an inventory as used in this study included qualities such as condition and dimensions. The various road signs were linked with sign that the signage is supposed to depict.

The process of capturing the road signs inventory process consisted of two steps, that is detection of the sign position followed by identification of the sign type for example informatory or warning. Unlike the manual process, these two steps were done concurrently using a Mobile LiDAR scanner mounted on a moving vehicle over the sampled 132-kilometre distance. As the vehicle moved, sensors onboard simultaneously collected various asset 3D point data, 2D images, position and altitude. An onboard GPS unit and an Inertial Measurement Unit (IMU) recorded each asset's position points in reference to the ground. A global coordinate system, Universal Transverse Mercator (UTM), was deployed to present measurements in meters in the cartesian plane and divide the earth into 60 zones each 6 degrees.

Reliability of the data collection technology and its outputs was tested using Riegl VMX 250 which is a Mobile Laser Scanning system that has an accuracy of 10mm and precision of 5mm. This test method was implemented through an application of C++ language using the Point Cloud Library. Filtering of the dataset was conducted based on the identified key factors, namely; how many hits were segmented and correctly detected as signs; how many signs were not detected or missed; and finally, the x false hits which is the number of segments that were falsely detected and marked as signs. Automatic and semi-automatic methods of feature extraction were used to extract the information from the datasets for graphic presentation and onward inferencing. Accordingly, using height and dimension constraints, points that did not belong to road signs were eliminated. The information extracted from the datasets was imported into Geographic Information System (GIS) environment for overlay and analysis.

4.0 RESULTS AND DISCUSSIONS

The initial reflexivity filter and segmentation captured 2145 possible signs in the area of 132 kilometers. The described filtering rules were applied to these segments. Out of a total number of 2,476 signs that were inside a tested area, 2145 signs were detected correctly with only 138 misses. The number of falsely identified signs was 193. These values are summarized in Table 1. The entire test of sign detection and localization took an aggregate of 660 minutes over the sampled distance.

Table 1. Lidar point cloud sign detection and localization

Measure factor	Lidar point cloud	Percentage
Hits	2,145	86.6
False hits	193	7.8
Misses	138	5.6

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The findings revealed that the accuracy level of data collection using mobile LiDAR was high at 86.6 % accuracy rate. The false hit and false miss percentages were 7.8 % and 5.6 % respectively. The interpretation of the high level of hits was that KeNHA had reasonably ensured maintenance of road assets in various highways in Nairobi City County despite the cited cases of vandalism. The false hits at 7.8% indicated the level of damaged signs not yet replaced at the time of the study. Such false hits implied a high risk of roads accident occurrence if the damaged signs are not rectified. It is key to note that the number of misses could be much higher in some road sections compared to others depending on road design service levels, population, economic activity and other contextual conditions. Moreso, some traffic signs may have been heavily blocked by other objects hence could neither be identified from RGB images nor from the point clouds. In practice, this challenge is expected to be more magnified when applying manual road inventory taking methods such as individual observation.

The findings of this study are supported by Guan et al. (2014) who used the LiDAR technology to locate and extract manhole covers by applying distance-dependent thresholding, multi-scale tensor voting and morphological operations to the interpolated feature images. Likewise, Landa and Prochazka (2014) applied the same technology to trace road signs where 86 signs were inside a tested area; 80 signs were detected correctly representing 93% success rate 6 (7%) misses were reported. Out of the 6 misses, 3 were caused by low point density; a larger distance of the sign from the sensor or by the degradation of the paint; and the other 3 misses were bus stop signs that were near the sensor.

The imagery findings were in support of the study, Nautiyal and Sharma (2021) discovered that GIS may be used to gather both spatial and non-spatial data, as GIS is a multi-criteria decision-making technique that can be used in pavement repair and maintenance operations. Furthermore, Duffell and Rudrum (2005) discuss inventory mapping as a secondary benefit that can be utilized from a point cloud. Inventory mapping can include any structure, pavement, signage and traffic signalling devices that can be extracted from a point cloud. In addition to feature extraction, they also demonstrate the ability of software to automatically detect road signs and classify them by shape as defined by the Manual on Uniform Traffic Control Devices (MUTCD).

Examples of road furniture captured on the KeNHA highways in Nairobi City County are as shown in Figures 1, 2 and 3.

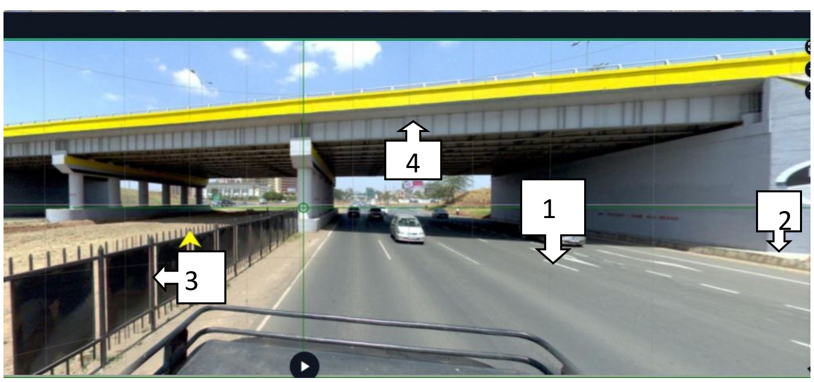

Figure 1: Mombasa Road Interchange showing the 1 road Markings, 2 Kerb, 3 Barrier as well as 4 bridge columns (Source: Authors data)

Figure 1 shows the various road furniture assets captured at Mombasa Road Interchange with Nairobi Expressway above. The findings of the captured imaged revealed that all the hits were visible and in good condition. The implication was that road users could clearly identify the various signs located in the areas.

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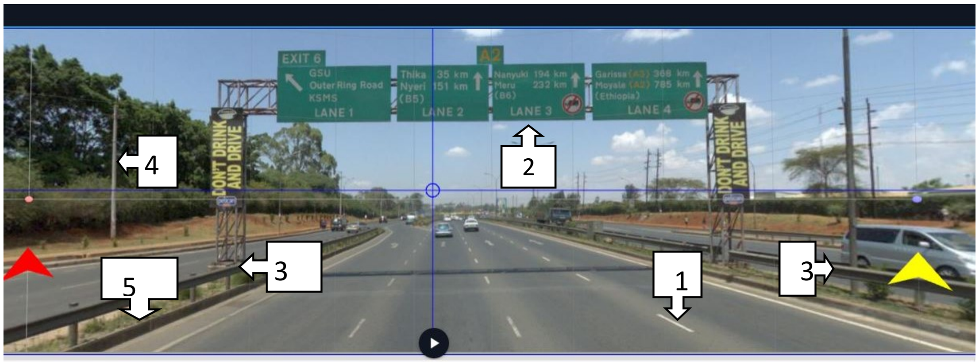

Figure 2: Thika Road showing the 1 Road Markings, 2 Signage, 3 guard rails, 4 street lights, 5 road kerb (Source: Authors data)

Figure 2 shows a section of Thika road imagery where a section of 1 kilometer was captured. Findings shows that all the hits captured were visible. However, some signs were missed in some section considering the wide range of the road and the need to focus the camera to enhance image quality.

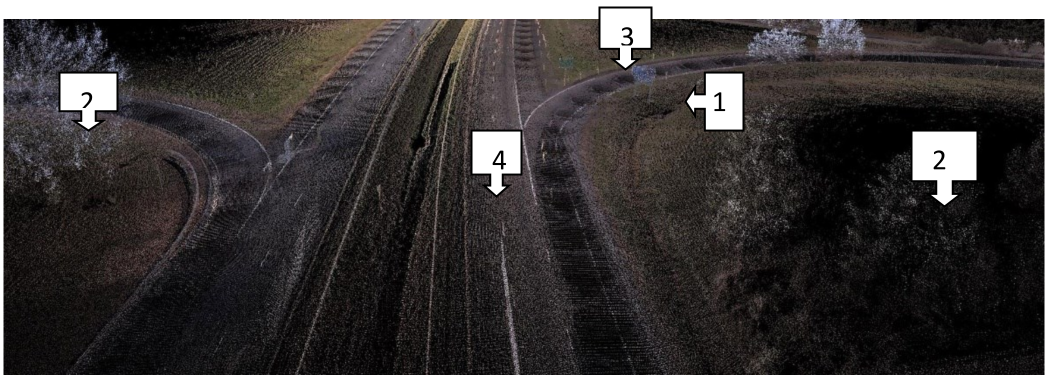

Figure 3: Section of Mombasa Road at Southern Bypass Interchange; Colorized Point cloud showing; 1 road signs, 2 road side trees, 3 guardrails and 4 road surface & markings. (Source: KeNHA data)

Figure 3 shows a section of Mombasa Road captured using manual method. The Image was extracted from the KeNHA reports. The road assist was not clear and the image rating was of low quality as compared to images captured using mobile LiDAR technology. Sign boards are not visible and cannot be easily capture using this method as demonstrated in figure 3.

5.0 CONCLUSION

The main study objective was to evaluate effects of mobile LiDAR technology use on management of road furniture inventory. The survey aimed at addressing existing challenges on how field data is collected and analyzed to give a clear picture of the road assets management policy and practices in KeNHA as a lead roads agency in Kenya. As observed by JICA (2020), the manual methods of road assets data collection do not guarantee accuracy, are time consuming, costly and their outputs are susceptible to manipulation thus not reliable. With a success rate of about 87%, automation of roads asset management practices using the Mobile LiDAR technology presents an opportunity to improve reliability, validity and timeliness of inventory data for effective decision making, budgeting and planning purposes.

Specifically, the use of Mobile LiDAR technology has the following effects on management of road furniture inventory along KeNHA highways within Nairobi City County:

(i) Data accuracy and quality: The data collected using the Mobile LiDAR technology is deemed timely, reliable and accurate, providing both spatial and non-spatial data on the quantity of road furniture assets.
(ii) Decision making support: The use of Mobile LiDAR technology enables collection and analysis of real-time data to inform effective budgeting, procurement and monitoring of road maintenance contractors and KeNHA technical staff.
(iii) Innovation and knowledge management: The mobile LiDAR technology promotes integration of output databases into existing KeNHA project management information systems. The data and information

On the flipside, the misses indicated the need to collaborate with other Government agencies such as the National Police Service and County Governments in order to address encroachment on road reserves, vandalism and erection of structures blocking visibility of road signs. To complement the Mobile LiDAR technology use, manual spot checks may be conducted to follow up on such cases.

6.0 RECOMMENDATIONS

The study recommends that KeNHA and other road agencies in Kenya consider adopting the use of Mobile LiDAR technology for undertaking their Annual Road Condition and Inventory Surveys in order to benefit from its capabilities. This way, they will be able to collect timely, reliable, accurate and quality data on various road networks thereby informing effective decision making for better budgeting, resource allocation and operational planning.

The study also recommends for adequate budgetary planning to ensure cost-effective replacement of damaged road furniture based on the findings of analysed LiDAR and imagery data. This will improve on the maintenance of roads to good condition as well as enhancement of road safety. The policy makers and regulators are encouraged to develop requisite legislative and regulatory framework for promoting sector-wide adoption and use of Mobile LiDAR technology for integrated road assets inventory management including mitigation of vandalism.

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