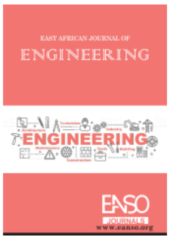

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Original Article

Maintenance of Roads Implemented under the Roads 2000 Strategy in Central Kenya

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ABSTRACT

Road maintenance is an integral component of the low-volume sealed roads provision process, the type and cost of which are influenced significantly by decisions made during the preceding planning, design, and construction phases. Low-volume sealed roads are particularly sensitive to the whims of the physical environment so timely and effective control of their deterioration becomes the key challenge to the management of road maintenance. In Kenya, the Kenya Roads Board (KRB) holds the mandate for funding, oversight, and coordination of road maintenance, rehabilitation, and development through the optimum utilisation of resources for a sustainable road network. Each year, KRB finances the maintenance of the road network through the Kenya Roads Board Fund (KRBF). The Fund is distributed among the road agencies charged with maintenance. KRB reviews, individually, the Annual Road Works Programmes (ARWPs) submitted by Road Agencies and consolidate these ARWPs into an Annual Public Roads Programme (APRP). This study aimed at assessing the level and prioritisation of maintenance of the completed and handed-over projects under the Roads 2000 strategy. The condition of the carriageway was assessed, as well as the resilience and adaptation measures in place to respond to climate change. For climate resilience, data such as erosion, problematic soils, drainage from the road and its near environment as well as from outside the road reserve, instability of embankments and cuttings, construction issues and maintenance problems were collected using a standard form for rating against each data type. The assessment conducted on the performance of the side drainage showed that the majority of the roads have side drainage with inadequate depths and are not free-flowing. The high roughness values obtained, which were deduced to be as a result of distresses such as rutting and potholes, were concluded to be as a result of inadequate and untimely maintenance of the surface of the road. The recommended maintenance strategy should be such that interventions for the defects such as cracks, potholes, and edge breaks, among others are carried out as soon as they are identified. It was observed that all the roads surveyed did not have adequate adaptability measures for climate resilience. It was recommended that the Annual Road

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Inventory and Conditional Survey (ARICS) incorporates the collection of additional data in the assessment on issues that touch on climate resilience, the assessment of which should inform the implementation of appropriate adaptation techniques to improve the climate resilience of the completed roads, and more so the low volume sealed roads.

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INTRODUCTION

As part of research at the Department of Civil and Construction Engineering, University of Nairobi, on the evaluation of the Roads 2000 strategy in central Kenya, the maintenance of implemented roads under the Roads 2000 program was analysed, with a view to establishing the maintenance priority and adequacy for the roads. In Kenya, the Kenya Roads Board (KRB) holds the mandate for funding, oversight, and coordination of road maintenance, rehabilitation, and development through the optimum utilisation of resources for a sustainable road network (KRB, 2018).

KRB was established in 1999 to manage the Road Maintenance Levy Fund (RMLF) and Transit Tolls, a sustainable source of funding for the maintenance of the road network. Each year, KRB finances the maintenance of the road network through the Kenya Roads Board Fund (KRBF). The Fund is distributed among the road agencies charged with maintenance. KRB reviews, individually, the Annual Road Works Programmes (ARWPs) submitted by Road Agencies and consolidate these ARWPs into an Annual Public Roads Programme (APRP) (KRB, 2018).

The fuel levy is distributed to the road agencies on the basis of the legislated formula of forty per cent to KeNHA, twenty-two per cent to KeRRA, ten per cent to KURA, one per cent to Kenya Wildlife Services (KWS) and fifteen per cent to County Governments. The fund is released to the agencies on a monthly basis in accordance with the approved disbursement schedule and after deliberation and resolution of the Board (KRB, 2018).

In addition, the APRP offers a plan of action for road maintenance in subsequent years, gives a framework for funds disbursement and a basis for monitoring the utilisation of the fund by the agencies. The document is issued annually and is availed to the stakeholders, thereby enhancing transparency and accountability (KRB, 2018).

LITERATURE REVIEW

Maintenance

Road maintenance is an integral component of the LVSR provision process, the type and cost of which are influenced significantly by decisions

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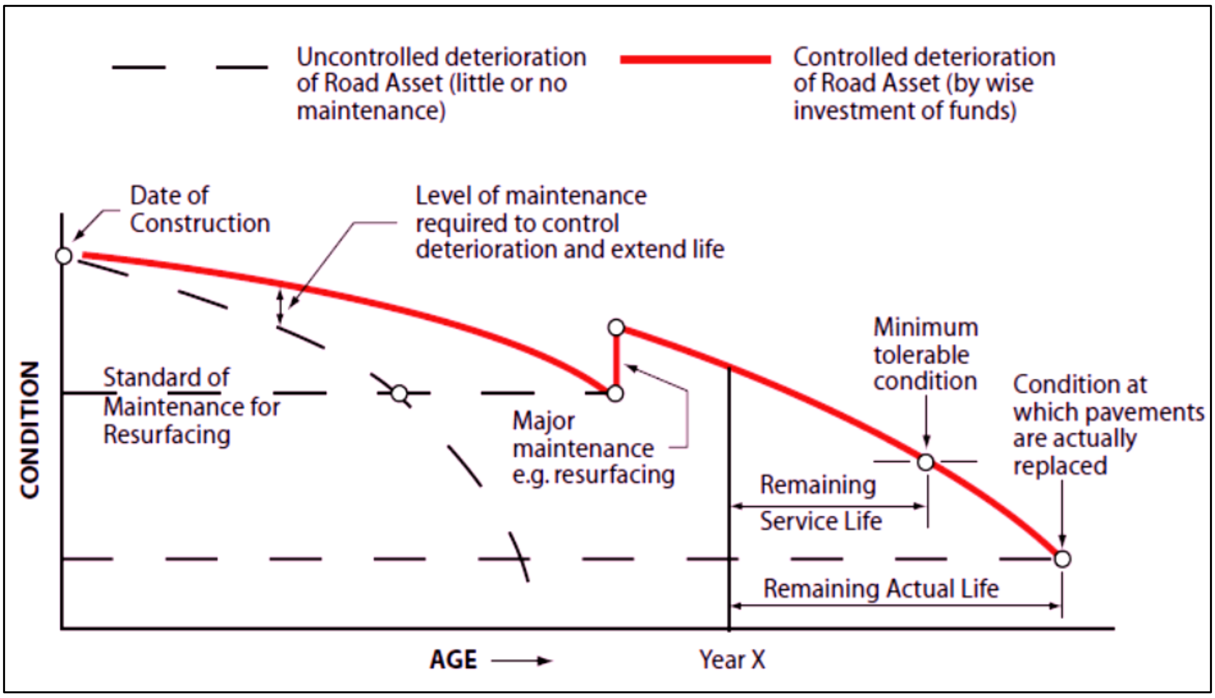
made during the preceding planning, design, and construction phases. Proper maintenance contributes to the preservation of the road asset and to prolonging the road's life to its intended service duration. Without adequate maintenance, roads deteriorate rapidly, become dangerous and costly to use and, ultimately, the costs to the economy are substantial (SADC, 2003).

Maintenance activities are either cyclic or reactive and can be of a routine or periodic nature. Cyclic activities are those that are carried out at regular intervals. Reactive activities are those that are carried out in response to an occurrence and include erosion, drainage repairs or a condition defect exceeding values dictated by maintenance standards, for instance, rutting greater than a given value. Many of the activities can be carried out cost-effectively using labour-based methods. Some periodic maintenance work such as bitumen sealing may still require specialised equipment, while labour-based methods can be used for many activities (SADC, 2003).

Road deteriorates with time, regardless of the standard of construction. The extent to which they deteriorate varies depending on climate, pavement and underlying subgrade strength, traffic volume and axle loading. The deterioration of road surface by traffic is heightened by runoff and by changes in temperature. Cracking arises in the bituminous surfacing, and with water ingress, the pavement fails (SADC, 2003).

All roads deteriorate with time. However, LVSRs are particularly sensitive to the vagaries of the physical environment so timely and effective control of their deterioration becomes the key challenge to the management of road maintenance. *Figure 1* illustrates how road condition deteriorates with time and how road life may be extended by controlled maintenance (SADC, 2003).

Figure 1: Typical Road condition deterioration with time



Source: (SADC, 2003).

Climate Change Effects

The effects of climate change are putting large lengths of the world's road infrastructure at risk and thus need to be considered in both present road operation scenarios as well as decisions on future road infrastructure investments (Paige-Green et al., 2019).

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In Sub-Saharan Africa, the climate changes likely to occur include increased temperatures (average, maximum and number of extremely hot days (> 35°C) per year); decreased precipitation and longer drier periods; increases in extreme weather events – violent storms, heavy precipitation, and heat waves; rising sea-level; northward migration of the tropical cyclone belt, and increased wind speeds (Paige-Green et al., 2019).

These climate changes could be accompanied by related secondary effects that include: longer/shorter crop-growing seasons and possible changes in crop types, potentially impacting farm-to-market traffic loading conditions; increase/reduction in general soil moisture; larger fluctuations in groundwater levels; changes in vegetation density and type and rate of growth, affecting sight distances around road bends and slope stability. Others include flooding; changed frequency of extreme storm surges; changes in ecological equilibrium, and changes in the optimum construction season (possibly timing and length) and conditions due to precipitation and temperature constraints, affecting the availability of resources for road construction and maintenance, while also affecting the window of safe working and productivity of outdoor workforces (Paige-Green et al., 2019).

Together with these climatic changes and secondary effects, the impacts of, for instance, more severe flooding, increased wildfire hazards, rising sea levels and lowered groundwater tables on the road infrastructure need to be considered. Other associated influences such as water shortages under increased temperature environments because of higher evaporation could also have an indirect impact on infrastructure provision (e.g., availability of water for compaction of layer works). The facilities and operations that can be considered vulnerable to climate change include (Paige-Green et al., 2019):

- Unpaved roads – earth, engineered earth and gravel;
- Paved roads – thin bituminous, asphalt and concrete;
- Earthworks – embankments and cuttings;
- Subgrade soils – particularly problematic soils such as expansive, dispersive, collapsible, saline, and karst areas;
- Drainage (water from within road reserve) – road and shoulder surface, side drains, mitre drains, and small culverts for cross drainage of surface water;
- Drainage (water from outside road reserve) – large culverts and bridges associated with water derived in adjacent catchment areas;
- Construction processes and activities;
- Maintenance practices and frequencies.

METHODOLOGY

The sampled completed roads, already handed over to the authorities comprising of KeRRA and County Governments, were assessed, with a keen emphasis on the budgetary allocation for maintenance by the authorities. The APRPs for the last three, i.e., financial years of 2020/2021, 2021/2022 and 2022/2023 were analysed to see the level of investment put in place on the sampled roads for the maintenance regimes. Comparisons were drawn on the level of maintenance priority and the present condition of the roads.

The implementation of appropriate adaptation techniques to improve the climate resilience of the road's infrastructure was assessed, and data obtained included issues such as erosion potential, subgrade material problems, drainage efficiency from the road and its near environment as well as from outside the road reserve, slope stability of embankments and cuttings, construction quality issues and maintenance effectiveness. Other indications of possible problems observed included the accumulation of sand and debris (due to wind and flooding) and excessive vegetation caused by increased rainfall and high temperatures, leading to sight distance and passability problems.

A standard form for recording the data was used, as shown in *Table 1*. The cells in the assessment

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form were completed for the degree and extent of the issue being assessed.

The study focussed on Phase 2 of the R2000 program in the Kiambu and Murang'a regions. Phase 2 was implemented in three batches, with the level of investment as detailed in *Table 1*. *Table 2* gives the sample valuation taken in the research.

Table 1: Phase 2 Project Investment in Kiambu and Murang'a

Batch No.	Gravel Roads Amount (Kshs)	Low Volume Sealed Roads Amount (Kshs)	TOTAL (Kshs)
Batch 1	258,591,783.60	186,064,818.84	444,656,602.44
Batch 2	812,522,729.26	487,171,684.74	1,299,694,414.00
Batch 3	-	1,126,152,837.67	1,126,152,837.67
TOTAL (Kshs)	1,071,114,512.86	1,799,389,341.25	2,870,503,854.11

Table 2: Summary of the sample investigated

Batch No.	Total Investment Amount (Kshs)	Sample Value Amount (Kshs)	Sample Percentage
Batch 1	444,656,602.44	337,542,432.49	75.91%
Batch 2	1,299,694,414.00	892,775,079.84	68.69%
Batch 3	1,126,152,837.67	1,126,152,837.67	100%
TOTAL (Kshs)	2,870,503,854	2,356,470,350	82.09%

FINDINGS AND DISCUSSION

Maintenance Priority and Investment

The level of maintenance on the completed and handed-over roads was assessed based on the field visual inspections over the three financial years of 2020/2021, 2021/2022 and 2022/2023 and informed by the data gathered from visual condition assessments.

It was observed that the assessed low-volume sealed roads did not perform well on maintenance priority by the authorities, and deterioration by potholes and edge subsidence were not addressed timely. Overgrown vegetation was observed on most roads, and drainage systems were not free-flowing owing to siltation and impedance by vegetation.

Scrutiny of the Annual Road Works Programmes (APRPs) as provided by Kenya Roads Board did not yield evidence of the specific values of investment allocated to the complete roads. *Tables 3* and *4* show the observations on maintenance as found through field surveys.

Table 3: Maintenance Priority – Murang'a

Region	Road No.	Section Name	Length	Maintenance Priority and Condition
Murang'a		**Batch 1**		
	D419 (I)	Maragwa Town – Gakoigo Junction Road	2.1	Poor
	D419 (II)	Gakoigo Junction – Nginda Sec. School	3.6	Poor
	D421	Gakoigo Junction – Maragwa River Road	3.3	Poor
		Batch 2		
	D415(I)	Muruka - Kandara Town	3.75	Poor
	D415(II)	Muruka - Kandara Town	3.75	Poor

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Table 4: Maintenance Priority – Kiambu

Region	Road No.	Section Name	Length	Maintenance Priority and Condition
Kiambu		**Batch 2**		
	E443/1	Gichiengo – Kijabe Hospital Road	3.25	Poor
	E443/2	Gichiengo – Kijabe Hospital Road	3.25	Poor
	E1531	Kang'oo - Kamwangi Road	5.6	Poor
		Batch 3		
	D378	Wangige- Nyathuna	6.4	Fair
	D378	Nyathuna - Ngecha - Rironi	5.4	Fair
	D402	Kimende- Kagwe Ruiru River/1	6.0	Fair
	D402	Kimende- Kagwe- Ruiru- Githunguri/2	6.6	Poor
	D402	Kimende- Kagwe- Ruiru- Githunguri/3	2.4	Poor
	E1520	Kanunga – Banana	3.0	Fair
	D378	Kirangari - Gikuni - Nyathuna Hosp - Jnct	6.0	Fair
	D379	Wamwangi- Ruburi	7.1	Fair

Climate Resilience Assessment

The degree of a particular type of distress is a measure of its severity. Since the degree of distress can vary over the segment assessed, the degree was recorded in concurrence with the extent of manifestation for most parameters. The extent of any distress is a measure of how widespread the distress is over the length of the road segment. This provided the best average assessment of the seriousness of a particular type of distress. The findings of the climate resilience assessment have been summarised in *Tables 5* and *6*.

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Table 5: Visual Assessment of Climate Resilience

Road Name and No.		**Gichiengo – Kijabe Hospital Road (E443/1)**	**Gichiengo – Kijabe Hospital Road (E443/2)**	**Kang' oo - Kamwangi Road (E1531)**	**Wangige- Nyathuna (D378)**	**Nyathuna - Ngecha - Rironi (D378)**	**Kimende- Kagwe Ruiru River/1 (D402)**	**Kimende- Kagwe- Ruiru-Githunguri/2 (D402)**	**Kanunga - Banana - E1520**	**Kirangari - Gikuni - Nyathuna Hosp - Jnctn (D378)**	**Wamwangi- Ruburi (D379)**	**Maragwa Town – Gakoigo Junction road (D419-1)**	**Gakoigo Junction – Nginda Sec. School (D419-2)**	**Gakoigo Junction – Maragwa River Road (D421)**	**Muruka - Kandara Town (D415-1)**	**Muruka - Kandara Town (D415-2)**
Erodibility	Subgrade	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Road Surface - Unpaved	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Side drains - Unlined	0.67	0.67	0.67	0.67	0.67	1.50	1.50	0.67	1.00	1.00	1.00	1.00	0.67	0.67	0.67
	Embankment Slopes	1	1	0.5	0.5	0.5	1.5	1.5	0.5	1	1	1	0.5	0.5	0.5	0.5
	Cut Slopes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Subgrade Problems	Material Type	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
	Moisture	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Drainage (in reserve)	Road shape	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Shoulders	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Side slopes	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	Side drains	1.5	1.5	1.5	1.5	1.5	0.75	0.75	1.5	0.75	0.75	1.5	1.5	1.5	1.5	1.5
	Mitre drains	2.5	2.5	2.5	2.5	2.5	1.25	1.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Drainage from outside the road reserve (Streams)	Structure	0	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0
	Embankments	1	1	2	2	2	2	2	2	1	1	2	2	2	2	2
	Erosion	2	2	2	2	2	1	1	2	2	2	1	2	2	2	2
	Protection Works	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Slope Stability	Cut stability	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Fill stability	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Construction	Overall finish	0.60	0.60	0.60	0.67	0.67	0.75	0.75	0.60	0.67	0.67	1.00	0.60	0.60	0.60	0.60
	Erosion Protection works	2	2	2	2	2	0.5	0.5	2	2	2	1	2	2	2	2
Maintenance	Quantity	0.8	0.8	0.8	1	1	1	1	0.8	0.75	0.75	0.8	0.8	0.8	0.8	0.8
	Quality	0.8	0.8	0.8	1	1	1	1	0.8	0.75	0.75	0.8	0.8	0.8	0.8	0.8

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Table 6: Summary of Climate Resilience Assessment

Description		Condition Summary
Erodibility	Subgrade	100% of the roads surveyed showed evidence of localised materials loss due to channelised water flows
	Road surface - unpaved	All roads surveyed were paved.
	Side drains	27% showed a slight occurrence of erosion of drains.
		60% showed the extensive occurrence of erosion of drains requiring periodic maintenance and reshaping to reinstate flow.
		13% showed warning levels of erosion of drains.
	Embankment slopes	53% showed minor evidence of water damage
		33% had discernible channels on the embankment slopes
		13% showed warning signs of channels on slopes and a notable loss of slope material. Channels greater than 75 mm deep and 300 mm wide.
	Cut slopes	80% had minor evidence of water damage on isolated occurrences.
		20% had minor evidence of water damage over parts of the segment length, more than isolated.
Subgrade Problems	Material type	100% of the roads surveyed showed no evidence of problematic soils adjacent to the road
	Moisture	100% of the roads surveyed showed minor evidence of localised but controllable water problems or seepage.
Drainage (in reserve)	Road shape	100% of the roads surveyed had good shape and cross fall and showed minor susceptibility to retaining shallow water on the surface.
	Shoulders	100% of the roads surveyed showed slight to warning and more than isolated cases of vulnerability to ponding of water on the shoulders.
	Side slopes	100% of the roads surveyed showed evidence of poor removal of water from roads and shoulders into side drains, and maybe erosion that could block the drains, on more than isolated occurrences.
	Side drains	73% of the roads surveyed showed evidence of drains being incorrectly graded or having uneven surfaces that had the potential to retain water for prolonged periods. Cases more than isolated.
		27% of the roads surveyed showed evidence of drains being incorrectly graded or having uneven surfaces that had the potential to retain water for prolonged periods. Distress is more frequent in occurrence over a major portion of the segment length.
	Mitre drains	87% of the roads surveyed had insufficient mitre drains or were totally ineffective on more than isolated occurrences.
		13% of the roads surveyed had insufficient mitre drains or totally ineffective, and they were more frequent in occurrence over a major portion of the segment length.

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Description		Condition Summary
Drainage (Streams)	Structure	One road with a new box culvert showed minor evidence of localised damage.
	Embankments	73% of the roads surveyed with existing structures had minor evidence of water damage to approach fills and embankments to the structures
		27% of the roads surveyed with existing structures had slight to warning loss of material from embankment and could be repaired.
	Erosion	80% of the roads surveyed with existing structures had minor evidence of stream erosion
		20% of the roads surveyed with existing structures had a slight loss of material from the river bank and signs of erodibility.
	Protection works	100% of the roads surveyed showed slight evidence of damage to protection works requiring significant repairs on isolated occurrences.
Slope stability	Cut stability	100% of the roads surveyed showed minor evidence of surface instability, with major failures unlikely.
	Fill stability	100% of the roads surveyed showed minor evidence of surface instability.
Construction	Overall finish	7% of the roads surveyed showed minor evidence of failure.
		27% of the roads surveyed showed slight to warning signs of failure, with the intermittent occurrence of failure, like potholes and edge subsidence.
		13% of the roads surveyed showed warning signs of failure, with more frequent occurrences of failure, like potholes and edge subsidence, over a major portion of segment lengths.
		53% of the roads surveyed showed warning signs of failure, with more extensive occurrences of failure, like potholes and edge subsidence, over entire segments.
	Erosion protection works	7% of the roads surveyed showed minor evidence of distress in erosion protection measures.
		80% of the roads surveyed showed slight to warning evidence of distress in erosion protection measures on isolated cases.
		13% of the roads surveyed showed slight to warning evidence of distress in erosion protection measures, on more frequent occurrence over a major portion of the segment lengths.
Maintenance	Quality	13% of the roads surveyed showed warning evidence of poor-quality maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses more frequently.
		13% of the roads surveyed showed warning to severe evidence of poor-quality maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses more frequently.

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Description		Condition Summary
		60% of the roads surveyed showed warning to severe evidence of poor-quality maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses extensive over entire road segments.
		13% of the roads surveyed showed severe evidence of poor-quality maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses extensive over entire road segments.
	Quantity	13% of the roads surveyed showed warning evidence of the inadequate level of maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs, asphalt cracks sealing, and the occurrence of distresses more frequently.
		13% of the roads surveyed showed warning to severe evidence of an inadequate level of maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses more frequently.
		60% of the roads surveyed showed warning to severe evidence of an inadequate level of maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses extensive over entire road segments.
		13% of the roads surveyed showed severe evidence of an inadequate level of maintenance on vegetation control, cleaning of drains, gravel shoulders shaping, pothole repairs and asphalt cracks sealing, and the occurrence of distresses extensive over entire road segments.

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CONCLUSION

Maintenance

The design criteria for low-volume sealed roads are based on the anticipation that essential maintenance will be carried out routinely and periodically to deal with the expected deterioration caused by traffic loading, climatic effects, and other deleterious influences. The maintenance of the completed roads needs to be planned, designed and carried out in the knowledge that the road is there to provide a high level of service to users, who expect their needs to be met even when activities are being carried out on the network.

In Kenya, the development of physical road infrastructure and maintenance is capital-intensive. There has been a need to entrench road asset management in the country's development strategy. This requires accurate and reliable data, and this data gathered in the form of a Road Inventory and Condition Survey (RICS) is eventually used as a basis for prioritisation for maintenance.

Road Inventory and Conditions Survey (RICS) is the process by which a country acquires data on road assets to enable them to make evidence-based decisions on how to invest in physical infrastructure. The data provides insight into how the condition of assets gets affected by their financial decisions. It also provides a reference to measure performance and helps in aligning maintenance and capital plans with a strategic goal.

Road agencies annually conduct condition surveys to inform their maintenance priorities. The data collected normally comprise data on pavement deterioration covering:

- Whole carriageway has minor deterioration that includes potholing, crazing, surface fretting and permeability, loss of chippings and excess bitumen at the surface of surfaced dressed roads. The level of defectiveness is expressed as a percentage of the section area.
- Whole carriageway has major deterioration that includes cracking, coarse crazing, loss of aggregate and serious fretting. The level of deterioration is given in terms of the percentage of the section area.
- Loss of skidding resistance can have significant safety implications and is noted for prompt action.
- Wheel track rutting is attributed to either plastic deformation at the surface or failure of the foundation. Plastic deformation requires only a surface treatment; failure of the foundation would warrant major strengthening works. The measure of rutting is the rut depth and is considered together with other indicators like cracking in the wheel track.
- Surface irregularity reduces the ride comfort and, in worst cases, vehicle stability. This distress is fast established with roughness measurements.

It is observed that standardised collection of road condition data across road agencies and county governments vested with maintaining the completed low-volume sealed roads still remains a challenge. In order to continuously make sound investment decisions on the network against the limited funding, there is a need to acquire up-to-date and reliable road network data. It is also noted that data on non-motorised transport facilities are not captured on the condition survey data, despite this transport mode being very significant in the Kenyan road network.

Further, it was established that the required data inputs for climate resilience assessments and the implementation of appropriate adaptation techniques to improve the climate resilience of the infrastructures are never captured as part of the required data by the road agencies. This data includes issues such as erosion, problematic soils, drainage from the road and its near environment, drainage from outside the road reserve, instability of

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embankments and cuttings, construction issues and maintenance problems.

Climate Adaptation

The effect of climate variability and change on roads requires that vulnerable segments of the road infrastructure are identified and adaptations made to reduce potential future climate-related damage. The considered climate changes include temperature variations, excessive rainfall patterns, increased wind patterns, probable occurrences of increased records and frequencies of extreme events.

As observed with the Kenyan road agencies, for road management, maintenance and rehabilitation planning purposes, visual condition assessments of the road network are usually routinely carried out at specified frequencies. The collected data only assess the road carriageway for problems such as surfacing cracks, pavement deformation, ruts, and potholes, which are rated and inform the prioritisation and funding for subsequent maintenance.

It is important to incorporate additional data in the assessment on issues that touch on climate resilience, the assessment of which should inform the implementation of appropriate adaptation techniques to improve the climate resilience of the completed roads, and more so, the low volume sealed roads.

The analysis of the climate resilience assessment of the sampled roads, as presented in *Tables 5* and *6* arrives at the following conclusions:

- That there were signs of erodibility of the road surface, embankment slopes and side drains of the sampled assessed roads, which can result in significant problems, not only aesthetic and environmental but more importantly, in the road management context, leading to excessive maintenance requirements (both road surface and drains) and potentially to complete failure of the infrastructure facility. Surface damage caused by erosion leads to concentrations of water, excessive loss of material as silt and increased water flow velocities. Uncontrolled erosion of the road support layers can ultimately lead to the collapse of the pavement or structure as well as excessive siltation of drainage structures.

- That there was no visible evidence of problematic soils on the sampled and assessed roads. Changes in rainfall and temperature patterns over time result in high moisture fluctuations in subgrade materials. Most problematic soils such as expansive clays, dispersive clays and collapsible sands, will be affected by both wetting up of subgrades due to increased precipitation or more extreme events and drying out of the soils caused by longer dry periods, increased temperatures and windiness and drought conditions.

- That there were areas where the side drains and metre drains were not adequate and effective. It is essential that water is moved from the road surface and close vicinity into suitable side drains and then removed from the road reserve by mitre drains or culverts as quickly and effectively as possible. The effectiveness of side drains in removing water rapidly and effectively from the side of the road is related to their shape (cross-section) and grade. A sufficient meter should be provided to remove water from the side drains so as to avoid the accumulation of water or the build-up of excessive water velocities such that erosion of the side drains becomes a problem. The mitre drains should also be sufficiently long to remove water far enough from the road not to affect the road structure. During maintenance, care should be taken so that windrows are not left blocking access to the mitre drains.

- That there were minimal evidence of localised damage to new and existing structures. It was deduced that the existing structures would

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perform adequately under changing precipitation, temperature, or wind conditions. There was minimal damage to protection works (gabions, stone pitching, and rip-rap) associated with the drainage structures caused by high water levels.

- That there was no major evidence of slope instability and failures. It was observed that cuts and embankments are stable enough to resist changes in precipitation. The cut slopes showed no signs of movement behind the slope (tension cracks or subsidence) or at the toe of the slope (bulging or deformation of side drains). Also, embankments showed no signs of arcuate cracks in the shoulders or the road surface, unusual settlement of parts of the fill, bulging at the base of the fill, nor periodic seepage of water from beneath the fill.
- That there were signs of poor construction overall finish and erosion protection measures. Failures were evident, demonstrated by the various mechanisms of deterioration such as potholes, ruts, and edge subsidence. There were signs of failure of protective erosion measures, as some were not intact and allowed water to enter behind them.
- Maintenance is critical in preserving low-volume sealed roads and should be done in a timely manner. As climatic conditions change, the need for adequate and efficient maintenance becomes more paramount. On the sampled roads, there was huge evidence established of a lack of quantity and quality maintenance on the completed roads. Issues such as poor shape of shoulders, inadequate vegetation control, insufficient cleaning and shaping of side-and-mitre drains and lack of free flow in culverts and drains. Quality and quantity maintenance should be availed in regard to vegetation control, cleaning of drains, shaping of gravel shoulders, repair of potholes and cracks in paved roads.

Recommendation

The projects completed under phase two of the program had thirty-six months of performance-based routine maintenance contracts embedded in the original contracts, and thereafter the roads were to transition to maintenance by Kenya Rural Roads Authority (KeRRA) under the 22% Road Maintenance Levy Fund (RMLF) allocation.

The maintenance funds are administered by KeRRA regional offices and Constituency Road Committees (CRCs). It was established that the committees normally prioritise the opening of new roads as opposed to maintaining the newly improved roads. Given this backdrop, uncontrolled deterioration is occasioned on these roads, and most are unattended.

In addition, where there are attempts to maintain the roads, the scope for implementation is determined by a condition survey, which focuses on collecting data only on the road carriageway for problems such as surfacing cracks, pavement deformation, ruts, and potholes, which are rated and inform the prioritisation and funding subsequent maintenance.

The required data inputs for climate resilience assessments and the implementation of appropriate adaptation techniques to improve the climate resilience of the infrastructure are never captured as part of the required data by road agencies. This data includes issues such as erosion, problematic soils, drainage from the road and its near environment, drainage from outside the road reserve, instability of embankments and cuttings, construction issues and maintenance problems.

The effect of climate variability and change on roads requires that vulnerable segments of the road infrastructure are identified and adaptations made to reduce potential future climate-related damage. The considered climate changes include temperature variations, excessive rainfall patterns, increased wind patterns, probable occurrences of increased records and frequencies of extreme events.

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It is recommended that the Annual Road Inventory and Conditional Survey (ARICS) incorporates the collection of additional data in the assessment on issues that touch on climate resilience, the assessment of which should inform the implementation of appropriate adaptation techniques to improve the climate resilience of the completed roads, and more so the low volume sealed roads.

REFERENCES

Kenya Roads Board (KRB). (2018). *The Annual Public Roads Programme FY2018/19*. Kenya Roads Board

Kenya Roads Board (KRB). (2019). *The Annual Public Roads Programme FY2019/20*. Kenya Roads Board

Kenya Roads Board (KRB). (2020). *The Annual Public Roads Programme FY2020/21*. Kenya Roads Board

Paige-Green, P., B. Verhaeghe, M. Head, Council for Scientific and Industrial Research (CSIR), Paige-Green Consulting (Pty) Ltd and St Helens Consulting Ltd, (2019). *Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa, Engineering Adaptation Guidelines*, GEN2014C. London: ReCAP for DFID.

Paige-Green, P., Verhaeghe, B., Roux, M.P. Council for Scientific and Industrial Research (CSIR), Paige-Green Consulting (Pty) Ltd and St Helens Consulting Ltd (2019). *Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa, Visual Assessment Manual*, GEN2014C. London: ReCAP for DFID.

Southern African Development Community (SADC), (2003). *Guideline on Low-volume Sealed Roads.* Southern Africa Transport and Communications Commission.