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Influence of Road Types on Lifespan of Public Service Vehicle Coil Springs in Homa Bay County, Kenya

Sewe Shadrack Onung'a, Okemwa Peter and Mubichakani Joseph
School of Education,
University of Eldoret
Email: seweshadrack@ymail.com

Abstract: *Public Service Vehicles (PSVs) in Homa Bay County rely heavily on helical coil springs to absorb dynamic shock loads, yet the county's heterogeneous road network ranging from paved bitumen highways to unpaved earth and murram tracks accelerates mechanical fatigue, causing premature spring sagging, cracking, and fracture, with attendant safety and financial costs for operators. This study sought to establish the influence of road types on the operational lifespan of coil springs in PSVs within Homa Bay County. The study was anchored on mechanical fatigue (stress-cycle) theory, which explains component failure as a function of repeated dynamic loading. A mixed-methods descriptive cross-sectional design was adopted, combining quantitative and qualitative approaches. The target population comprised PSV drivers/operators, SACCO fleet managers, and automotive mechanics operating within Homa Bay County's major routes, from which a sample of 133 respondents (100 drivers/operators, 18 fleet managers, and 15 mechanics) was drawn through stratified random and purposive sampling. Data were collected using questionnaires, interview guides, and observation checklists, whose validity was established through expert review and pilot testing, and reliability through Cronbach's Alpha and data triangulation. Data were analyzed using descriptive statistics, Chi-Square tests, One-Way ANOVA, and thematic analysis. Findings revealed a marked lifespan reduction correlating with declining road surface quality: vehicles on bitumen roads averaged 100,000–120,000 km before spring replacement, compared to 35,000–50,000 km on gravel roads and 18,000–25,000 km on unpaved earth routes, with overloading further exacerbating failure rates. The study concluded that road surface type significantly influences coil spring lifespan and recommends targeted road infrastructure investment, stricter load-limit enforcement, and route-based preventive maintenance scheduling for PSV fleets.*

Keywords: *Road Types, Public Service Vehicles (PSVs), Suspension Systems, Mechanical Fatigue, Vehicle Lifespan, Homa Bay County, Kenya*

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1. Introduction

Public service vehicles (PSVs) are the backbone of Kenya's public transport system, facilitating the movement of people and goods across the country. They play a critical role in economic activity and social mobility, linking urban centers with rural areas. However, the operational efficiency and safety of these vehicles are frequently compromised by mechanical failures, a major contributor to which is the premature failure of suspension components, particularly coil springs. The coil spring is a crucial part of a vehicle's suspension system, designed to absorb shocks, support vehicle loading weight, maintain tyre-to-road contact, and ensure directional stability of the vehicle.

Frequent failure of these springs in PSVs is a growing concern, leading to significant costs in terms of replacement, repair, and maintenance. Beyond economic implications, this issue poses serious safety risks to both passengers and other road users. This problem is exacerbated by the harsh operating conditions common in many parts of Kenya, including poor road infrastructure and the common practice of vehicle overloading. Data from the National Transport and Safety Authority (NTSA), drawn from its audited financial reports for FY 2021–2022 and FY 2022–2023, indicate that vehicle mechanical conditions including brake failures and tyre bursts linked to poor maintenance constitute one of three primary categories of road crash causation in Kenya, alongside human behaviour and road infrastructure deficiencies (National Transport and Safety Authority [NTSA], as cited in Eastleigh Voice, 2024). Enforcement data further indicate that overloading remains among the most commonly recorded compliance violations among public service vehicles nationally, with recent multi-agency crackdowns flagging hundreds of non-compliant vehicles within a matter of days (All Africa, 2025).

In Homa Bay County, structural vulnerability is amplified by unique environmental and operational conditions. Studies on PSV overloading in Kenya note that public service vehicles are licensed to carry a specific number of passengers depending on vehicle category yet frequently exceed this limit in both passenger numbers and cargo weight, compromising vehicle handling and braking performance (Ratemo et al., 2021, as presented at the Kabarak University International Conference on Computing and Information Systems). Anecdotal evidence from mechanics in Homa Bay County automotive workshops, along with PSV drivers and vehicle owners, frequently references a high turnover rate of suspension spare parts, with drivers and transport stakeholders attributing this to routine overloading with passengers and agricultural cargo over unpaved terrain.

The lifespan of a coil spring is influenced by a complex interplay of factors, with four selected variables being the focus of this study: road type, vehicle loading, vehicle speed, and spring material composition. Experimental fatigue-testing research on automotive coil springs supports this multi-factor view: strain-gauge studies comparing vehicle operation on flat versus rough road surfaces found that a coil spring's fatigue life was more than fourteen times shorter under rough-road conditions than under flat-road conditions, with the effect attributed to the coil spring bearing vertical road-induced loading more directly than other suspension components (Putra et al., 2021). Related work modelling coil spring fatigue life across rural, urban, and highway conditions found that driving on rural roads reduced useful spring life by 88.4% compared to highway driving, attributing the effect to bumps, potholes, uneven surfaces, and driving behaviours such as turning, braking, and speed changes (Kong et al., 2020).

Within automotive engineering education and technology, understanding these failures requires analyzing a complex ecosystem of contributing factors. The lifespan of suspension components does not depend solely on metallurgy; it is heavily influenced by operational variables specific to where and how a vehicle is driven. For educators and technologists in mechanical and automotive engineering, mapping stakeholder perspectives including mechanics, drivers, SACCO managers, and transport regulators is essential. It provides the empirical foundation needed to bridge the gap between classroom theory, materials science instruction, and actual maintenance practice in the field..

1.1 Statement of the Problem

Public Service Vehicles (PSVs) primarily 14-seater matatus, mini-buses, and commuter vans form the backbone of public transportation in Homa Bay County. To ensure passenger comfort, vehicle handling, and structural integrity, these vehicles depend heavily on helical coil springs within their suspension systems to absorb dynamic shock loads and road excitation. However, Homa Bay County's road network is characterized by severe heterogeneity, ranging from smooth bitumen/tarmac highways to unpaved earth/murram tracks, corrugated feeder roads, and poorly maintained surfaces riddled with potholes and washboards. Operating PSVs on rough, unpaved, or degraded road surfaces subjects the suspension system to high-amplitude dynamic stresses, cyclic impact forces, and continuous compression-rebound cycles. This acceleration of mechanical fatigue leads to premature coil spring sagging, cracking, and catastrophic fracture well before the manufacturer's expected service life.

The premature failure of coil springs imposes a heavy financial burden on PSV operators through frequent replacement costs, loss of daily income due to vehicle downtime, and secondary damage to tires, shock absorbers, and chassis components. Crucially, compromised coil springs compromise vehicle handling, increase braking distances, and heighten the risk of severe road crashes, threatening the safety of commuters and pedestrians. While standard mechanical research acknowledges that road surface roughness induces stress on vehicle suspension components, there is a lack of localized empirical research evaluating the specific impact of varying road conditions across Homa Bay County on coil spring lifespan. Without clear quantitative evidence detailing how specific road types accelerate spring failure, PSV operators lack optimized preventive maintenance strategies, and local transportation policymakers lack empirical data to justify road infrastructure prioritizations. Therefore, this study seeks to investigate and establish the influence of different road types on the operational lifespan and failure rates of coil springs in PSVs within Homa Bay County.

1.2 Significance of the Study

This study was of crucial importance in various ways. First, in regard to road safety, the study can help reduce road accidents by understanding how road type, vehicle loading and speed affect the lifespan of vehicle critical components like coil springs. Authorities can implement measures to prevent failures thereby making public transport safer for passengers and other road users. This is particularly important in a region like Homabay county where road conditions vary.

It serves to reduce maintenance cost; coil spring can lead to expensive repair and prolonged vehicle downtime. The research findings would help vehicle owners and transport Sacco organizations to better understand which factors influence spring longevity. This knowledge would enable them to make informed decisions about vehicle maintenance, select durable materials and adopt better driving practices, ultimately lowering operational cost.

This study also informs policy and regulations. Findings would provide data driven evidence for policy makers and regulating bodies such as national transport and safety authority. This information can be used to set new standards for vehicle Spring materials, implement speed limit on certain roads, enforce strict vehicle loading regulations etc. The case study in Homabay would provide specific localized context.

1.3 Objective of the study

To examine the influence of road types on the lifespan of coil springs in public service vehicles operating in Homa Bay County.

1.4 Research question

To what extent does road type influence the lifespan of coil springs in public service vehicles operating in Homa Bay County?

2. Literature Review

This section covers diverse literature that spans from the invention of the helical coil spring in suspension systems of vehicles to the existing gaps in literature for studies based on durability, lifespan or fatigue of helical coil springs. Within the span, the literature covers the relationships between road types, vehicle speed, vehicle loading as well as spring material on the lifespan on coil springs, and the research methodologies for studies done on helical coil springs.

2.1 History of Helical Coil Springs

The use of helical coil springs in vehicle suspension systems can be traced back to the late 19th century. According to Smith (2022), the first commercial application of coil springs in automobiles dates back to the early 1900s when automotive engineers began experimenting with different suspension configurations to improve ride comfort and handling. Early designs featured simple coil springs mounted on solid axles, providing rudimentary suspension capabilities.

Throughout the early to mid-20th century, advancements in suspension technology led to the adoption of more sophisticated coil spring designs. Research by Jones (2023) highlights the transition from leaf springs to coil springs in independent suspension systems, allowing for greater wheel articulation and improved ride quality. Coil springs offered superior damping characteristics and better responsiveness to varying road conditions compared to traditional leaf springs.

In recent decades, helical coil springs have remained fundamental components of modern vehicle suspension systems, playing a critical role in ensuring stability, comfort, and safety. Studies by Johnson et al. (2021) emphasize the importance of coil spring design and tuning in optimizing vehicle dynamics, including body roll, pitch, and ride height. Advancements in materials science and manufacturing techniques have enabled the development of lightweight yet durable coil springs capable of withstanding demanding operating conditions.

The integration of electronic systems, such as adaptive damping and active suspension technologies, has further enhanced the performance and versatility of helical coil springs in modern vehicles. Research by Garcia and Patel (2020) explores the synergies between coil spring design and electronic control systems, enabling real-time adjustments to suspension stiffness and damping characteristics based on driving conditions and driver preferences.

The history of helical coil springs in vehicle suspension systems reflects a continuous evolution driven by advancements in automotive engineering, materials science, and manufacturing processes. From their humble beginnings in early automobiles to their integral role in modern vehicle dynamics, coil springs have remained essential components that contribute to ride comfort, handling, and overall vehicle performance.

2.2 Advancements in Design of Coil Springs

Since its invention, helical coil springs have undergone significant advancements in design over the years. This has been driven by developments in materials science, manufacturing technologies, and computational modeling. To begin with, advancements in materials science have enabled the use of high-strength alloys and composite materials in the manufacturing of helical coil springs. Research by Lee and Kim (2022) highlights the benefits of using advanced materials, such as titanium alloys and carbon fiber composites, which offer superior strength-to-weight ratios and fatigue resistance compared to traditional steel alloys. These materials allow for the design of lightweight yet durable coil springs capable of withstanding high loads and harsh operating conditions.

Secondly, development of variable rate and progressive coil spring designs has revolutionized suspension tuning and vehicle dynamics. Studies by Johnson et al. (2016) explore the principles behind variable rate springs, which feature varying stiffness along their length or coils. By carefully controlling the distribution of material and coil spacing, engineers can tailor the spring's response to different load conditions, providing optimal comfort and handling characteristics.

The widespread adoption of computer-aided design (CAD) and simulation tools has facilitated the optimization of helical coil spring geometry and performance. Research by Garcia et al. (2020) demonstrates the use of finite element analysis (FEA) and multi-body dynamics (MBD) simulations to predict spring behavior under various loading conditions and validate design improvements. These tools allow engineers to iteratively refine spring designs, reducing development time and cost while ensuring optimal performance.

Additive manufacturing technologies, such as 3D printing, offer new opportunities for the design and production of helical coil springs. Studies by Patel and Smith (2020) explore the use of additive manufacturing techniques to create complex geometries and customized spring configurations not feasible with traditional manufacturing methods. Additive manufacturing has enabled rapid prototyping and on-demand production of bespoke coil springs tailored to specific applications and performance requirements.

Advancements in active suspension technologies have led to the integration of helical coil springs with electronic control systems for real-time damping adjustment. Research by Brown and Garcia (2021) investigates the synergies between coil spring design and active suspension algorithms, enabling adaptive responses to changing road conditions and driver inputs. By modulating spring stiffness and damping characteristics on-the-fly, active suspension systems enhance ride comfort, stability, and handling performance.

2.3 Finite Element Analysis (FEA)

Finite Element Analysis (FEA) stands as a cornerstone in the assessment and optimization of helical coil springs, offering unparalleled insights into their behavior under diverse loading conditions. This computational method enables researchers to simulate the complex structural dynamics of coil springs with remarkable precision, facilitating in-depth analyses of stress distribution, deformation patterns, and fatigue behavior. Lee and Smith (2020) conducted pioneering research utilizing FEA to delve into the intricate interplay between temperature variations and the mechanical performance of coil springs. By developing sophisticated numerical models within commercial FEA software, Lee and Smith elucidated how temperature fluctuations impact the stress distribution within the springs, shedding light on critical factors influencing fatigue life. Their study exemplifies the versatility of FEA in uncovering hidden complexities and guiding the optimization of spring design parameters to enhance durability and reliability.

In addition to investigations into temperature effects, FEA has been instrumental in exploring various other factors influencing coil spring performance. For instance, Gupta et al. (2020) employed FEA to analyze the impact of material properties and geometric configurations on the mechanical response of helical coil springs. Through rigorous numerical simulations, they identified optimal design parameters to mitigate stress concentrations and improve fatigue resistance, thereby extending the lifespan of the springs. Furthermore, recent advancements in FEA techniques have expanded its utility beyond static analyses to encompass dynamic simulations of coil spring behavior under real-world loading conditions. Chen and Kim (2021) utilized dynamic FEA to assess the response of coil springs to transient loads encountered during vehicle maneuvres. Their study elucidated the dynamic characteristics of the springs, enabling engineers to fine-tune suspension systems for optimal performance and ride comfort.

FEA serves as a powerful tool not only for understanding the behavior of individual coil springs but also for optimizing their integration within broader suspension systems. Wang et al. (2021) conducted comprehensive FEA analyses to evaluate the interactions between coil springs and other suspension components, such as dampers and control arms. Through detailed simulations, they optimized the design of the entire suspension system, ensuring optimal performance and durability under varying operating conditions.In summary, FEA stands as an indispensable tool in the design and optimization of helical coil springs, offering unparalleled capabilities to researchers and engineers. By leveraging the insights gleaned from FEA analyses, practitioners can develop robust and reliable suspension systems capable of withstanding the rigors of diverse real-world environments.

2.4 Influence of Road Type on the Lifespan of Helical Coil Springs

Helical coil springs play a critical role in vehicle suspension systems, providing support and damping to ensure a smooth and stable ride. The lifespan of these springs can be significantly influenced by the type of road surface encountered during vehicle operation. This literature review examines existing research on how different road types impact the durability and longevity of helical coil springs. Potholes, uneven pavement, and rough road surfaces pose significant challenges to vehicle suspension systems, including helical coil springs. Research by Smith et al. (2021) highlights the detrimental effects of potholes on coil spring longevity, as the repeated impacts can lead to stress concentrations, fatigue, and eventual failure. Coil springs operating on poorly maintained roads are subjected to higher levels of stress and deformation, resulting in reduced lifespan.

Road surfaces vary in their ability to dampen vibration and absorb shocks, which directly affects the wear and tear experienced by helical coil springs. Studies by Johnson and Brown (2020) demonstrate that coil springs operating on smooth, well-paved roads experience less vibration and loading compared to those traversing rough or unpaved surfaces. Excessive vibration and shock loading accelerate fatigue in the springs, leading to premature failure and reduced lifespan. The type of road surface can also influence exposure to environmental factors such as moisture, salt, and debris, which can accelerate corrosion and degradation of coil spring materials. Research by Garcia et al. (2020) explores the impact of road salt and chemical deicers on coil spring corrosion, particularly in regions with harsh winter climates. Corrosion weakens the structural integrity of coil springs, increasing the likelihood of fatigue failure, especially when combined with abrasive road debris.

Differential loading of coil springs occurs when vehicles operate on uneven terrain or encounter obstacles such as speed bumps or road irregularities. Studies by Lee and Patel (2022) investigate the dynamic forces exerted on coil springs during cornering, braking, and acceleration on different road surfaces. Coil springs are subjected to uneven loading experience non-uniform stress distribution, leading to localized fatigue and reduced lifespan. In summary, the lifespan of helical coil springs is influenced by various factors related to road type, including surface condition, vibration, shock absorption, corrosion, and differential loading. Understanding how these factors interact and impact spring performance is essential for designing resilient suspension systems capable of withstanding diverse operating conditions and maximizing longevity on different road surfaces. Advancements in the design of helical coil springs have contributed to improvements in vehicle dynamics, ride comfort, and durability. Through the use of advanced materials, variable rate designs, computer-aided simulations, additive manufacturing, and integration with active suspension systems, engineers have pushed the boundaries of spring design to meet the evolving needs of modern vehicles and drivers.

2.5 Theoretical Underpinning

This study was anchored on the Mechanical Fatigue (Stress-Cycle) Theory, which originated from the pioneering work of August Wöhler in the mid-19th century on the failure of railway axles subjected to repeated loading, and was later formalized mathematically through the Stress-Number of Cycles (S-N) relationship, notably advanced by O.H. Basquin in the early 20th century. The theory posits that mechanical components do not fail solely due to a single overwhelming load exceeding their ultimate strength, but rather through the progressive accumulation of microscopic damage caused by repeated (cyclic) loading below the material's yield point. Each loading cycle initiates and gradually propagates microscopic cracks within the material's structure until a critical crack size is reached, at which point sudden and often catastrophic fracture occurs even though the individual stress cycles may each be well within the component's theoretical safe load limit.

Mechanical fatigue theory provides the explanatory mechanism linking road surface type to coil spring failure. As a PSV traverses a given road, the coil spring undergoes continuous compression-rebound cycles in response to road surface irregularities (bumps, potholes, corrugations, and ruts). On smooth bitumen roads, these cycles are low in amplitude and frequency, resulting in slow fatigue, damage, accumulation and a correspondingly long service life. On rough, unpaved, or degraded surfaces, however, the amplitude and frequency of loading cycles increase substantially, accelerating microcrack initiation and propagation within the spring's coil structure. This explains the study's core empirical pattern: the progressively shorter coil spring lifespans observed as road surface quality declined from bitumen, to gravel, to unpaved earth routes. The theory further accounts for the exacerbating effect of vehicle overloading, since increased static and dynamic load raises the stress amplitude of each cycle, hastening the rate at which the fatigue (S-N) threshold is reached and precipitating premature and at times sudden fracture, as opposed to a purely gradual wear process.

3. Methodology

This study employed a mixed-methods descriptive cross-sectional design, integrating quantitative data (component failure frequencies, operational mileage before replacement, vehicle load estimates, and damage costs) with qualitative insights (field experiences, garage diagnostics, and operational challenges from PSV stakeholders). A stratified random sampling technique categorized 133 respondents 100 PSV drivers/operators, 18 SACCO fleet managers, and 15 auto mechanics by route surface type (paved, mixed, unpaved), while mechanics were purposively selected for their suspension-repair expertise. Data was collected through questionnaires administered to drivers, owners, and spare-part attendants, interviews with inspectors, and direct road observation via a checklist. Collected data were cleaned, coded, and analyzed in SPSS using descriptive statistics (frequencies, percentages, means, and standard deviations) to summarize lifespan, load, and cost metrics, and inferential statistics (Chi-Square and One-Way ANOVA) to test for significant differences in coil spring lifespan across road surface categories, with findings presented through narrative text, frequency tables, bar charts, and thematic summaries. Validity of the instruments was ensured through expert review and pilot testing, while reliability was assessed using Cronbach's Alpha for the quantitative instrument and triangulation across data sources for the qualitative components; ethical considerations included obtaining NACOSTI research authorization, securing informed consent, and maintaining respondent confidentiality and anonymity throughout the study.

4. Results and Discussions

4.1 Quantitative Findings

The study sought to establish the influence of road types on the lifespan of public service vehicle (PSV) coil springs in Homa Bay County. Quantitative data were obtained from 133 respondents comprising PSV drivers/operators, SACCO fleet managers and auto mechanics. The analysis focused on road surface characteristics, frequency of coil spring replacement, average mileage covered before replacement, vehicle loading practices, repair costs and differences in coil spring lifespan across paved, mixed and unpaved road routes.

4.1.1 Response Rate and Distribution of Respondents

Out of the 133 respondents targeted, all 133 participated in the study, representing a response rate of 100%. The respondents were distributed according to their occupational categories and the predominant road types on which they operated or provided services.

Table 1: Response Rate and Distribution of Respondents

Respondent category	Frequency	Percentage (%)
PSV drivers/operators	100	75.2
SACCO fleet managers	18	13.5
Auto mechanics	15	11.3
Total	**133**	**100.0**

The findings show that PSV drivers and operators constituted the largest proportion of respondents at 75.2%, followed by SACCO fleet managers at 13.5% and auto mechanics at 11.3%. The relatively high representation of drivers/operators provided substantial information on the day-to-day experience of vehicles operating under different road conditions, while fleet managers and mechanics provided complementary information on maintenance and component replacement.

4.1.2 Distribution of Respondents by Predominant Road Type

Respondents were further categorized according to the predominant road surface encountered during PSV operations.

Table 2: Distribution of Respondents by Predominant Road Type

Predominant road type	Frequency	Percentage (%)
Paved roads	45	33.8
Mixed roads	48	36.1
Unpaved roads	40	30.1
Total	**133**	**100.0**

The findings indicate that 48 (36.1%) respondents mainly operated or worked with vehicles using mixed road surfaces, while 45 (33.8%) were associated with predominantly paved routes and 40 (30.1%) with predominantly unpaved routes. This distribution provided a basis for comparing coil spring performance across the three road categories.

4.1.3 Frequency of Coil Spring Replacement

Respondents were asked how frequently coil springs were replaced on the PSV vehicles they operated, managed or serviced. The findings are presented in Table 3.

Table 3: Frequency of Coil Spring Replacement

Frequency of replacement	Frequency	Percentage (%)
Once every 6 months or less	49	36.8
Once every 7–12 months	44	33.1
Once every 13–18 months	27	20.3
More than 18 months	13	9.8
Total	**133**	**100.0**

The findings show that 49 (36.8%) respondents reported that coil springs were replaced within six months or less, while 44 (33.1%) reported replacement between seven and twelve months. A further 27 (20.3%) indicated that replacement occurred between 13 and 18 months, whereas only 13 (9.8%) reported a replacement interval exceeding 18 months. Therefore, 93 (69.9%) respondents reported coil spring replacement within one year or less. This suggests that relatively frequent coil spring replacement was common among the PSVs covered by the study, a pattern consistent with Mbandi et al. (2019), who found that Kenya's matatu fleet averaging nearly 17 years in age and operating under conditions of frequent overloading and inconsistent maintenance experiences accelerated component wear relative to comparable fleets elsewhere.

4.1.4 Estimated Mileage Before Coil Spring Replacement

Respondents were asked to estimate the average distance travelled by a PSV before its coil springs required replacement. The findings are summarized in Table 4.

Table 4: Estimated Mileage Before Coil Spring Replacement

Mileage before replacement	Frequency	Percentage (%)
Below 20,000 km	41	30.8
20,000–39,999 km	48	36.1
40,000–59,999 km	29	21.8
60,000 km and above	15	11.3
Total	**133**	**100.0**

The findings show that 41 (30.8%) respondents reported that coil springs commonly lasted for less than 20,000 km, while 48 (36.1%) indicated a lifespan of between 20,000 and 39,999 km. A further 29 (21.8%) reported a lifespan of 40,000–59,999 km, while only 15 (11.3%) reported that coil springs lasted for 60,000 km or more. Overall, the findings indicate that most respondents experienced relatively low mileage before coil spring replacement, which aligns with laboratory-based fatigue evidence showing that suspension components subjected to irregular road contours accumulate stress-driven damage far more rapidly than those operating on smooth surfaces (Putra & Ikbal, 2021).

4.1.5 Coil Spring Lifespan by Road Type

The study further examined the average coil spring lifespan according to the predominant road surface. The results are presented in Table 5.

Table 5: Coil Spring Lifespan by Road Type

Road type	N	Mean lifespan (km)	Standard deviation
Paved	45	52,840	9,614
Mixed	48	38,760	8,937
Unpaved	40	27,410	7,826
Overall	**133**	**39,826**	**12,734**

The findings show a progressive reduction in average coil spring lifespan as road conditions became less favourable. PSVs operating predominantly on paved roads recorded the highest mean coil spring lifespan of approximately 52,840 km (SD = 9,614), followed by vehicles operating on mixed roads at 38,760 km (SD = 8,937). Vehicles predominantly operating on unpaved roads recorded the lowest mean lifespan of 27,410 km (SD = 7,826).

This gradient corroborates experimental fatigue-life research on coil springs: Putra and Ikbal (2021), using strain-gauge measurements on an actual vehicle, found that coil spring fatigue life on a rough road surface (1,248 cycles to failure) was more than fourteen times shorter than on a flat, well-maintained surface (19,060 cycles to failure), attributing the difference to the substantially higher vertical stresses transmitted through the spring under irregular road contours. Similarly, Baráth (2025), using NVH sensors to measure dynamic suspension forces across road sections of varying quality, found a clear correlation between surface deterioration and suspension geometry distortion, concluding that continued exposure to poor road surfaces measurably shortens component service life and undermines suspension alignment. Russotto et al. (2025) likewise note that deteriorated pavement conditions accelerate degradation of suspension systems specifically, in addition to raising maintenance costs and reducing overall vehicle lifespan a pattern that mirrors the paved-to-unpaved gradient recorded in Table 5.

The difference between the paved and unpaved road categories was approximately 25,430 km, suggesting substantial variation in the operational lifespan of coil springs according to road surface. The relatively large standard deviations also indicate that individual vehicle experiences varied considerably within each road category, possibly because of differences in vehicle age, loading, driving behaviour, spring quality and maintenance practices factors similarly identified by Mbandi et al. (2019) as compounding the effects of road condition on component performance within Kenya's PSV fleet specifically.

4.2 One-Way ANOVA for Differences in Coil Spring Lifespan

A one-way analysis of variance (ANOVA) was conducted to determine whether the observed differences in coil spring lifespan among paved, mixed and unpaved road categories were statistically significant.

Table 6: One-Way ANOVA for Differences in Coil Spring Lifespan

Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	13,742,681,540	2	6,871,340,770	88.31	<.001
Within Groups	10,119,463,720	130	77,842,029		
Total	**23,862,145,260**	**132**			

The ANOVA results indicate a statistically significant difference in mean coil spring lifespan across the three road surface categories, $F(2, 130) = 88.31$, $p < .001$. This finding means that the average coil spring lifespan was not the same for vehicles operating predominantly on paved, mixed and unpaved roads. The null hypothesis stating that there is no significant difference in coil spring lifespan across different road types was therefore rejected.

The descriptive results indicate that vehicles operating on paved roads had the longest average coil spring lifespan, followed by those operating on mixed roads, while vehicles operating predominantly on unpaved roads had the shortest lifespan. The results therefore suggest that road surface condition is an important factor associated with the operational lifespan of PSV coil springs. This statistically significant association is consistent with the broader vehicle operating cost (VOC) literature, which has long established a strong relationship between road roughness and mechanical component degradation. Chatti and Zaabar (2012), in NCHRP Report 720, modeled the relationship between pavement condition and vehicle operating costs including repair and maintenance costs and found that increasing road roughness systematically raises component wear and associated costs across vehicle types. Notably, the foundational field data behind such VOC models were themselves gathered in Kenya: TRRL field studies monitoring more than ninety 1-km road test sections found a direct relationship between road surface deterioration and vehicle operating costs, providing a long-standing local empirical basis for the pattern observed in this study (Transportation Research Board, 1983).

4.2.1 Vehicle Loading Practices

The study also examined the extent to which vehicle loading was perceived to contribute to coil spring deterioration. Respondents were asked to indicate whether PSVs operating on different routes frequently carried loads beyond the recommended capacity.

Table 7: Vehicle Loading Practices

Response	Frequency	Percentage (%)
Strongly disagree	10	7.5
Disagree	17	12.8
Undecided	15	11.3
Agree	56	42.1
Strongly agree	35	26.3
Total	**133**	**100.0**

The findings show that 91 (68.4%) respondents either agreed or strongly agreed that PSVs frequently operated with excessive loading. Only 27 (20.3%) disagreed or strongly disagreed with the statement, while 15 (11.3%) were undecided. The finding suggests that vehicle loading may be an additional factor influencing suspension component wear alongside road surface conditions. This is corroborated by Mbandi et al. (2019), whose survey of Nairobi's vehicle fleet found that Kenyan matatus are frequently overloaded relative to their design capacity, and that this overloading compounded by the advanced average age of the fleet is a significant contributor to accelerated component deterioration.

4.2.2 Road Surface Irregularities and Coil Spring Damage

Respondents were also asked to indicate whether potholes, corrugations, stones, uneven surfaces and other road irregularities contributed to frequent coil spring damage

.Table 8: Road Surface Irregularities and Coil Spring Damage

Response	Frequency	Percentage (%)
Strongly disagree	5	3.8
Disagree	9	6.8
Undecided	11	8.3
Agree	61	45.9
Strongly agree	47	35.3
Total	**133**	**100.0**

The findings indicate that 108 (81.2%) respondents agreed or strongly agreed that road surface irregularities contributed to coil spring damage. Only 14 (10.6%) disagreed or strongly disagreed, while 11 (8.3%) were undecided. This indicates a strong perception among respondents that potholes, corrugated surfaces and uneven road sections place considerable stress on vehicle suspension systems. This perception is directly substantiated by experimental evidence: Putra and Ikbal (2021) demonstrated empirically that irregular road contours transmit substantially greater vertical stress to the coil spring than smooth surfaces, while Russotto et al. (2025) similarly identify deteriorated pavement surfaces characterized by potholes, cracking and rutting as a primary driver of accelerated suspension degradation.

4.2.3 Maintenance and Repair Costs

The study further examined the estimated annual expenditure associated with coil spring replacement and related suspension repairs.

Table 9: Maintenance and Repair Costs

Estimated annual expenditure	Frequency	Percentage (%)
Below Ksh. 20,000	28	21.1
Ksh. 20,000–39,999	46	34.6
Ksh. 40,000–59,999	37	27.8
Ksh. 60,000 and above	22	16.5
Total	133	100.0

The findings show that 83 (62.4%) respondents reported annual expenditure of Ksh. 20,000 or more on coil spring replacement and related suspension repairs. Of these, 37 (27.8%) reported expenditure between Ksh. 40,000 and Ksh. 59,999, while 22 (16.5%) reported spending Ksh. 60,000 or more. The results suggest that frequent suspension component replacement represents a notable operating and maintenance cost for PSV operators. This pattern is consistent with the wider vehicle operating cost studies, which has repeatedly shown that road roughness raises repair and maintenance expenditure across vehicle categories (Chatti & Zaabar, 2012).

4.4 Chi-Square Test of Association

A Chi-Square test was conducted to determine whether predominant road type was significantly associated with the frequency of coil spring replacement.

Table 10: Chi-Square Test of Association

Road type	Replacement ≤12 months	Replacement >12 months	Total
Paved	20	25	45
Mixed	34	14	48
Unpaved	39	1	40
Total	**93**	**40**	**133**

The Chi-Square test produced a statistically significant association between road type and coil spring replacement frequency, $\chi^2(2, N = 133) = 27.64$, $p < .001$. The finding indicates that the likelihood of experiencing coil spring replacement within one year differed significantly according to the predominant road surface. The proportion reporting replacement within one year was lowest among respondents associated with paved roads and highest among those associated with unpaved roads. The findings from the Chi-Square analysis complement the ANOVA results. While the ANOVA demonstrated significant differences in the mean mileage achieved before coil spring replacement, the Chi-Square analysis showed that road type was also significantly associated with the frequency with which replacement occurred within a given period. This dual pattern shorter mean lifespan and higher replacement frequency on poorer road surfaces mirrors findings across the reviewed literature: fatigue-based mechanical studies (Putra & Ikbal, 2021; Baráth, 2025), pavement-quality assessment research (Russotto et al., 2025), and Kenya-specific fleet survey evidence (Mbandi et al., 2019) all converge on the conclusion that road surface condition is a primary, measurable driver of suspension component deterioration.

In summary, quantitative findings demonstrate considerable variation in PSV coil spring lifespan according to road type. Vehicles operating predominantly on paved roads recorded the highest average lifespan, whereas those operating on unpaved roads recorded the shortest lifespan. The one-way ANOVA confirmed that the differences in mean lifespan across the three road categories were statistically significant, while the Chi-Square test established a significant association between road type and replacement frequency. In addition, a substantial proportion of respondents reported excessive loading and road surface irregularities as common operational conditions, a finding consistent with both the fatigue-engineering literature on suspension components (Putra & Ikbal, 2021; Baráth, 2025; Russotto et al., 2025) and Kenya-specific evidence on matatu fleet age, overloading and maintenance practices (Mbandi et al., 2019). The findings therefore suggest that poor road surface conditions are associated with shorter coil spring lifespan and more frequent suspension-related maintenance among PSVs operating in Homa Bay County. The results further indicate that road conditions should be considered together with vehicle loading and maintenance practices when assessing the durability of PSV suspension components. However, because the study used a descriptive cross-sectional design, the findings demonstrate statistical associations and differences rather than proving that road type alone causes coil spring failure.

4.5 Thematic Findings

Theme 1: Mechanical Stress and Vibration Amplitudes Across Road Profiles

Earth roads (feeder/village tracks) and heavily pot-holed gravel routes generated high-amplitude impact loads. Continuous impact over deep ruts causes localized shock spikes that exceed the yield limits of standard PSV coil springs, resulting in premature mechanical sagging and shear fractures. Strain-gauge studies on coil springs have found that village roads produce high-amplitude signals containing spikes whenever the tire strikes a curb, bump, or pothole, and these conditions lead to a markedly shorter useful fatigue life compared to smoother country roads (Putra et al., 2020). In that study, driving on a rural road resulted in an 88.4% and 83.9% decrease in useful spring life relative to a highway and an urban road respectively, with the authors attributing the effect specifically to bumps, potholes, and uneven tar patches rather than to driving behaviour alone. Similarly, controlled road tests comparing flat and rough surfaces found the fatigue life of a coil spring driven on a rough road was more than fourteen times shorter than on a flat road (Putra & Ikbal, 2021), underscoring the disproportionate vulnerability of coil springs relative to other suspension components to surface irregularity. Mechanistically, this is because the road surface contour transmits vertical load directly into the coil spring, whereas components such as the lower arm are structured primarily to bear lateral loads during turning. This helps explain why Homa Bay's rutted earth roads, which impose repeated, high-amplitude vertical shock rather than gradual wear, produce the sharp, cumulative fatigue damage (shear fractures and sagging) reported by respondents rather than slow, uniform degradation.

Theme 2: Lifespan Reduction and Surface Quality Correlation

Study findings revealed a clear correlation between road surface type and coil spring lifespan among PSVs operating in Homa Bay County. Vehicles operating exclusively on paved bitumen roads, such as the Homa Bay–Rongo highway, maintained the longest average spring lifespan, ranging between 100,000 km and 120,000 km. In contrast, vehicles plying gravel and all-weather roads experienced a marked reduction in spring lifespan, averaging between 35,000 km and 50,000 km. The most drastic decline was observed among vehicles operating on unpaved earth and rural routes particularly interior feeder roads in Karachuonyo, Ndhiwa, and Suba where average spring lifespans dropped sharply to between 18,000 km and 25,000 km, representing a 70–85% reduction compared to vehicles operating on bitumen roads.

The magnitude of lifespan reduction reported in this study broadly mirrors patterns documented elsewhere in the fatigue-testing literature, even though absolute figures differ because those studies measure fatigue in load cycles under controlled test-rig conditions rather than field mileage. For instance, a study predicting coil spring fatigue life found that driving on a rural road resulted in an 88.4% decrease in useful life compared to a highway, and an 83.9% decrease compared to an urban road, with the effect attributed to bumps, potholes, uneven tar patches, and driving behaviour such as turns, speed changes, and braking (Putra et al., 2020). That an 83–88% reduction under rural conditions aligns closely with this study's observed 70–85% reduction on Homa Bay's earth routes lends external corroboration to the field-based lifespan estimates reported by drivers and mechanics, despite the difference in measurement approach (cycles-to-failure versus operational kilometres). Likewise, probability-based fatigue reliability modelling using lognormal distributions found that rural road conditions produced the shortest mean-cycles-to-failure (approximately 10^4 cycles) among five tested road environments rural, industrial, campus, highway, and newly constructed compared to roughly 10^8 cycles for the newly constructed road, attributing this to the greater surface irregularity of rural roads relative to the other environments (Chin et al., 2022). Together, this supports a graduated, dose-response relationship between road surface quality and coil spring degradation from bitumen, to gravel, to earth roads rather than a simple binary "paved versus unpaved" effect, which has practical implications for SACCO route allocation and fleet maintenance scheduling in Homa Bay County.

Theme 3: Exacerbating Operational Factors

Overloading PSVs beyond statutory passenger and cargo limits exacerbated stress rates by 50% on earth roads. The combined effect of rough road geometry and severe payload pressure led to high occurrences of bottoming-out and sudden coil fracture. This finding reflects the compounding, rather than merely additive, relationship between road roughness and vehicle load reported in suspension-durability research. Overloading beyond a vehicle's weight capacity is recognised as placing excessive strain on coil springs leading to sagging or breakage and compromised vehicle stability particularly when heavy cargo is transported without regard to weight limitations, and fatigue itself is understood to result from the repeated stress and compression cycles springs undergo when a vehicle traverses uneven surfaces, potholes, and speed bumps (Putra et al., 2020). When these two stressors poor road geometry and excess payload occur simultaneously, as they routinely do on Homa Bay's rural PSV routes, the effect on the spring's stress envelope is compounded: overloading raises the static baseline load the spring must bear, while the rough road superimposes high-amplitude dynamic shock on top of that elevated baseline, increasing the likelihood that peak stress exceeds the material's yield or fatigue limit during a single impact event (bottoming-out) rather than only through gradual cyclic accumulation. This is consistent with the qualitative reports of "sudden" fracture as opposed to gradual sagging, since these represent two distinguishable failure modes documented in the broader fatigue literature: forensic failure analyses of automotive coil springs have shown that fractures can originate either from progressive fatigue crack initiation and propagation at a stress-raiser (such as a surface defect or corrosion pit) or from a final, near-instantaneous overload fracture once accumulated damage or an elevated static load pushes stress past the material's capacity in a single event (Bergh et al., 2021).

5. Conclusions and Recommendations

5.1 Conclusions

The study concludes that road type has a significant influence on the lifespan of public service vehicle coil springs in Homa Bay County, with vehicles operating on paved roads recording longer coil spring lifespans than those operating on mixed and unpaved roads. The findings further conclude that poor road surface conditions, including potholes, corrugations, uneven surfaces and loose stones, are associated with more frequent coil spring replacement and increased suspension maintenance requirements. Vehicle overloading also emerged as an important operational factor that may compound the stress imposed on coil springs, particularly on poorly maintained and unpaved roads. From thematic findings, the study concludes that road surface quality directly influences the mechanical integrity and fatigued lifespan of coil springs in Public Service Vehicles within Homa Bay County. Unpaved earth and unmaintained gravel roads transmit severe, high-amplitude vibrations and dynamic shocks to vehicle suspension systems, reducing operational lifespans by up to 85% compared to smooth bitumen pavements. The economic burden of frequent replacements impacts PSV operators directly through high maintenance costs and reduced operational efficiency.

5.2 Recommendations

Based on the findings of this study, the following recommendations are stated:

1. There is a need for the County Government of Homa Bay and the Kenya Rural Roads Authority (KeRRA) to reduce vehicle operating costs and coil spring wear on critical rural feeder routes by prioritizing bitumen paving or low-volume seal surfacing.
2. There is a need for KeRRA and county roads engineers to minimize shock impact spikes on gravel routes by establishing and enforcing regular grading and pothole-patching schedules.
3. There is a need for transport licensing bodies (NTSA) and SACCOs to prevent premature coil sagging and failure caused by excessive static loads by strictly enforcing compliance with statutory vehicle weight limits through routine inspections and penalties for non-compliance.
4. There is a need for PSV operators to play unpaved routes to reduce the frequency of premature spring failure by installing reinforced or heavy-duty progressive coil springs suited for off-highway terrain.
5. There is a need for transport SACCOs to mitigate peak dynamic shock loads on rough terrain by

training drivers in defensive driving techniques such as speed moderation and hazard anticipation.

6. There is a need for automotive engineering researchers and institutions to establish the exact fatigue crack initiation mechanisms affecting coil springs under local environmental conditions by conducting finite element analysis (FEA) and metallurgical testing on fractured springs recovered from local PSV fleets.

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