**Chapter**

# Quality Impairments in Flexible Road Pavements

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## Abstract

The purpose of this chapter is to present the reader with the physical processes of how flexible road pavements progressively fail and impair the quality of finished roads arising from non-adherence to roads construction quality outlines and requirements. This was achieved by investigating eight (8) roads from a sample of nineteen (19) roads based on purposive sampling. Using instruments of steel tapes, paints for failed sections, rolling rule and pictures, measurement of length, width and depth of various failed sections were taken for five (5) daily measurements at three (3) monthly visit intervals for Four Hundred and Thirty Five (435) days to show the rate of deterioration. Data obtained were analyzed for reliability of pavements using Weibull distribution statistics on ReliasoftWeibull$^{++}$to extrapolate pavement reliability from bathtub function. Findings showed that roads failed progressively within six (6) months after finished construction and deteriorated fast with increased failures on length, depth and width of pavements. The practical implications of this is that the process of construction did not conform with required/stipulated quality control metrics of flexible road construction especially in the areas of geomaterials compaction, temperature and density of materials laid. It was recommended that organization adhere to quality control guidelines and requirements to forestall quality impairment.

**Keywords:** flexible pavement, Weibull test, quality control, quality impairment, deterioration rate, reliability

## 1. Introduction

Issues of total quality management implementation in different construction industries around the world are well validated in studies to be at various levels of implementation between developing and developed countries [1]. Structural failures of roads before the designed lifetime are regular features especially amongst developing countries in the form of evidential failure of a small structural component, accelerative failure with visible weakness such as cracks and abrupt, sharp failures [2] etc.

Non-compliance to specification outlines of projects demand –amongst others- the use of non-standard materials, ineffective/unqualified team members of quality control rangers, fast track construction, poor detailed designs, etc. and may be regarded as are remote and immediate factors leading to failures [3]. Quality Control as a process in road construction ensures conformity of the finished road pavement with required standards [4]. Quality defects are obtainable from the difference in the coefficient of variation of required elasticity modulus ($C_v^{req}$) from the standard elasticity modulus ($C_v^{std}$) which is based on deflection patterns of geomaterials composition and dynamic load intensity on pavements. The wider the difference between such elasticity moduli, the higher the propensity to failure of pavements [5]. Owing to such probability outlook, their reliability estimate, takes the form of

$$R_{p_t} = 0.5 + F\left[\frac{E_{eq} - E_m}{\sqrt{\sigma_{eq}^2 + \sigma_m^2}}\right] \tag{1}$$

where $E_{eq}$ is the equivalent modulus of elasticity, $E_m$ is the maximum modulus of elasticity, $\sigma_{eq}$ is the equivalent modulus of elasticity and $\sigma_m$ is the mean square deviation of the maximum modulus of elasticity.

The process of quality control in road pavements follows the examination and test of composite materials towards meeting the correct specifications and required quality. Quality control in road projects follow stratification checks by separating roads composite materials and bringing them to specialized and accredited laboratories in order to conduct a series of tests on them. However, it is worth noting at this point that specific tests may also be done on site using checklists as the construction progresses.

Absence of quality control checks has often resulted to impaired quality outputs and poor workmanship [6]. Quality impairment in road construction processes shows that finishing road surfaces, construction process, labour workforce and materials used are in need of quality review and standardization for improvement [7]. The same applies to the workforce involved. Evidences of quality failures in constructed roads is revealed in their reliability values from their mean survival time to failure time, which are consequential fall-outs of quality management principles not being implemented. Quality in the context of road construction is when functionality is at equilibrium with a construction process output based on road utilization from effective road performance, durability, conformance, reliability, uniformity and serviceability [8]. Further to this, impaired quality of constructed roads are revealing in varying forms of cracks, potholes, bulges and surface depressions that often results in poor transportation systems, and delayed economic growth [9]. Quality impairment of roads indicates an increased level of reliability failures. The aim of this paper is to parametrically estimate their durability.

## 2. Road construction and quality practice

Road constructions are either flexible or rigid highway pavements with most or all of the following construction materials *viz.*, soil, aggregates, admixtures, Portland cement concrete, Bituminous materials, structural steel and pavement markers [10]. All of these materials are compositely layered together in a definite mix and proportion to output a quality road carriageway [11]. Determinants of high quality roads are subjects of quality tests on the various road materials enumerated above. Test on highway materials such as, Moisture Content Value (MCV), Los Angeles Abrasion Value, Dynamic Cone Penetrometer, Flakiness Index, Penetration Test on Bitumen,

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California Bearing Ratio (CBR), Softening point test on Bitumen and Ground Penetrating Radar tests are various laboratory test prerequisites for quality road [12].

**Table 1** presents road construction tests for quality assured output.

Flexible road pavements construction primarily consist of 70% asphalt bitumen content that provides binder mix with aggregate to produce asphalt concrete. This is laid on a bituminous base of a binder course. Stabilization of this process is followed by the application of tack coat of 0.75 kg per sq. metre [8]. Quality control standard as required in the preparation and placing of premix material is that bitumen is heated in the temperature range of ($150–177^0$) C within which aggregate temperature must not differ by 14°C from the binder temperature [13]. The hot mixed material of the bitumen and the aggregate together with the binder is then paved at a satisfactory temperature of not more than 163°C. This is followed for a smoother surface with a roller compaction at a speed not exceeding 5 km per hour. Preliminary or breakdown rolling uses 8 to 12 tonnes rollers and further pressurized or intermediate rolling is done using 15 to 30 tonnes fixed wheel pneumatic rollers.

During construction, the routine quality control checks carried-out to ensure quality output are often stipulated in the watch-out for resulting pavement mix, temperature at point of laying and pavement gauge or thickness. Other checks not necessarily routine but periodical are checks for aggregate grading, bitumen content grade, temperature of aggregate temperature of paving mix at mixing and compaction [14]. At every 100 tonnes of mix discharged by the hot mix plant samples are collected for the above tests. Another test for quality compliance is carried-out by implementing the Marshall test for every $100m^2$ paved and compacted [15]. This is also followed by the field density check to see if 95% of laboratory density obtained shows congruency in the field. Tolerance of 6 mm per 5 m length of paved surface is allowed for variations in depth of pavements [16]. Variations from longitudinal undulations along the straight edge at every 3.0 m check must not exceed 8.00 mm and the number of undulations higher than 6.0 mm should not exceed 10 for every 300 m of road. Near absence of quality checks in road construction projects are traceable to road failures in the form of cracks, potholes, bulge and creter depressions. A typical quality controlled road pavement construction is shown in **Figure 1**.

Failed roads maybe regarded as evidences of quality neglects. Road failures are progressive in nature with monotonic properties of lebesgue measure theory with respect to progressive road component failures. A collection of road used in a similar traffic pressured fashion normally will show propensity to fail within predictable time measures [17]. Determination of such failings owing to quality neglect is provided for in Weibull reliability analysis under the scheme of plotting the percentage of road sections that have yielded to failure over a randomized time period measurable in cycle-starts, hours of run-times, miles driven, etc. [18]. Usually, classification of quality impairment is obtainable from Weibull reliability analysis with non-linear bathtub graph having to be approximated with line of best-fit, with $\beta$ describing the classification in:

$\beta < 1.0$= > Infant mortality = > Optimum quality impairment in construction.

$\beta = 1.0$= > Randomized failure = > Progressive quality impairment during construction.

$\beta > 1.0$= > Wear-Out Failure = > High quality impairment during construction.

Most decent and prudent statistical inferences in Weibull test are parametrized with Time-to-Failure component of the road. This is historically accounted for by B (F) with 'F' representing the percentage of road section that have failed, while some parametrize by lifetime L(F) and 'B' representing bearing time. In the Weibull

| S/N | Test type | Purpose | Test methods | Quality criterion | Expected outcome |
|---|---|---|---|---|---|
| 1. | CBR – Test for Subgrade | A penetration test for the determination of mechanical fitness strength of the natural ground, subgrade and base course underweight on the carriageway | • Load bearing capacity<br>• Moisture content<br>• Potential for shrinkage and/or swelling | • Ease of compaction<br>• Strength retention<br>• Low volume response to adverse weather condition and capillary movement of ground water<br>• Inability to compress<br>• Bearing capability for stability | • Ability to furnish and dispense support to the finished pavements in resistance to traffic loads<br>• Must have enough stability under inclement weather and heavy stack situation |
| 2. | Aggregate Testing | Load transfer potentials or capability of finished pavement | • Crushing test<br>• Abrasion test<br>• Impact test<br>• Soundness test<br>• Bituminious adhesion test<br>• Specific gravity and water absorption test | • Enabling relative offer of resistance to gradual traffic load<br>• Ability to show hardness property of aggregate material<br>• Ability to offer resistance to impacts on aggregate obtained as a percentage of aggregate passing sieve<br>• Showing potential to resisting actions of weathering on aggregate under conditions of varying temperatures in sulfate solutions of sodium and magnesium. Weight loss not exceeding 12% and 18% on these solutions<br>• Offering propensity to resist water permeability in voids on road surfaces.<br>• Ability to show adhesion of bitumen binding to aggregate free from moisture and has no permeable water inlet | Aggregates in finished pavements must show promise of load transfer potential and capability according to test pass. |
| 3. | Penetration test | Hardness or softness of Bitumen | • Penetration depth under the action of standard loaded needle | • Able to show penetration resistance with reference to hardness or softness of bitumen when needle load is applied under conditions of pouring temperature, size of needle and loading weight on needle | A desirable penetration value of 150 – 200 mm within 5 seconds, for cold climates or lower for hot climates |
| 4. | Ductility test | Envisaged Bitumen deformation or elongation | • Measurement of distance to which a standard field sample of Bitumen material will be elongated without breaking at 27°C and 90 minutes rapid cooling | • Output a minimum ductility value of 75 cm under stressed condition of pulling rate, test temperature and pouring temperature | Bitumen must show ability to slow gradual deformation or elongation even at quick optimized stress and strain. |

| S/N | Test type | Purpose | Test methods | Quality criterion | Expected outcome |
|---|---|---|---|---|---|
| 5. | Softening Point Test | To show at what temperature bitumen attains a specific point of softening | Using ring and ball apparatus where a brass ring holding sample of bitumen is placed in water or glycerin at a given temperature. Then the steel ball is placed on a bitumen sample also in the liquid medium and heated to 50°C in one minute | Output a temperature for which the softened bitumen touches the metal plate at a designated distance | Higher softening point shows lower temperature propensity and rudimentary in hot weather regions. |
| 6. | Specific Gravity test | Determination of Bitumen binder density variation with aggregate | Specific gravity test by pycnometer or using weight of samples in air and water at 27°C. | Ensuring that mineral impurities of aromatic types are separated in the chemical composition of bitumen to keep the density at normal. With such mineral impurities, specific gravity of bitumen may increase | Obtaining a specific gravity of bitumen within 0.97 to 1.02 |
| 7. | Water content test | Prevention of bitumen foaming on heating to boiling point of water | Water distillation from a known weight of Bitumen specimen in a pure petroleum distillate, free of water. On heating, the water content in the specimen is collected from condensation and expressed as a percentage of weight of original specimen. | Water distilled is aimed at determination of allowable water content in the bitumen which it must contain to prevent foaming | Expected water content in Bitumen must be within the range of 0.2% by weight |
| 8. | Heating loss test | Determination of volatility loss | A sample of about 50gm of bitumen is weighed and heated to 161°C for 5 hours in a specified oven. The sample is weighed again after heating and loss expressed as percent of weight of original sample. | Loss in weight of bitumen after heating shows not exceed 1% so as to retain its volatility | Relationship between Bitumen penetration value and weight loss must be 150–200 to 2% loss in weight. |

**Table 1.**
*Quality test metrics in flexible road pavements.*

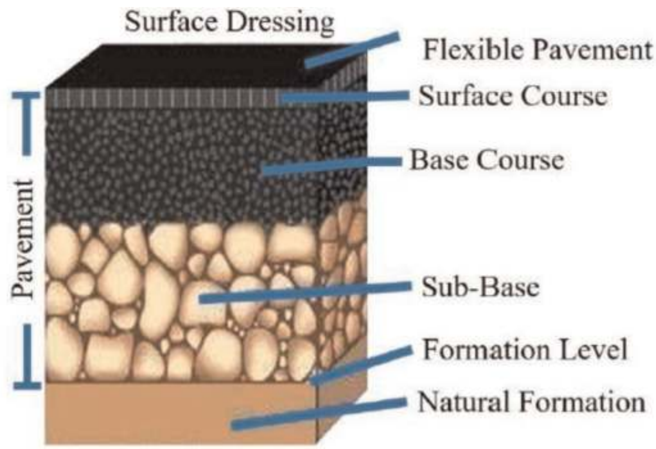


**Figure 1.**
*Components of flexible pavements in Hassan and Sobhan [13].*

statistics, the distribution shows the relationship between failed percentage with respect to time governed by constant shape factors $'\beta'$ and '$\eta$' that determines shape and scale of distribution respectively by the function:

$$F(t) = 1 - e^{\left(\frac{-t}{\eta}\right)^{\beta}} \quad (2)$$

Summing the monotonic progressive failures over time to the point of measurement generates a probability density function (PDF) describing the frequency of failures over time estimates as:

$$f(t) = \left(\frac{\beta}{\eta}\right)\left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^{\beta}} \quad (3)$$

Quality control checks on compacted geomaterials such as sub-base by a more precise measuring light weight deflectometer (LWD) device in the study of Duddu and Chennarapu [19] as against density and stiffness base methods with the aim of obtaining pavement deformation modulus ($E_{LWD}$ have shown better predictive ability of deformations). For instance LWD tests on geomaterials such as soils, aggregates, and asphalt had output of 35/60 $MP_a$ and 120/170 $MP_a$. As a quality control reference, LWD tests presents the user with information on longer life cycle pavement performance and predictive failure indicator time. Confirmation of such parametric evaluations follows the regressive test between LWD and other density/stiffness methods with better coefficient of determinations ($R^2$). For instance, as outlined in the work of aforementioned researchers investigation of Sandy soil regression-correlation on California bearing ratio (CBR) and $E_{LWD}$ by Dwivedi and Suman [4] gave $R^2$ values of 0.807 for unsoaked sand (US), 0.805 for soaked (S) sand and dry density 0.77 with the following relationship:

$$CBR_{(US)} = 0.0009{E_{LWD}}^2$$

$$CBR_{(S)} = 0.0001{E_{LWD}}^2 \quad (4)$$

$$\gamma_d = 1 \times 10^{-5}{E_{LWD}}^2$$

Quality controlled output limits using their coefficient of determination *($R^2$)* on lime based stabilized subgrade soil from correlative studies with $E_{LWD}$ by in the literature of Bisht, Dhar and Hussain [20] for unconfined compressive strength (UCS) at $R^2$ = 0.99 and CBR at $R^2$ = 0.93 showed the following relation:

$$UCS = 4.9E_{LWD} \tag{5}$$

$$CBR = 0.15E_{LWD} \tag{6}$$

Studies by Nazzal, Abu-Farsakh, Alshibli and Mohammad [21] on crushed limestone and sandy soil geomaterials gave $R^2$ value of 0.83 between CBR and $E_{LWD}$ with the following relation:

$$CBR = -14 + 0.66E_{LWD} \tag{7}$$

$$E_{v2} = (600 - 300)/(300 - E_{LWD-L_3}) \tag{8}$$

as a correlate between Static modulus of layer 2 ($E_{v2}$) and modulus of deformation measured by a Zorn LWD device with 300 mm diameter plate. Such stress/strain on flexible pavement layers often transfer elasticity modulus for determining pavement structural durability between layers. This is governed from the computation of road's elastic modulus ($E_{gen}$) based on 'g' the bearing capacity reserve of road bed and pavement in:

$$E_{gen} = \frac{E_1E_2\left[1 + \left(\frac{2h}{D}\right)^2\left(\frac{E_1}{E_2}\right)^{\frac{2}{3}}\right]^{\frac{1}{2}}}{E_1 - E_2\left\{1 - \left[1 + \left(\frac{2h}{D}\right)^2\left(\frac{E_1}{E_2}\right)^{\frac{2}{3}}\right]^{\frac{1}{2}}\right\}} \tag{9}$$

A similar correlation investigation on soil classification test between static modulus of pavement layer 1and deformation modulus using light weight deflectometer (LWD) by Alshibli, Abu-Farsakh and Seyman [22] showed a quality allowable $R^2-$value of 0.84. That of Rao, Shiva and Shankar [23] on subgrade geomaterials between CBR and $E_{LWD}$ gave an $R^2$ value of 0.90 with the following regression result;

$$E_{v1} = 0.91E_{LWD-P_3} - 1.81 \tag{10}$$

$$CBR = -2.754 + 0.2867E_{LWD} \tag{11}$$

where $E_{LWD-P_3}$ is the modulus of deformation measured by Prima 100 Cohesive and non-cohesive soils. Adam and Kopf [24] provided regression functions between static modulus of layer 1 ($E_{vI}$) and modulus of deformation from a Zorn LWD device with a 300 mm plate diameter. Deformation thresholds are predictable for quality control reasons for cohesive soils by the relationship:

$$E_{v1} = 0.833 \times E_{LWD-z3} \tag{12}$$

And for non-cohesive soils with the relation;

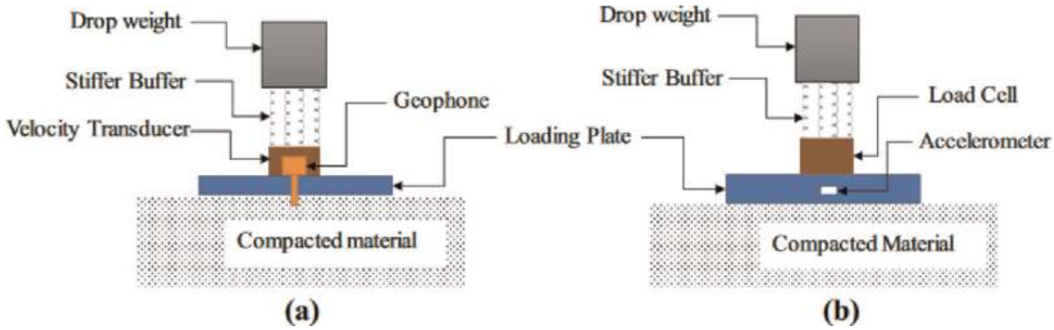


**Figure 2.**
*Schematic sketch of the location and type of transducer:* ***a*** *geophone measures velocity and is located on the compacted material,* ***b*** *accelerometer measures vibrations and is located in the plate. Photo credit: Duddu and Chennarapu [19].*

$$E_{v1} = 1.25 \times E_{LWD-z3} - 12.5(E_{LWD-z3}) \vee_{range} at 10 - 90 MPa \tag{13}$$

Quality control checks by light weight deflection (LWD) devices are conducted by velocity tracks using geophones or vibration tracks using accelerometer which is located on the test plate (see **Figure 2** from Duddu and Chennarapu [19]).

On the basis of limit state engineering designs, there are progressive failures at retail scales to yield a point of total failure beyond which roads become unserviceable to users before their expected lifetime span. Bazhanov and Saksonova [25] and Hassan and Sobhan [13] have shown that yield point in a quality impaired constructed road is attainable after a dynamic load is applied on pavements surface originating from a plastic deformation. Forms and types of road failures are shown in the accompanying **Table 2**.

According to Gupta [26], points of statistical references in reliability of pavement estimations are marked in the pavements failure rate (hazard rate) defined by:

$$r_F(k) = \frac{P(k)}{\sum_{i=k} P^{(i)}}, \tag{14}$$

$$\frac{P(X = k)}{P(X \leq k)}, k = 0, 1, 2, \ldots$$

With $P(k) = P(X = k)$ being the mass function, cumulative distribution function $f(k) = P(X \leq k)$ and pavement survival function $\bar{F}(k) = 1 - f(k)$ respectively. The pavements' mean residual life, $(\mu_F(k)$is indicated by estimation bias as:

$$\mu_F(k) = E(X - k | X \geq k) = \frac{\sum_{x=k} \bar{F}(x)}{F(k-1)}, k = 0, 1, 2, \ldots.. \tag{15}$$

This estimation is premised on the deterioration force of decrement on the pavement lifespan which bears representation in plastic deformation in other to understand pavement tolerance [27]. Consequently, the pavement failure rates or hazard rates which are competing in risk value by a mortal force of decrement with mean residual life of pavement are relationally obtained by:

$$r_f(k) = \frac{1 + \mu_f(k+1) - \mu_f(k)}{1 + \mu_f(k+1)} \tag{16}$$

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| Failure Type | Figure | Description |
|---|---|---|
| 1. Cracks | | |
| i. Alligator cracking |  | Originates from inadequate structural bends, poor drains. If poorly managed can deteriorate to potholes |
| ii. Transverse cracking |  | Originates from heavy traffic and poor materials mix design |
| iii. Block cracking |  | Originates from poor unstabilized base and defective ramming. This crack enables percolation of moisture and infiltration. |

| Failure Type | Figure | Description |
|---|---|---|
| iv. Longitudinal cracking |  | This form of crack is traceable to unstable base and defective construction. Moisture infiltration into the bed is prevalent. |
| v. Slippage Cracking |  | This form of crack failure originate from unstable wearing course and poor drainage |
| 2. Depression |  | This form of road failure is very visible with creter form of depression. Its occurrence is traceable to heavy rainfall and improper side drainage |

| Failure Type | Figure | Description |
|---|---|---|
| 3. Raveling |  | Failure is traceable to the inability of asphalt primers, binders and tack coats to hold aggregate in place, partial compaction and wearing off or weakening of asphalt binders. |
| 4. Potholes |  | Failure is attributed to the exposure of road structural members to gradual wearing by heavy vehicular loads due to accumulation of surface rain water from cracks on pavements. It produces visible three (3) dimensional failures of depth, width and length. |
| 5. Water Bleeding |  | Failure is occasioned by poor mix design of structural materials and with unsuitable binder. Failures of this nature lessens car skidding resistance. |

| Failure Type | Figure | Description |
|---|---|---|
| 6. Corrugation and Shoving |  | Failure is often associated with roughness and elevated sections of the pavement. Poor materials mix design, high traffic loads and unstable binders are most the causes of this failure |

**Table 2.**
*Types of road failure.*

$$1 - \frac{\mu_f(k)}{1 + \mu_f(k+1)}, k = 0, 1, 2, \ldots ..$$

The augmented pavements failure rate, mean residual life and its survival which are estimable consequences of an impaired engineering works is signified in a quality deficit index by relating the three statistical variables as:

$$\bar{F}(k) = \prod_{0 \le i \le k} [1 - r_f(i)]$$

$$\prod_{0 \le i \le k} \left[\frac{\mu_f(i)}{1 + \mu_f(i+1)}\right], \mu(0) = E(x) \quad (17)$$

Following the competing mortal forces of decrement on pavements with failure induced components yield from several real time traffic loadings, correspond to variations in the lifetime survival of pavement obtainable by:

$$\sigma_F^2(k) = Var(x - k \vee x \ge k)$$

$$k^2 + \frac{\sum_{i=k}^{\infty}(2i+1)\bar{F}(i)}{\bar{F}(k-1)} - \left(\frac{\sum_{i=k}^{\infty}\bar{F}(i)}{\bar{F}(k-1)} + k\right)^2$$

$$2\frac{\sum_{i=k}^{\infty}\bar{F}(i)}{\bar{F}(k-1)} - (2k-1)\mu_F(k) - \mu_F^2(k) \quad (18)$$

In order to idealize how quality is impaired by statistical reliability variables, the pavement's failure rate, mean residual life and variance residual life functions have causal aggregation and estimated by:

$$\sigma_F^2(k+1) - \sigma_F^2(k) = r_F(k)$$

Consequently, decreasing pavement variance residual life is X if X

$$\sigma_F^2(k+1) \le \mu_F(k)[1 + \mu_F(k+1)].$$

and it is an increasing variance residual life if

$$\sigma_F^2(k+1) \ge \mu_F(k)[1 + \mu_F(k+1)]$$

These statistical narrations in their numerical values are indicators of progressive failures with monotonicity properties for quality impairments assessment. In recent times, researches into deterioration rates of road pavements particularly in Riveros and Arredondo [28] and Al-Zahrani and Stoyanov [29] with transition probabilities indicated changes from one state to another (owing to deterioration). This illustrates precision predictability by Weibull distribution estimation. The probability density function are parametrized by $\propto$- and $\beta$- for which $(\propto > 0, \beta > 0)$ and given as:

$$F_{(t)} = \int_{\frac{\propto}{\beta}}^{o} \left(\frac{t}{\beta}\right)^{\propto - 1} exp\left[-\left(\frac{t}{\beta}\right)^{\propto}\right] \begin{matrix} fort < 0 \\ fort \ge 0 \end{matrix} \quad (19)$$

And its distribution function as:

$$F(x) = \int_1^0 exp\left[-\left(\frac{x}{\beta}\right)^{\propto}\right] \begin{matrix} forx < 0 \\ forx \geq o \end{matrix} \tag{20}$$

Under the Weibull test for pavement deterioration, expected values and variance are estimated by:

$$\mu = \beta^{-1}\left(1+\frac{1}{\propto}\right), \sigma^2 = \beta^2\left[\left(1+\frac{2}{\propto}\right) - {}^2\left(1+\frac{1}{\propto}\right)\right] \tag{21}$$

In this case, rather than Laplacian integral, the Weibull distribution is predicted on the gamma function

with:

$$((x))$$

$$(x) = \int_o^{\infty} t^{x-1}e^{-t}dtforx > 0 \tag{22}$$

This chapter deployed the use of Weibull test to obtaining the deterioration rates of selected Benin city roads in cluster from generating their deterioration model by linear regression having deterioration state as a dependent variable and pavement as an independent variable.

## 3. Methodology

In this research study, quality impairment in road construction was assessed by field investigation of eight (8) failing roads from a purposive sampling from 19 failed roads in the Benin city metropolis of Nigeria. Obtaining life right censored data through measurements of component failed depth, width and length with a start and end observation times were obtained. In achieving this, a seven (7) days growth rate study of failed portions in five (5) different field visitations at an interval of three (3) months for each visit was conducted to enable the capture of variation in growth rate between visits. The research team also engaged four daily undergraduate students to support obtaining measurements and controlling traffic. From the historical data gathered, mixed Weibull distribution software (Reliasoft Weibull$^{++}$) was used to analyze data goodness-of-fit test. Their reliability function was also tested in terms of their failure rate function and mean life function by estimating the parameters that makes the reliability function most closely fit the life data set. A review of the statistical criterion reference analytically for model fitness, shape parameters, assumed *βs* and graphically for fit to line, S-shape and minimum life was done from the reliability bathtub curve plot while computing their statistical function at 90% confidence bounds. **Tables 3–5** depict life data measurement of failed roads.

## 4. Results and discussion

**Figures 3–12** and **Tables 3–5** are discussed in this section.

**Figure 3.**
*Showing how water aids road failure.*

**Figure 4.**
*Showing how water aids road failure.*

**Figure 5.**
*Showing how failed portion of roads affects or increase journey time.*

**Figure 6.**
*Failed portion in Luckyway Road.*

**Figure 7.**
*Failed portion in Mission Road.*

**Figure 8.**
*Failed portion in New Benin Road.*

## 5. Weibull reliability test for the deterioration of the width of the roads in Lucky Way, Mission Road, New Benin Road, Ogida Road, Ring Road, Sapele Road, Technical College Road and Textile Mill Road

The shape parameter $\beta$ and the 95% confidence interval of $\beta$ for the data regarding the width of the roads in Lucky Way, Mission Road, New Benin Road, Ogida Road, Ring Road, Sapele Road, Technical College Road and Textile Mill Road are given in

**Figure 9.**
*Failed portion in Technical College Road.*

**Figure 10.**
*Failed portion in Textile Mill Road.*

**Figure 11.**
*Failed portion in Ogida/Upper Siluko Road.*

**Table 6**. The road is reliable and there is not enough evidence for the deterioration of the road if the shape parameter $\beta$ is close to 1 and the 95% confidence interval of $\beta$ contains 1.

There is enough evidence though for the deterioration of the width of the roads in Ikpoba Hill, Lucky Way, Mission, New Benin, Ogida, Ring, Sapele and Technical College since the value of $\hat{\beta} = 22.29$ from **Table 6** is far from 1, and the approximately 95% confidence interval for $\hat{\beta}[11.45, 43.40]$ does not contain 1. The plot of the failure

**Figure 12.**
*Failed portion in Upper Sapele Road.*

rate or hazard function, which describes the likelihood of deterioration in width during the next time increment is given in **Figure 13**.

There is a steeper increase after 225 days in the hazard function in **Figure 13**. This shows that the tendency of the width of the road to deteriorate increases after the 225th day. This is due to the value of $\hat{\beta} = 22.29$ being far from 1, and the approximately 95% confidence interval for $\hat{\beta}[11.45, 43.40]$ does not contain 1. The plot of the reliability test that shows the trend of reliability (the probability of the width of the road not deteriorating at time t) with time is given in **Figure 14**. The deterioration started after the 225th day. There was a sharp rate of deterioration (decrease in the reliability status) of the width of the roads in Lucky Way, Mission Road, New Benin Road, Ogida Road, Ring Road, Sapele Road, Technical College Road and Textile Mill Road after the 225th day.

## 6. Weibull reliability test for the deterioration of the depth of the roads in lucky way, Mission road, new Benin road, Ogida road, ring road, Sapele road, technical college road and textile mill road

The shape parameter $\beta$ and the 95% confidence interval of $\beta$ for the data pertaining to depth of the roads in Lucky Way, Mission Road, New Benin Road, Ogida Road, Ring Road, Sapele Road, Technical College Road and Textile Mill Road are given in **Table 7**. It may be stated the road is reliable and there is not enough evidence for the deterioration of the road if the shape parameter $\beta$ is close to 1 and the 95% confidence interval of $\beta$ contains 1.

There is enough evidence for the deterioration of the depth of the roads in Lucky Way, Mission Road, New Benin Road, Ogida Road, Ring Road, Sapele Road, Technical College Road and Textile Mill Road since the value of $\hat{\beta} = 22.50$ from **Table 7** is far from 1, and the approximately 95% confidence interval for $\hat{\beta}[10.02, 50.53]$ does not contain 1. The plot of the failure rate or hazard function, which describes the likelihood of deterioration in depth during the next time increment is given in **Figure 15**.

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| Routes | Serial No | 1st Visit | | | 2nd Visit | | | 3rd Visit | | | 4th Visit | | | 5th Visit | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Length (M) | Width (M) | Depth (M) | Length (M) | Width (M) | Depth (M) | Length (M) | Width (M) | Depth (M) | Length (M) | Width (M) | Depth (M) | Length (M) | Width (M) | Depth (M) |
| **Lucky Way** | 1 | 18 | 11 | 0.15 | 18.6 | 11 | 0.16 | 20 | 11 | 0.17 | 20 | 11 | 0.17 | 19.7 | 11 | 0.16 |
| | 2 | 6 | 2 | 0.23 | 6.8 | 2.2 | 0.23 | 7 | 4 | 0.24 | 7.3 | 4.2 | 0.24 | 7 | 3 | 0.24 |
| | 3 | 3 | 4 | 0.2 | 3.2 | 4.1 | 0.21 | 4 | 5 | 0.22 | 4.1 | 5.3 | 0.24 | 4 | 4.5 | 0.21 |
| | 4 | 135 | 11 | 0.1 | 137 | 11 | 0.11 | 141 | 11 | 0.12 | 141 | 11 | 0.12 | 139 | 11 | 0.11 |
| **Mission Road** | 1 | 2 | 3 | 0.1 | 2.3 | 3.7 | 0.11 | 2.5 | 4 | 0.12 | 2.5 | 4 | 0.12 | 2.4 | 3.9 | 0.11 |
| | 2 | 3 | 1 | 0.15 | 3.6 | 1.8 | 0.18 | 3.7 | 2 | 0.18 | 3.7 | 2 | 0.18 | 3.6 | 2 | 0.18 |
| | 3 | 5 | 2 | 0.089 | 5.3 | 2.3 | 0.1 | 6.2 | 3 | 0.11 | 6.2 | 3 | 0.11 | 6 | 2.5 | 0.1 |
| | 4 | 1 | 1 | 0.1 | 1.3 | 1.5 | 0.12 | 1.8 | 2 | 0.12 | 1.8 | 2 | 0.12 | 1.5 | 1.8 | 0.12 |
| | 5 | 1 | 1 | 0.076 | 2 | 1.7 | 0.097 | 2.4 | 2 | 0.1 | 2.4 | 2 | 0.1 | 2.2 | 1.9 | 0.097 |
| | 6 | 3 | 3 | 0.18 | 4 | 3.6 | 0.2 | 4.5 | 4 | 0.21 | 4.5 | 4 | 0.21 | 4.1 | 3.6 | 0.2 |
| **New Benin** | 1 | 2 | 3 | 0.051 | 2.2 | 3.8 | 0.61 | 2.7 | 3.9 | 0.071 | 2.7 | 3.9 | 0.071 | 2.5 | 3.9 | 0.066 |
| | 2 | 1 | 1 | 0.076 | 1.2 | 1.5 | 0.079 | 1.5 | 3 | 0.091 | 1.5 | 3 | 0.091 | 1.3 | 2.8 | 0.089 |
| **Ogida (Upper Siloku)** | 1 | 473 | 11 | 0.076 | 474 | 11 | 0.084 | 483 | 11 | 0.094 | 483 | 11 | 0.094 | 479 | 11 | 0.089 |
| | 2 | 204 | 8 | 0.051 | 205 | 8.2 | 0.061 | 208 | 8.5 | 0.066 | 208 | 8.5 | 0.066 | 208 | 8.3 | 0.061 |
| | 3 | 6 | 1 | 0.063 | 6.5 | 1.5 | 0.066 | 7 | 2 | 0.074 | 7 | 2 | 0.074 | 6.8 | 1.8 | 0.07 |
| | 4 | 5 | 2 | 0.058 | 5.1 | 2.1 | 0.061 | 6 | 2.5 | 0.074 | 6 | 2.5 | 0.074 | 5.3 | 2.3 | 0.07 |
| | 5 | 23 | 1.6 | 0.076 | 24 | 1.7 | 0.081 | 25 | 2 | 0.091 | 25 | 2 | 0.091 | 25 | 2 | 0.084 |
| | 6 | 4.7 | 1.5 | 0.089 | 5 | 2.5 | 0.1 | 5.2 | 3 | 0.1 | 5.2 | 3 | 0.1 | 5 | 2.8 | 0.1 |
| | 7 | 14 | 1.3 | 0.053 | 14.2 | 1.8 | 0.074 | 14.8 | 2 | 0.089 | 14.8 | 2 | 0.089 | 14.5 | 2 | 0.079 |

| Routes | Serial No | 1st Visit | | | 2nd Visit | | | 3rd Visit | | | 4th Visit | | | 5th Visit | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Length (M) | Width (M) | Depth (M) | Length (M) | Width (M) | Depth (M) | Length (M) | Width (M) | Depth (M) | Length (M) | Width (M) | Depth (M) | Length (M) | Width (M) | Depth (M) |
| **Ring Road** | 1 | 1 | 1 | 0.025 | 1.7 | 2.1 | 0.033 | 2 | 2.5 | 0.041 | 2 | 2.5 | 0.041 | 2 | 2.2 | 0.038 |
| | 2 | 2 | 4 | 0.13 | 2.3 | 4.6 | 0.14 | 2.4 | 4.9 | 0.13 | 2.4 | 4.9 | 0.13 | 2.3 | 4.7 | 0.13 |
| **Sapele Road** | 1 | 1 | 1 | 0.051 | 2.5 | 3.6 | 0.069 | 3 | 4 | 0.076 | 3 | 4 | 0.076 | 2.8 | 4 | 0.069 |
| | 2 | 2 | 3 | 0.13 | 5.6 | 6.2 | 0.13 | 6.9 | 7 | 0.13 | 6.9 | 7 | 0.13 | 6 | 6.7 | 0.13 |
| **Technical College Road** | 1 | 2 | 5 | 0.051 | 2.6 | 5.3 | 0.056 | 3 | 5.5 | 0.066 | 3 | 5.5 | 0.066 | 2.9 | 5.4 | 0.058 |
| | 2 | 1 | 1 | 0.1 | 2 | 1.7 | 0.1 | 2.2 | 1.9 | 0.12 | 2.2 | 1.9 | 0.12 | 2 | 1.9 | 0.11 |
| **Textile Mill Road** | 1 | 1005 | 11 | 0.22 | 1008 | 11 | 0.23 | 1010 | 11 | 0.23 | 1010 | 11 | 0.23 | 1008 | 11 | 0.23 |
| | 2 | 258 | 11 | 0.22 | 259 | 11 | 0.23 | 262 | 11 | 0.24 | 262 | 11 | 0.24 | 261 | 11 | 0.23 |
| | 3 | 50 | 9 | 0.22 | 50 | 9 | 0.23 | 53 | 9.3 | 0.24 | 53 | 9.3 | 0.24 | 50 | 9.2 | 0.24 |

**Table 3.**
*Life data measurement of failed road sections.*

| Routes | 2nd and 1st Visits | | | 3rd and 2nd Visits | | | 4th and 3rd Visits | | | 5th and 4th Visits | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Length (M) | Width (M) | Depth (M) | Length (M) | Width (M) | Depth (M) | Length (M) | Width (M) | Depth (M) | Length (M) | Width (M) | Depth (M) |
| **Lucky Way** | 0.6 | 0 | 0.01 | 1.1 | 0 | 0 | 0.3 | 0 | 0.01 | 0.3 | 0 | 0.01 |
| | 0.8 | 0.2 | 0 | 0.2 | 0.8 | 0.01 | 0 | 1 | 0 | 0 | 1 | 0 |
| | 0.2 | 0.1 | 0.01 | 0.8 | 0.4 | 0 | 0 | 0.5 | 0.01 | 0 | 0.5 | 0.01 |
| | 2 | 0 | 0.01 | 2 | 0 | 0 | 2 | | 0.01 | 2 | | 0.01 |
| **Mission Road** | 0.3 | 0.7 | 0.01 | 0.2 | 0.2 | 0 | 0.1 | 0.1 | 0.01 | 0.1 | 0.1 | 0.01 |
| | 0.6 | 0.8 | 0.03 | 0 | 0.2 | 0 | 0.1 | 0 | 0 | 0.1 | 0 | 0 |
| | 0.3 | 0.3 | 0.011 | 0.7 | 0.2 | 0 | 0.2 | 0.5 | 0.01 | 0.2 | 0.5 | 0.01 |
| | 0.3 | 0.5 | 0.02 | 0.2 | 0.3 | 0 | 0.3 | 0.2 | 0 | 0.3 | 0.2 | 0 |
| | 1 | 0.7 | 0.021 | 0.2 | 0.2 | 0 | 0.2 | 0.1 | 0.003 | 0.2 | 0.1 | 0.003 |
| | 1 | 0.6 | 0.02 | 0.1 | 0 | 0 | 0.4 | 0.4 | 0.01 | 0.4 | 0.4 | 0.01 |
| **New Benin Lagos Rd** | 0.2 | 0.8 | 0.01 | 0.3 | 0.1 | 0.005 | 0.2 | 0 | 0.005 | 0.2 | 0 | 0.005 |
| | 0.2 | 0.5 | 0 | 0.2 | 1.3 | 0.01 | 0.2 | 0.2 | 0.002 | 0.2 | 0.2 | 0.002 |
| **Ogida** | 1 | 0 | 0.008 | 5 | 0 | 0.005 | 4 | 0 | 0.005 | 4 | 0 | 0.005 |
| | 1 | 0.2 | 0.01 | 3 | 0.1 | 0.001 | 0 | 0.2 | 0.006 | 0 | 0.2 | 0.006 |
| | 0.5 | 0.5 | 0.003 | 0.3 | 0.3 | 0.004 | 0.2 | 0.2 | 0.004 | 0.2 | 0.2 | 0.004 |
| | 0.1 | 0.1 | 0.003 | 0.2 | 0.2 | 0.009 | 0.7 | 0.2 | 0.001 | 0.7 | 0.2 | 0.001 |
| | 1 | 0.1 | 0.005 | 1 | 0.3 | 0.003 | 0 | 0 | 0.007 | 0 | 0 | 0.007 |
| | 0.3 | 1 | 0.011 | 0 | 0.3 | 0 | 0.2 | 0.2 | 0 | 0.2 | 0.2 | 0 |
| | 0.2 | 0.5 | 0.021 | 0.3 | 0.2 | 0.005 | 0.3 | 0 | 0.01 | 0.3 | 0 | 0.01 |

| Routes | 2nd and 1st Visits | | | 3rd and 2nd Visits | | | 4th and 3rd Visits | | | 5th and 4th Visits | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ring Road** | 0.7 | 1.1 | 0.008 | 0.3 | 0.1 | 0.005 | 0 | 0.3 | 0.003 | 0 | 0.3 | 0.003 |
| | 0.3 | 1.4 | 0 | 0 | 0.1 | 0 | 0.1 | 0.2 | 0 | 0.1 | 0.2 | 0 |
| **Sapele** | 1.5 | 2.6 | 0.018 | 0.3 | 0.4 | 0 | 0.2 | 0 | 0.007 | 0.2 | 0 | 0.007 |
| | 3.6 | 3.2 | 0 | 0.4 | 0.5 | 0 | 0 | 0.3 | 0 | 0 | 0.3 | 0 |
| **Technical College Rd** | 0.6 | 0.3 | 0.005 | 0.3 | 0.1 | 0.002 | 0.1 | 0.1 | 0.008 | 0.1 | 0.1 | 0.008 |
| | 1 | 0.7 | 0 | 0 | 0.2 | 0.01 | 0.2 | 0 | 0.01 | 0.2 | 0 | 0.01 |
| **Textile Mill Road** | 3 | 0 | 0.01 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 |
| | 1 | 0 | 0.01 | 2 | 0 | 0 | 1 | 0 | 0.01 | 1 | 0 | 0.01 |
| | 0 | 0 | 0.01 | 0 | 0.2 | 0.01 | 3 | 0.1 | 0 | 3 | 0.1 | 0 |

**Table 4.**
*Alternate visit comparison showing deterioration rate.*

| Routes | Ltime | Wtime | Dtime | Lstatus | Wstatus | Dstatus |
|---|---|---|---|---|---|---|
| **Lucky Way** | 81 | 384 | 27 | 0 | 1 | 0 |
| | 39 | 42 | 165 | 0 | 0 | 0 |
| | 48 | 35 | 18 | 0 | 0 | 0 |
| | 62 | 380 | 54 | 0 | 1 | 0 |
| **Mission Road** | 68 | 36 | 58 | 0 | 0 | 0 |
| | 78 | 45 | 36 | 0 | 0 | 0 |
| | 49 | 85 | 45 | 0 | 0 | 0 |
| | 41 | 39 | 48 | 0 | 0 | 0 |
| | 40 | 31 | 75 | 0 | 0 | 0 |
| | 50 | 47 | 80 | 0 | 0 | 0 |
| **New Benin** | 65 | 49 | 65 | 0 | 0 | 0 |
| | 68 | 54 | 68 | 0 | 0 | 0 |
| **Ogida (Upper Siloku)** | 74 | 370 | 76 | 0 | 1 | 0 |
| | 72 | 62 | 16 | 0 | 0 | 0 |
| | 49 | 92 | 35 | 0 | 0 | 0 |
| | 68 | 88 | 65 | 0 | 0 | 0 |
| | 60 | 77 | 48 | 0 | 0 | 0 |
| | 38 | 74 | 49 | 0 | 0 | 0 |
| | 74 | 73 | 52 | 0 | 0 | 0 |
| **Ring Road** | 72 | 45 | 50 | 0 | 0 | 0 |
| | 69 | 65 | 385 | 0 | 0 | 1 |
| **Sapele Road** | 21 | 81 | 69 | 0 | 0 | 0 |
| | 92 | 70 | 378 | 0 | 0 | 1 |
| **Technical College Road** | 43 | 60 | 74 | 0 | 0 | 0 |
| | 25 | 42 | 132 | 0 | 0 | 0 |
| **Textile Mill Road** | 92 | 364 | 64 | 0 | 1 | 0 |
| | 88 | 388 | 63 | 0 | 1 | 0 |
| | 394 | 149 | 58 | 1 | 0 | 0 |

**Table 5.**
*Road deterioration status change.*

There is a steeper increase after 225 days in the hazard function in **Figure 15**. This shows that the tendency of the depth of the road to deteriorate increases after the 225th day. This is due to the value of $\hat{\beta} = 22.50$ being far from 1, and the approximately 95% confidence interval for $\hat{\beta}[10.02, 50.53]$ does not contain 1. The plot of the reliability test that shows the trend of reliability (the probability of the depth of the road not deteriorating at time t) with time is given in **Figure 16**. The deterioration started after the 225th day. There was a sharp rate of deterioration (decrease in the reliability status) of the depth of the roads Lucky Way, Mission Road, New Benin

| $\beta$ | LCL | UCL |
|---|---|---|
| 22.29 | 11.45 | 43.40 |

**Table 6.**
*The shape parameter $\beta$ and the 95% confidence interval of $\beta$.*

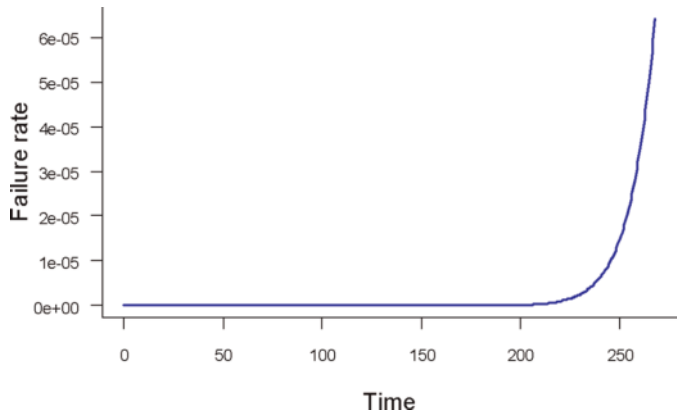


**Figure 13.**
*The failure rate or hazard function plot for the width of the roads.*

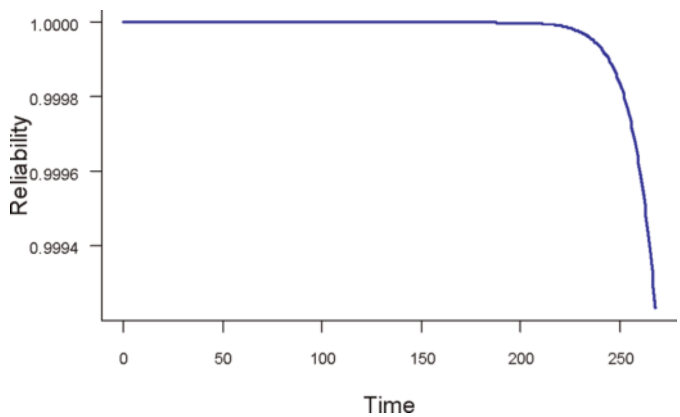


**Figure 14.**
*The reliability test plot for the width of the roads.*

| $\beta$ | LCL | UCL |
|---|---|---|
| 22.50 | 10.02 | 50.53 |

**Table 7.**
*The shape parameter $\beta$ and the 95% confidence interval of $\beta$.*

Road, Ogida Road, Ring Road, Sapele Road, Technical College Road and Textile Mill Road after the 225th day.

Weibull Reliability Test for the Deterioration of the Length of the Roads in Lucky Way, Mission Road, New Benin Road, Ogida Road, Ring Road, Sapele Road, Technical College Road and Textile Mill Road.

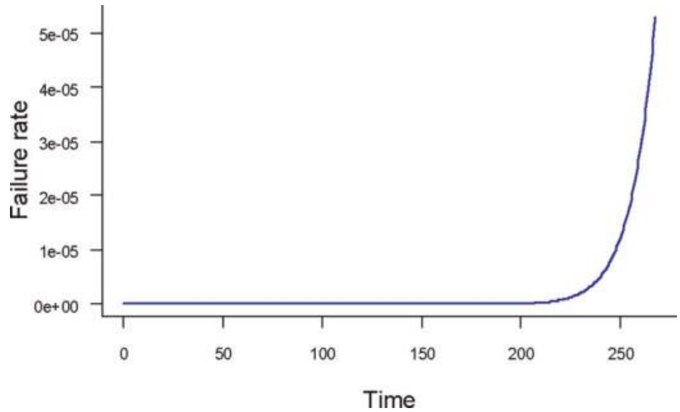


**Figure 15.**
*The failure rate or hazard function plot for the depth of the roads.*

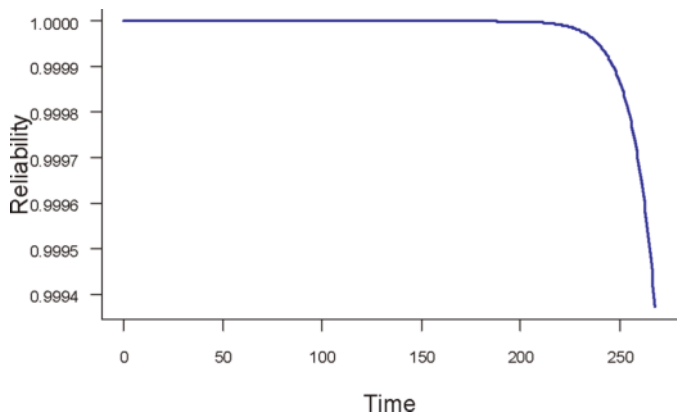


**Figure 16.**
*The reliability test plot for the depth of the roads.*

| $\beta$ | LCL | UCL |
|---|---|---|
| 6.71 | 2.50 | 17.99 |

**Table 8.**
*The shape parameter $\beta$ and the 95% confidence interval of $\beta$.*

The shape parameter $\beta$ and the 95% confidence interval of $\beta$ for the data on length of the roads in Lucky Way, Mission Road, New Benin Road, Ogida Road, Ring Road, Sapele Road, Technical College Road and Textile Mill Road are given in **Table 8**. The road is reliable and there is not enough evidence for the deterioration of the road if the shape parameter $\beta$ is close to 1 and the 95% confidence interval of $\beta$ contains 1.

There is sufficient evidence for the deterioration of the length of the roads in Lucky Way, Mission Road, New Benin Road, Ogida Road, Ring Road, Sapele Road, Technical College Road and Textile Mill Road since the value of $\hat{\beta} = 6.71$ from **Table 8** is far from 1, and the approximately 95% confidence interval for $\hat{\beta}[2.50, 17.99]$ does not contain 1. The plot of the failure rate or hazard function, which describes the likelihood of deterioration in length during the next time increment is given in **Figure 17**.

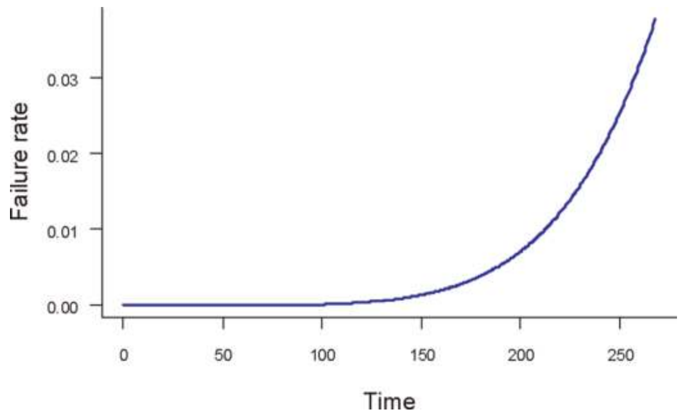


**Figure 17.**
*The failure rate or hazard function plot for the length of the roads.*

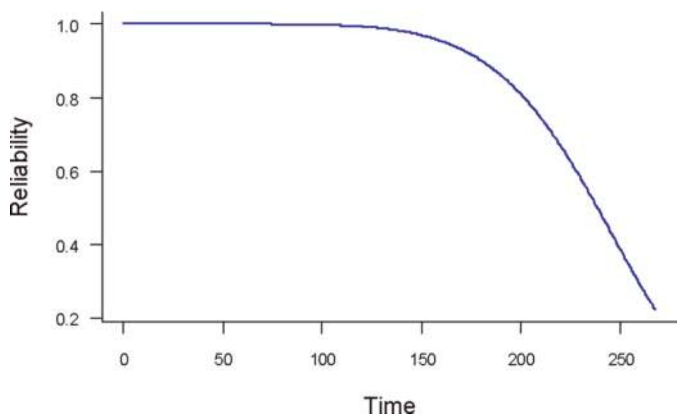


**Figure 18.**
*The reliability test plot for the length of the roads.*

There is a steeper increase after 140 days in the hazard function in **Figure 17**. This shows that the tendency of the length of the road to deteriorate increases after the 140th day. This is due to the value of $\hat{\beta} = 6.71$ being far from 1, and the approximately 95% confidence interval for $\hat{\beta}[2.50, 17.99]$ does not contain 1. The plot of the reliability test that shows the trend of reliability (the probability of the length of the road not deteriorating at time t) with time is given in **Figure 18**. The deterioration started after the 100th day. The rate of deterioration was minimal between the 100th to $150^{th}$day; after the $150^{th}$day, there was a sharp decline in the reliability status (increase in the deterioration rate) of the length of the roads in Lucky Way, Mission Road, New Benin Road, Ogida Road, Ring Road, Sapele Road, Technical College Road and Textile Mill Road.

## 7. Conclusion

In this study, eight (8) roads from Nineteen (19) mapped failing roads by means of purposive sampling the Benin city area of Edo state in Nigeria were assessed. Data collection follows five different routes in five (5) different field visitations at intervals of three (3) months for each visit. During visits variational failure growth in terms of length, width and depth was obtained by tape rule measurements, rolling measuring rule, pegs, paints and photographs. Data collected were scrutinized and subjected to Weibull analysis to obtain road failure-specific sequences in reliability terms to validate and underscore quality impairments in constructed road pavements. Quality impairments originating from road component materials failure were evident in roads failing as early as six (6) months after construction. Progressive failure was noticed to be aided by further deterioration owing to lack of maintenance according to the types of road failures photographed in this paper. This is further augmented by relation to monotonicity failure theory elucidated in Gupta [26] with steady state progressive deterioration shown in the bathtub log-convexity property of the Weibull measurement count. A validation of quality impairment was deduced from a degenerating reliability Weibull analysis as corroborated in the literature of Efimenko and Moisejenko [2] and Bazhanov [5]. By undermining quality control process at construction, steep failures from a deteriorating pavement aided by the stress/strain mortal force of decrement prevailed early enough in the lifetime of the pavement to cause road failure.

## 8. Recommendation

Arising from the study and the observations and analysis conducted, the following recommendations are made:

1. It is recommended that quality control should be acculturated in organizations specializing in road construction and set-up procedures and instruments for quality control at points of raw materials storage including blending, mixing and placing of asphalts.

2. Deploy a quality control metrics for checking the level of quality-specific work output during the entire construction process.

3. Evolve a quality and maintenance sequence of road construction for every and any activity in the construction process.

4. Overhauling and maintaining construction equipment as required in the ISO 9002 Quality Assurance Framework. This will enable equipment work optimally especially laboratory equipment so as measurements and investigations can be precise

5. Setting site and organization's agenda around QA/AC needs at project review phase and staff meetings. This aspect of quality management encourages team building and common purpose focus towards quality objective.

6. Go round site supervision with Engineers Instruction cards to direct the rework of construction defects. This is with the aim of ensuring that site instructions for defective works are carried out without omission.

7. Allow proper physical and chemical properties limits of materials to be attained before use, in order to avoid materials failure. It will also help in quality enhancement of finished output.

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