# INCORPORATION OF RELIABILITY INTO NIGERIAN EMPIRICAL MECHANISTIC PAVEMENT ANALYSIS AND DESIGN SYSTEM (NEMPADS)

BY

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## Dedication

This work is dedicated to my beloved parents Mr. Musa and Late Salamatu Sada (may her soul rest in peace), my lovely wife, Mrs. Maryam Abubakar Bayero, and My lovely daughters, Khadija and Fatima.

## Declaration

I hereby declare that this thesis has been composed by me and that it is a record of my own research work. This has not been accepted in any previous application for a degree anywhere. However, as it is required by research laws and ethics, all sources of information are specifically acknowledged by means of references.

…….

Muhammed Mustapha Musa

## Certification

This thesis titled "INCORPORATION OF RELIABILITY INTO NIGERIAN EMPIRICAL MECHANISTIC PAVEMENT ANALYSIS AND DESIGN SYSTEM (NEMPADS)" by MUHAMMED MUSTAPHA MUSA, meets the requirement governing the award of the degree of master of science of the Department of Civil Engineering, Ahmadu Bello University Zaria, and is approved for its contribution to knowledge and literary presentation.

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Musa M.M.

## Abstract

This work was aimed at providing the most appropriate Nigerian Empirical-Mechanistic Flexible Pavement Analysis and Design method (NEMPAD) by incorporating Reliability, using First order reliability method (FORM), considering all the input variabilities, uncertainties, and seasonal variations, with the aid of Matlab to express the algorithms. A frame work was developed for computation of component reliability index (R.I), system reliability index (R.I), and probability of failure. Inputs parameters considered includes: traffic load, material properties, and environmental conditions. Four seasons were considered in the design namely: *Hunturu*(1 week Dec-2 week Feb), *Bazara*(2 week Feb-2 week May), *Damina*(2 week may-1 week Oct), and Kaka(1 week Oct-1 week Dec) seasons, for the North West geographical zone, and the cumulated damage was computed for each season. Comparism was made between deterministic and reliability methods. The results indicates that at coefficient of variation (COV) of 25% , a surfacing thickness of 100mm (representing wearing and binder course), 165mm thickness of Base course material, and 180mm thickness of sub base course material, are adequate, while at coefficient of variation (COV) of 42% a surfacing thickness of 100mm (representing wearing and binder course), 200mm thickness of Base course material, and 250mm thickness of sub base course material, are adequate, as against the deterministic method cited in Olowosulu (2005),where higher thicknesses were used, under the same traffic load and conditions. The results also indicated that highest level of damage with respect to fatigue was recorded during *Bazara* season due to the effects of Temperature, while highest level of damage with respect to Rutting was recorded during *Damina* season due to the effects of water in the subgrade.

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## LIST OF SYMBOLS/ABBREVIATIONS

| | |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| ADT | Average Daily Traffic |
| AMV | Advanced Mean Value |
| ASTM | American Society for Testing and Materials |
| CBR | California Bearing Ratio |
| COV | Coefficient of Variation |
| DDF | Direction Distribution Factor |
| E | Elastic modulus |
| ELSYM-5 | Elastic Layered System Five |
| ESAL | Equivalent Single Axle Load |
| FORM | First Order Reliability Method |
| FOSM | First Order Second Moment |
| FTG | Future Total Growth Factor |
| HMA | Hot-Mix Asphalt |
| LDF | Lane Distribution Factor |
| LEA | Layered-Elastic Analysis |
| MATLAB | Matrix Laboratory |
| MCS | Monte Carlo Simulations |
| E-M | Empirical Mechanistic |
| MEPDG | Mechanistic Empirical Pavement Design Guide |
| Mn/Road | Minnesota Road Research |
| $M_R$ | Resilient Modulus |
| $M_{RB}$ | Resilient Modulus of Base Layer |

| | |
|---|---|
| $M_{RSB}$ | Resilient Modulus of Sub base Layer |
| MVFOSM | Mean Value First Order Second Moment |
| NCAT | Nigerian College of Aviation Technology |
| NEMPADS | Nigerian Empirical-Mechanistic Pavement Analysis and Design System |
| $N_F$ | Fatigue Allowable Number of Equivalent Single Axle |
| $N_R$ | Rutting Allowable Number of Equivalent Single Axle |
| PEM | Point Estimate Method |
| PEU | Pavement Evaluation Unit |
| Qf | Total Number of Vehicles Over the Design Period |
| R.I | Reliability Index |
| SORM | Second Order Reliability Method |
| Et | Horizontal tensile strain at the bottom of the bituminous layer |
| $E_V$ | Vertical compressive strain at the top of the sub-grade |

# CHAPTER ONE

# INTRODUCTION

## 1.1 BACKGROUND

Traditionally, flexible pavement thickness design has been accomplished throughempirically based procedures. One well-known procedure, the American Association ofState Highway and Transportation Officials (AASHTO,1993) method, was based upon theAASHTO Road Test held in Illinois between 1958 and 1960. The designprocedure utilized empirical relationships developed from the AASHTO road test and istherefore limited to the conditions of that test. In fact, all empirically based methodsshare the same common disadvantage in that they are limited to the conditions andobservations of the particular road sections on which the procedure was based. This factmay require engineers to extrapolate outside the original inference space, which could beproblematic.As a result of this limitation, many pavement sections failed prematurely while other sections far outlived their design lives(Rutherford, 2012)

Conversely, Empirical-Mechanistic (M-E) design is more robust since it combinesthe elements of mechanical modeling and performance observations in determining therequired pavement thickness for a set of design conditions. The Empirical-Mechanistic Empirical-Mechanisticbased method of pavement design is based on the mechanics of materials,which relates inputs such as wheel loadsto output such as pavement response.The response is then used to predict pavement distresses(including cracking)and other performance based laboratories and field testing outcomes.In essence, M-E design has the capability of changing andadapting to new developments in pavement design by relying primarily on the mechanicsof material (Timm*et al*, 1999).

The induced state of stress and strain in a pavement structure due to traffic loading and environmental conditions is predicted using theory of mechanics. Empirical models link these structural responses to distress predictions. The Analytical-Empirical (or Empirical-Mechanistic) approach to design of flexible pavements has two steps, as implied by the name. In the first step the critical stresses or strains (the response) in the individual pavement layers are calculated using an analytical model, and in the second step they are compared to permissible stresses or strains. In the more sophisticated versions, the critical stresses or strains are used for determining the rate of deterioration (the performance).

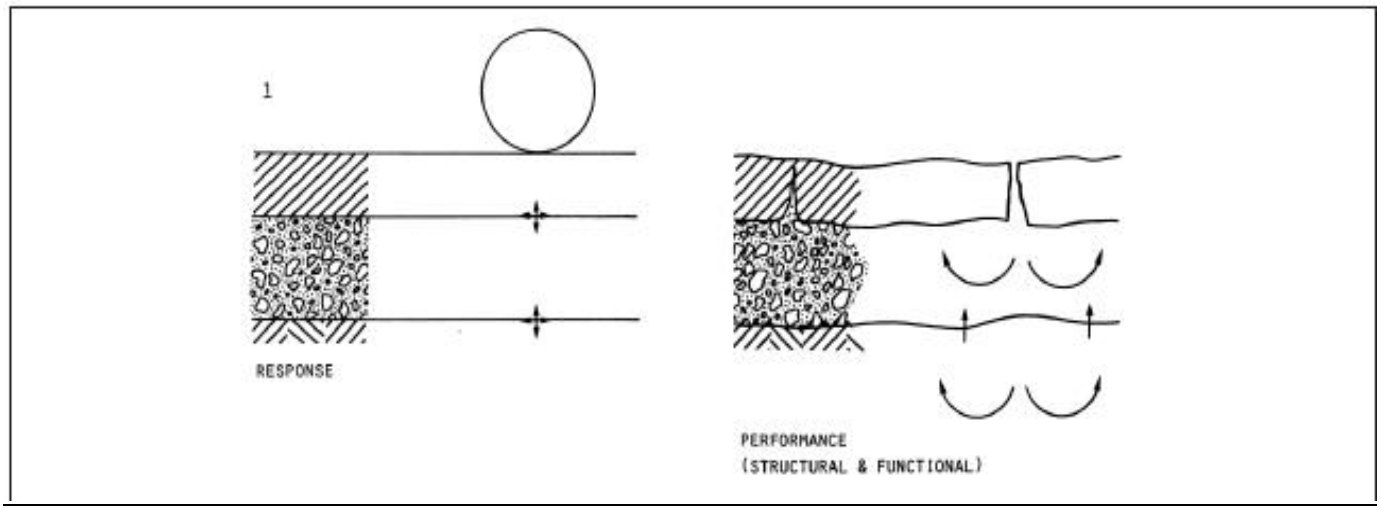



Fig. 1.1: Pavement response (analytical) and performance (empirical)

On the other hand,there are many definitions concerning the term reliability." In the general sense,reliability implies trustworthiness or dependability. When applied to structural pavementdesign**,** the 1993 AASHTOGuide defines reliability in this way *(AASHTO, 1993):*"The reliability of a pavement design-performance process is the probability that a pavement section designed using the process will perform satisfactorily over thetraffic and environmental conditions for the design period**."**

"To provide uniformity, pavement design reliability is defined as the probabilitythat the pavement's traffic carrying capacity exceeds the cumulative traffic loading onthe pavement during a selected design life."The above statement may be expressed mathematically as Kulkarni*1994)*

$R = P[N > n]$ (1.1)

Where "N" is the traffic load capacity of the pavement structure and "n" is the actualnumber of load applications. Design of flexible pavement involves many uncertainties, variabilities, and approximations regarding material properties, traffic loads, subgrade strength,drainage conditions, construction and compaction procedures and climatic factorssuch as temperature, rainfall, and snowfall, etc.The combination of the variances associated with inputvariables contributes to components and system uncertainty, and this combinationof variances can have a significant effect on the predicted performanceof the pavement. Reliability in pavement design isintroduced to consider these uncertainties..Advantages of usingreliability includes the calibration of new design methods, developing rational designspecifications, optimizing resources, and assessing the damage and remaining life of thepavement. For example, M-E methods can adapt to new design conditions (e.g., heavierloads, new pavement materials) by relying primarily upon mechanistic pavementmodeling.

While Monte carlo simulation (MCS) is by far the most accurate reliability approximationtechnique available, several other techniques have been employedin the structural reliability community, including those that haveachieved accuracy close to that of MCS for many practical engineeringdesign problems but require few model evaluations toimplement. Some examples includes:Point Estimate methods(PEM), the Mean value First-order secondmoment (MVFOSM), first-order reliability methods (FORMs),Rosenblueth, and advanced mean value (AMV) (Cornel *et al, 1975*).

## 1.2 STATEMENT OF PROBLEM

A Empirical-Mechanistic (M-E) pavement analysis and design has been proposed for use in Nigeria (Olowosulu, 2005;Murana, 2010;and Yakubu,2011). There is statistical variation in the input parameters. Consequently, there is variability in the calculated stresses and strains that lead to variations in the number of allowable loads. There is also variability in the number of expected loads during the design period. Finally, there is variability in regard to the transfer functions that predict pavement life (Timmet al, 1999). So there is need to incorporate reliability analysis into the design of pavement systems in order to improve the accuracy of pavement life prediction.

## 1.3 AIM AND OBJECTIVES

### 1.3.1 Aim

Theaim of this research is to improve the Nigerian Empirical- Mechanistic pavement analysis and design system (NEMPADS) by incorporating reliability into the methodology.

### 1.3.2 Objectives

i. To generate stresses and strains using a Multilayer elastic computer programme,ELSYM-5.

ii. To compute the allowable stresses in terms of Fatigue and Rutting failures using distress sub-models developed in NEMPAD.

iii. To calculate theaccumulated damage in each season due tofatigue and rutting.

iv. To calculate the reliability index usingFirst order Reliability method(FORM)andthrough a developed program in MatLab.

v. To perform systemreliability analysis using fatigue and rutting data as inputs.

In order to achieve these objectives, the relevant design input variables were identified and there variability statistically characterized.

## 1.4 SCOPE OF THE STUDY

The First order reliability method(FORM) is used to incorporate reliability into the existing Nigerian Empirical-Mechanistic pavement analysis and design, using NEMPAD Fatigue and Rutting distress model equations, and the data is obtained from Kaduna - Kano road project ,1987 (CH 25+000 TO CH35+000).

## 1.5METHODOLOGY

Material properties, Traffic load, and climatic condition, are enteredinto a load-displacement model (ELSYM-5) that calculates stresses and strains at critical locations.The calculated stresses and strains are used to compute the number of allowable loadsuntil failure, while the number of expected loads for each particular condition is also determined, the effects of variabilities of the inputs are determined using Reliability(first order reliability method, FORM).

## 1.6 SIGNIFICANCE OF THE STUDY

The significance of this study is to improve the accuracy of the pavement life prediction by incorporating reliability analysis into the design of pavement system.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 GENERAL

On Empirical- Mechanistic analysis and design ,similar Research work was carriedout by Timm*et al* (1999),in their paper titled “Incorporation of Reliability into the Minnesota Empirical-Mechanistic pavement design method”published by Minnesota department of Transportation office of research services,where a reliability method;Monte carlo simulation was used and incorporated into Empirical-Mechanistic flexible pavement design method for Minnesota.The research paper includes a comprehensive literature review of the state-of-the-art research. The Minnesota Road Research Project(Mn/ROAD) served as the primary source of data, andthe researchers quantified the variability ofeach pavement design input and developed a rational method of incorporating reliability analysis into the E-M procedurethrough Monte Carlo simulation.

Timm*et al* (1999) adapted the existing computer program, ROADENT in their work, this allowed the designer to perform reliability analysis forfatigue and rutting. Based upon theirfindings presented in their paper, the followingconclusions and recommendations were made.

1. Monte Carlo simulation is an effective means of incorporating reliability analysisinto the M-E design process for flexible pavements.

2. The resulting distributions of fatigue life and rutting life, obtained from MonteCarlo simulation using the input distributions, are governed byan extreme valuetype I function.
3. For most practical design scenarios, the number of Monte Carlo cycles should beset at 5,000**.** However, the designer may use his or her judgment to adjust thenumber of cycles accordingly.
4. The reliability analysis scheme used in ROADENT produced consistent estimatesof reliability when compared to the AASHTO (1993) design guide when ruttingperformance was considered.
5. The fatigue transfer function produces reliability estimates inconsistentwith observed performance in Minnesota and the AASHTO 1993 guide. Furtherrefinement of the function is required to improve the reliability estimates.

Another research work was carriedout by AGuiar,*et al* (2011)worked on "Development of reliable pavement models"Which proposed a framework for estimating the reliability of a given pavement structure as analyzed by the Empirical-Mechanistic Pavement Design Guide (MEPDG). The methodology proposes using a previously fit response surface, in place of the time-demanding implicit limit state functions used within the MEPDG, in combination with an analytical approach to estimating reliability using First-Order and Second-Order Reliability Methods (FORM and SORM). Additionally, in order to assess the accuracy of the FORM and SORM reliability estimates, Monte Carlo simulations were also performed.

Olowosulu(2005) alsodeveloped a Frame work for Empirical-Mechanistic Pavement Design for Tropical Climate In Nigeria. The study developed a multi layer elastic theory software,ELSYM-5, for calculating stresses and strains, that is,the horizontal tensile strain($E_t$) at the bottom of the asphalt pavement,and the vertical compressive

strain(Ev) at the top of the subgrade. The results obtained from ELSYM-5 were entered into Fatigue and Rutting Distress Sub models (Claros *et al*,1986)in order to calculate the allowable number of equivalent single axle (NF) and (NR) in terms of Fatigue and Rutting respectively. Miner's (1945)hypothesis theory equationwas used to calculate the cumulative damage due to stress and strains generated.. Failure occured when damageexceeded unity, in which case the layer thicknesses were increased. If damage is much lessthan unity, the pavement has been over-designed and the layer thicknesses should be decreased. When damage is near but not exceeding unity the design thickness hasbeen achieved.

Murana (2010) furthered aimed at providing most appropriate Pavement Performance distress model for the prediction of pavement fatigue and rutting life in the "NEMPADS". Empirical-Mechanistic simulation analysis based on some reliability levels in comparison with existing ones was carried out. Nine fatigue distress models and seven rutting distress models were evaluated for the Nigerian environment. Monte carlo simulation was used as a method of reliabilitywhereby simulation cycles was set at 2, 200 threshold to provide sufficient repeatability for a damage reliability relationship. The results from the parametric study demonstrated that both the Transport and Road Research Laboratory distress model at 60.82% show the most promising in terms of development and quick prediction for pavement reliability, and hence recommended it as Model for NEMPAD. Also, the Indian rutting distress model at 93% shows the highest promise for the same situations, which was also recommended as model for NEMPAD. Murana (2010) observed that axle weight has an overwhelming effect on the output variability as an increase in the applied load was highly noticed in the reliability values which therefore deserve more careful characterization practice.

Yakubu (2011) developed a procedure for quantifying the effect of climatic factors, sub-surface environmental conditions and pavement material mechanical properties for use in a Mechanistic–Empirical (M–E) design procedure using the Northwest geographical zone of Nigeria as case study. Data for the study was obtained from the Pavement Evaluation Unit (PEU) of the Federal Ministry of Works and Transport Office in Kaduna. Climatic and precipitation data were obtained from the Nigeria Meteorological Agency Offices of the Nigeria College of Aviation Technology (NCAT), Zaria and the MallamAminu Kano International Airport, Kano. Yakubu (2011) identified four seasons in the study and they are:*Hunturu*, *Bazara*, *Damina*and *Kaka*. Seasonal factors were then generated for the study.

Finally, the following also, worked in the relevant area: Zheluo and Radney (2014), Al-sugair and Almuldaiheem (1992), Young-chan*et al* ( 2013), Animeshi and Pandey (1999),Yijuan*et al* (2013), Bjereger (1990) ,Sean *et al* (2013), Brown and Foo (1991), Giulio*et al* (2012), Bruce (2001), Horald and Quintus (2007),Craus*et al* (1984), Arphan (2013) ,Darter and Hudson(1973), Neethu*et al* (2013), Ditlevson and Madsen (2005), Iswandaru (2008), Faver and Sorensen (2002), Joseph and James (2012),Hadley et al(1994), Hyung and Neeraj (2003), Hasofer and Lind (1974), Bans and Stires (2010), Heukelom and Klomp (1962), Theysee*t al* (1996), Huang (1993), Grahams and Tailor (1998), Harr (1987), Ali (2005), Irick*et al* (1987), Jennifer and Mark (2010), Jian-shiu*et al* (2004),Lusun and Fasce (2003), Jooste (1999), Amanda and Jeffery(2009), Joao *et al* (2008),Theyse (1994), Kher and Darter (1973), Uzan*et al* (1990), Lemer and Moavenzadeh (1971), Van (1988), Lusun et al (2003), Van (1994), Murana and Olowosulu (2012a),Yoder and Widzack (1975), Murana and Olowosulu (2012b), Reynoldo (2008), Roberts *et al* (1996),Rosenbluith (1975), and , Ronald *et al* (2006).

## 2.2TRANSFERFUNCTIONS

The empirical component of M-E design is pavement life equation, known as a transfer function. Transfer function use pavement responses calculated by the mechanistic model and predict the life of pavement in terms of fatigue cracking or rutting. It acts as a chain between the pavement reactions and appeared damages in the pavements (Ameri and Khavandi, 2009). It relatesthepavementresponses determinedfrommechanisticmodelstopavementperformanceas measuredbythetypeandseverityofdistress(rutting,cracking, roughness,andsoforth) (Thompson and Nauman, 1993).

## 2.3 RELIABILITY METHOD

### 2.3.1First Order Reliability Method (FORM)

The FORMare an improvement to the FOSM method andrequire additional computation. The FOSM method has a numberof deficiencies, one of which is the absence of the probabilistic distributionproperties of the random variables. A FORM uses the variable properties, transforms all the variables into equivalent normalvariates, and ultimately determines the reliability index by solvingfor the limit state defined by the performance function. Thereare multiple methods of solving FORM. The FORM I method (Rackwitz,*1976*) requires an iterative approach, and the FORM II method(Rackwitz *and*

fiessler,*1978*) incorporates an algorithm to solve for the reliability index. Athird method, FORM III, uses a generalized reduced-gradientsearch algorithm and is implemented with the solver function inMicrosoft Excel.

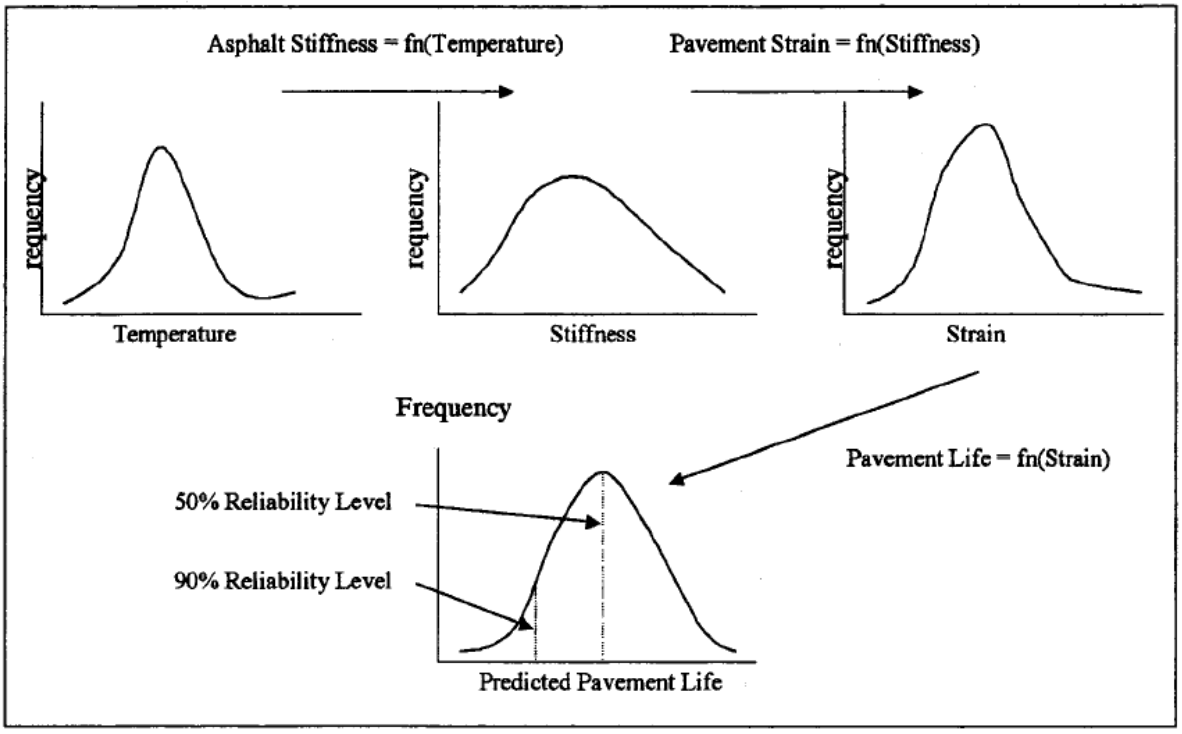



Figure 2.1: Example of Variability and Reliability

A simple example of how the variability of the inputs can be related to thevariability of the output, and ultimately reliability, is depicted in Figure 2.1 In thisexample, the predicted pavement life is a function of the pavement strain, which is afunction of the asphalt stiffness, which is a function of the asphalt temperature. Since theasphalt temperature is variable, it follows that the pavement life would also exhibit variability. The reliability may then be interpreted as the probability of the pavement structure exceeding some level of project life.

# CHAPTERTHREE

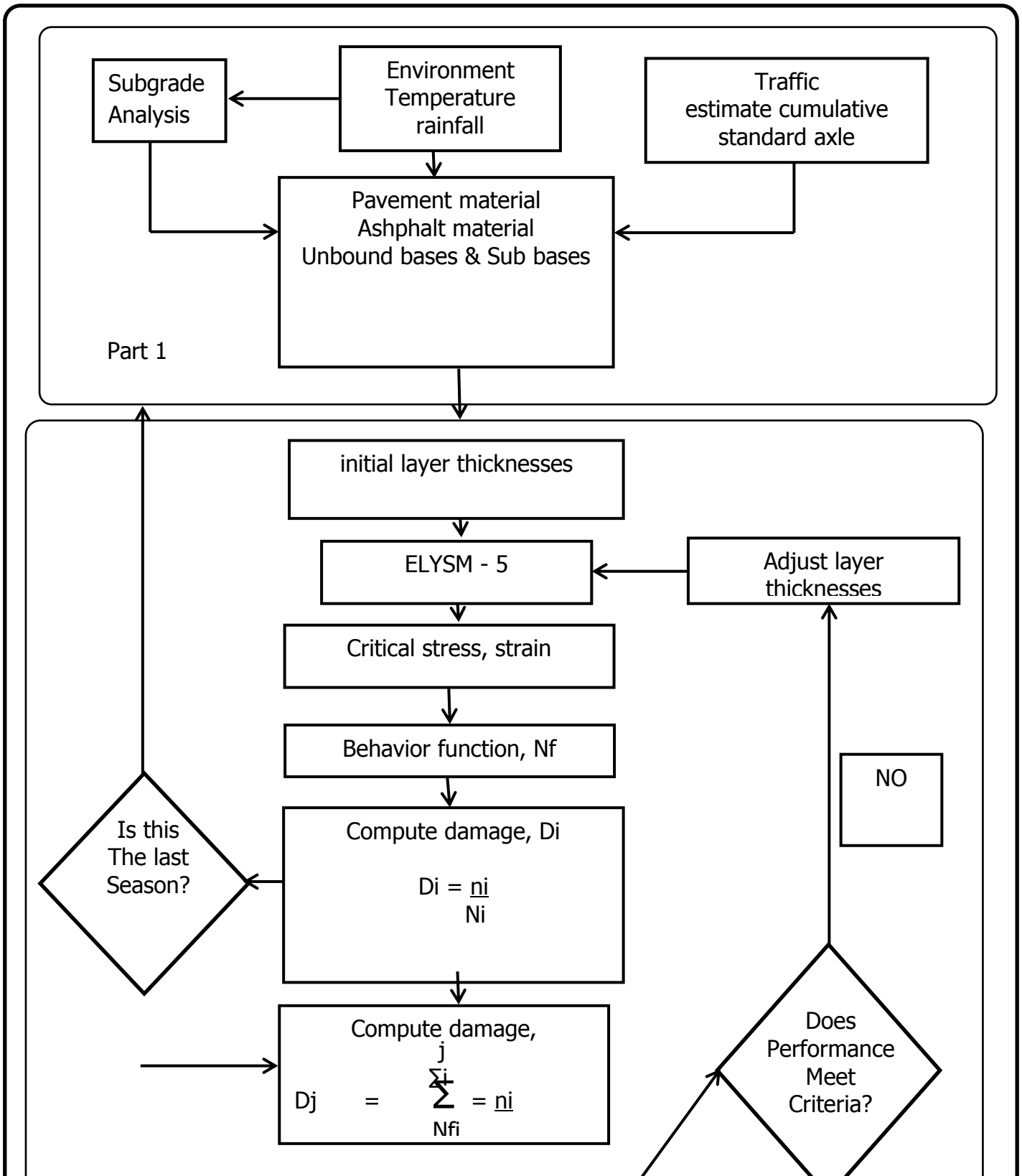
# METHODOLOGY

## 3.1 INTRODUCTION

**A**Empirical-Mechanistic (M-E) flexible design methodology has been proposedfor use.A flow chart depicting the procedure is shown in Figure **3.1**and a brief summary of the process is described below:Material properties, Traffic load, and climatic condition, are enteredinto a load-displacement model (ELSYM-5) that calculates stresses and strains at critical locations.The calculated stresses and strains are used to compute the number of allowable loadsuntil failure, while the number of expected loads for each particular condition must alsobe determined, the effects of variabilities of the inputs are determined using Reliability(first order reliability method, FORM). This process is then iterated for each seasonal condition and loadconfiguration and the accumulated damage is summed. Failure occurs when damageexceeds unity, in which case the layer thicknesses are increased. If damage is much lessthan unity, the pavement has been over-designed and the layer thicknesses should be decreased. When damage is near but not exceeding unity the design thickness hasbeen achieved.

A reliability method known as first order reliability method(Form) is used in this research.Design inputs includes:Traffic load, Material properties,and Environmental condition.

The data is obtained fromPavement Evaluation unit (PEU) for the 10KM (CH 25+000 to CH 35+000) length of the road, from Rigachikun, PEU, Federal Ministry of Works Kaduna , Kaduna- Kano road project,1987. It is in guinea savannah area and has an annual rainfall of between 1, 250 and 1, 500mm, and weighted annual air temperature of about 26 degrees. Other input values required for the road for 15 years are as shown in Table 3.1



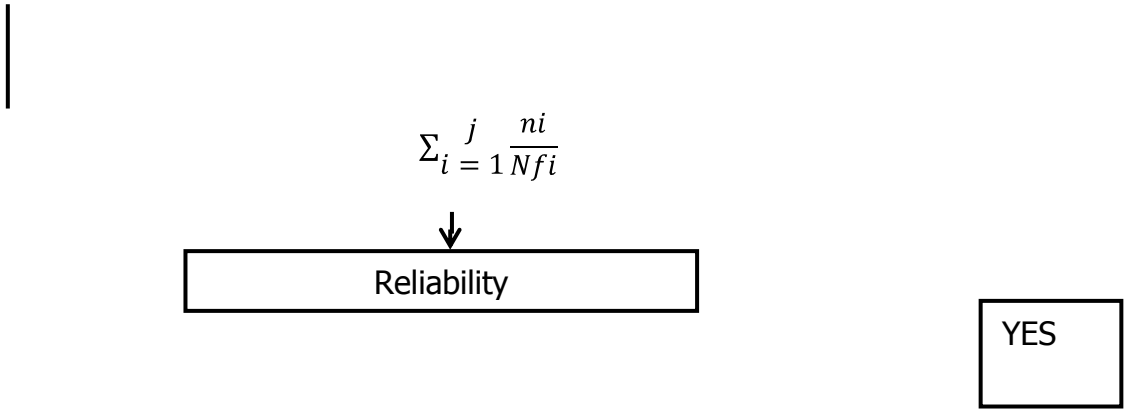



Table 3.1: Input Values for Empirical-Mechanistic Pavement Design

| Traffic | | Modulus | | Poisson ratio | |
|---|---|---|---|---|---|
| Average daily traffic | 1818 | Asphalt surfacing | 4827 | Asphalt surfacing | 0.35 |
| Percent trucks | 27.4 | | | | |
| Average load equivalence factor | 3.35 | Base | 551 | Base | 0.40 |
| Directional distribution factor | 0.5 | Sub-base | 344 | Sub-base | 0.40 |
| Lane distribution factor | 1.0 | Sub-grade | 193 | Sub-grade | 0.45 |
| Annual traffic growth rate | 5% | | | | |

Source: Olowosulu, (2005).

In Olowosulu (2005) a research on Nigerian empirical mechanistic pavement analysis and design ,NEMPAD, was conducted using the above mentioned data.

Yakubu (2011) used these same data to generate the effect of on the mechanistic empirical flexible pavement design, where Modulus seasonal factors were generated. In Murana (2010) different distress models for both Fatigue and Rutting were evaluated, and was able to establish theNEMPAD Fatigue and Rutting distress model equations.

In this project, the data demonstrated in Olowosulu (2005),Modulus seasonal factors

generated in Yakubu (2011),and recommended NEMPAD Fatigue and Rutting distress model equations evaluated in Murana(2010) were used, in order to incorporate reliability into the EmpiricalMechanistic flexible pavement design, so that comparism can easily be made in the accumulated damage.

### 3.2 METHODOLOGY

The first step in the M-E design procedure is to calculate the number of cumulative Equivalent Single Axle Load (ESAL) for each season expected to be carried on the design lane over the design period, which is estimated using the conventional formula in which seasonal variation was incorporated. Secondly, layers trial thicknesses, poison ratio, modulus of elasticity ,and modulus seasonal factors were entered into a multi layer elastic theory software,ELSYM-5,which in turn were used to calculate the Horizontal tensile strain($E_t$) at the bottom of the Asphalt pavement,and the vertical compressive strain(Ev) at the top of the subgrade for each season.Then the results obtained from ELSYM-5 were entered into Fatigue and Rutting Distress models in order to calculate the allowable number of equivalent single axle (NF) and (NR) in terms of Fatigue and Rutting respectively. Miner's(1945) hypothesis theory equation was used to calculate the cumulative damage due to stress and strains generated.Ultimately, the following stepsOf First Order Reliability Method(FORM) were followed to obtain Hasofer-Lind Reliability index(β).

1. Formulate the limit state function and appropriate parameters for all random variables involved.
2. Express the limit state function in terms of reduced variables $Z_i$.
3. Express the limit state function in terms of β and $\alpha i$ (Equation (3.5)) . β is the Hasofer – Lind Reliability index

Consider a limit state function $g(X_1, X_2, \ldots\ldots X_n)$ where the random variables $X_i$ are all uncorrelated. The limit state function is rewritten in terms of the standard form of the variables using:

$$Z_i = \frac{X_i - \mu_{X_i}}{\sigma_{X_i}} \qquad \textbf{(3.1)}$$

The hasofer – lind Reliability index is defined as the shortest distances from the origin of the reduced variable space to the limit state function g=0

An iteration is required to Find the design point $[Z^*_1, Z^*_2, \ldots\ldots, Z^*_n]$ in reduced variable space such that, β still corresponds to the shortest distance in fig 3.2.

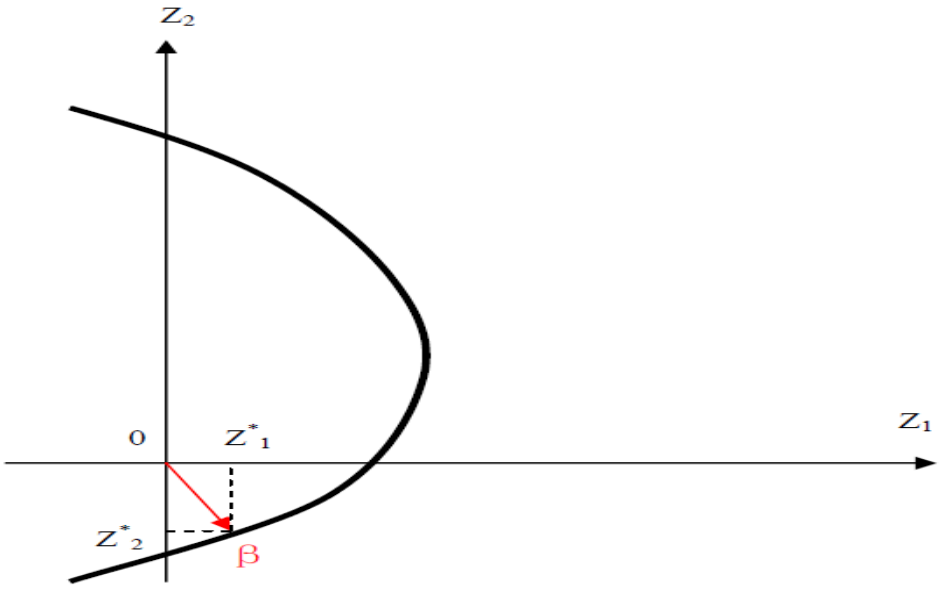



Fig 3.2:reduced variables and hasofer reliability Index

The iterative procedure require us to solve a set of (2n + 1) simultaneous equation with (2n + 1) Unknowns.

$\beta, \alpha_1, \alpha_2, \ldots\ldots\ldots, \alpha n, Z^*_1, Z^*_2, \ldots\ldots, Z^*_n,$

Where

$$\alpha 1 = -\frac{\frac{g}{zi}\text{Evaluated at design Point}}{\sqrt{\sum_{k=1}^{n}\left(\frac{g}{zk}\text{Evaluated at design Point}\right)^2}} \quad (3.2)$$

$$\frac{g}{zi}=\frac{g}{xi}\frac{xi}{zi}=\frac{g}{xi}\sigma xi \quad (3.3)$$

$$\sum_{i=1}^{n}(\alpha i)\,2=1 \quad (3.4)$$

$$Z_i^*=\beta\alpha i \quad (3.5)$$

$$g(Z_1^*,Z_2^*,.....Z_n^*)=0 \quad (3.6)$$

4. Calculate the n$\alpha i$ values. use equation (3.5) to express each $\alpha i$ as a function of all $\alpha i$ and $\beta$ (note the coupling effect between $\alpha i$) .
5. Contact the initial cycle: Assume Numerical values of $\beta$ and all$\alpha i$, noting the $\alpha_i$ values must satisfy Equation (3.4).
6. Use the numerical values of $\beta$ and $\alpha_i$ on the right hand side of the equation formed in steps (3) and (4 ) above.
7. Solve the n + 1 simultaneous equation in step( 6) for $\beta$ and $\alpha_i$
8. Go back to step (6) and repeat. Iterate until the $\beta$ and$\alpha_i$ values converge.

### 3. 3 FAILURE MODE-1(FATIGUE)

$N_F=1.66X10^{-10}\ (E_t)^{-4.32}$(3.7)

NEMPAD distress sub- model

Source:Murana (2010)

Where: $E_t$ = Horizontal tensile strain at the bottom of the asphalt layer

$N_F$ = the allowable number of equivalent single axle

Fatigue failuredistress model equation

$$G(x) = 1.66x10^{-10}\ (E_t)^{-4.32} - n_i \quad (3.8)$$

$$= N_f - n_i = o \quad (3.9)$$

Mean andstandard deviations of the random variables are listed in the following table.

Table3.2: Stochastic values of Random Variables

| Variable | Mean | Standard deviation |
|---|---|---|
| $N_f$ | $\mu N_f$ | $\delta N_f$ |
| $n_i$ | $\mu n_i$ | $\delta N_i$ |

$$Z_{Nf} = \frac{N_f - \mu_{nf}}{\delta_{Nf}} \quad (3.10)$$

$$Z_{ni} = \frac{n_i - \mu_{ni}}{\delta_{ni}} \quad (3.11)$$

⇨

$N_f = \mu_{Nf} + Z_{nf}\delta_{Nf}$(3.12)

$n_i = \mu_{ni} + Z_{ni}\delta_{ni}$(3.13)

Substitute equations (3.12) and(3.13) in aqn(3.6)

$(\mu_{Nf} + Z_{nf}\delta_{Nf}) - (\mu_{ni} + Z_{ni}\delta_{ni}) = 0$ (3.14)

$Z_{Nf}\delta_{Nf} - Z_{ni}\delta_{ni} + \mu_{Nf} - \mu_{ni} = 0$ (3.15)

Formulate in terms of

$Z^*_i = \beta\alpha i$

$\delta_{Nf}\beta\alpha 1, -\delta_{ni}\beta\alpha 2 + \mu_{Nf} - \mu_{ni} = 0$ (3.16)

$\beta(\delta_{Nf}\alpha 1 - \delta_{ni}\alpha 2) = -(\mu_{Nf} - \mu_{ni})$ (3.17)

⇨

$$\beta = -\frac{(\mu_{Nf} - \mu_{ni})}{(\delta_{Nf}\alpha 1 - \delta_{ni}\alpha 2)} \quad (3.18)$$

Now$\alpha i$ Values

Der 1 = $\delta_{Nf}$(3.19)

Der 2 = $\delta_{ni}$(3.20)

$$\beta = -\frac{(\mu_{Nf} - \mu_{ni})}{(\delta_{Nf}\alpha_1 - \delta_{ni}\alpha_2)} \quad (3.21)$$

$$\alpha_1 = \frac{\text{Der 1}}{\text{Der1 + der 2}}(3.22)$$

$$= \frac{\delta_{Nf}}{\delta_{Nf} + (-\delta_{ni})}(3.23)$$

$$\alpha_2 = \frac{\delta_{ni}}{\delta_{Nf} + (-\delta_{ni})} \quad (3.24)$$

### 3.4 FAILURE MODE-2(RUTTING)

$N_R = 2.56 \times 10^{-8} (Ev)^{-4.5337}$(3.25)

NEMPAD Distress Sub- Model

Source:Murana (2010)

Where: $E_v$ =the vertical compressive strain at the top of the subgrade

$N_R$ = the allowable number of equivalent single axle

Rutting failure distress model equation

$G(x)= 2.56x10^{-8} (\Sigma v)^{-4.5337} - n_i$(3.26)

$= N_R - n_i = 0$(3.27)

$$\beta = \frac{-(\mu_{NR} - \mu_{ni})}{(\delta_{NR}\alpha_1 - \delta_{ni}\alpha_2)} \quad (3.28)$$

$$\alpha_1 = \frac{\delta_{NR}}{\delta_{NR} - (-\delta_{ni})} \quad (3.29)$$

$$\alpha_2 = \frac{\delta_{ni}}{\delta_{NR} + (-\delta_{ni})} \quad (3.30)$$

Table 3.3: Modulus seasonal factors

| S/N | Layers | Season 1 (*HUNTURU*) | Season II (*DAMINA* ) | Season III (*BAZARA*) | Season IV (*KAKA*) |
|---|---|---|---|---|---|
| 1 | HMA | 4.39 | 2.14 | 0.57 | 1 |
| 2 | Base | 4.16 | 0.60 | 0.99 | 1 |
| 3 | Sub Base | 2.85 | 0.69 | 0.93 | 1 |
| 4 | SuB Grade | 5.5 | 0.57 | 0.96 | 1 |

Source: (Yakubu, 2011)

Table 3.4: Trial pavement layers thickness

| Design | Surfacing | Base Course | Sub base | Sub grade |
|---|---|---|---|---|

| alternatives | mm | Inch | mm | Inch | mm | Inch | mm | Inch |
|---|---|---|---|---|---|---|---|---|
| 1 | 100 | 3.94 | 165 | 6.50 | 180 | 7.09 | 7,620 | 300 |
| 2 | 100 | 3.94 | 200 | 7.87 | 250 | 9.84 | 7,620 | 300 |
| 3 | 125 | 4.92 | 200 | 7.87 | 250 | 9.84 | 7,620 | 300 |
| 4 | 125 | 4.92 | 250 | 9.84 | 275 | 10.83 | 7,620 | 300 |
| 5 | 150 | 5.91 | 250 | 9.84 | 275 | 10.83 | 7,620 | 300 |

Source :(Olowosulu, 2005)

### 3.5 PROBABILITY DISTRIBUTION OF N AND n

In order to quantify reliability, the distribution of each must be determined. Typically, N and n are determined from functions that utilize relevant input parameters. The variability of the input parameters causes N and n to exhibit variation. Therefore, the characterization of N and n are critical to reliability.

A graphical representation is shown in Figure 3.3,when N, and n are considered as Normal distribution. The shaded area in the figure concerns reliability but is not the explicit representation of reliability. Kulkami(1994) explains that the figure simply illustrates how the two distributions may overlap and moving them further apart increases the reliability. In this project, bothnumber of allowable 8200kg ESALS application(**N**F or NR), andnumber of cumulative ESALS(**n),** are considered as: **Normal**, **Lognormal**, and **Gumbel distribution**in turn, so that their respective component and system reliability index is determined in order to define the sensitivity of each probability distribution mentioned above.

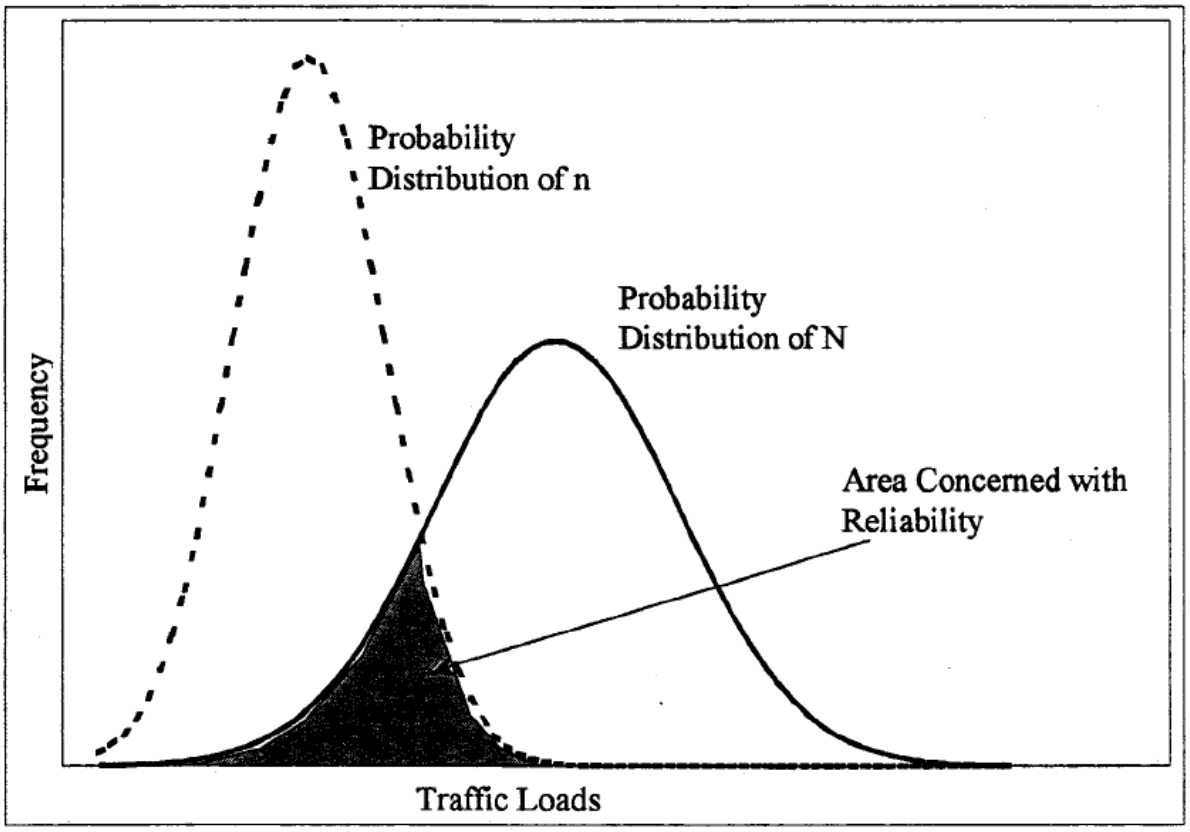



**Figure 3.3 Probability Distributions of N and n.**

### 3.6 TRAFFIC DATA INPUT FOR E-M PROCEDURE

Traffic data are required in the M-E pavement design procedure. Design traffic is expressed in terms of 8, 200 kg (80 kN) equivalent single axle loads (ESAL). Estimate of ESAL projected for the design life of the pavement (future traffic) is made using information from historical data to predict future growth parameters. Future traffic can be estimated from traffic growth rate factors as follows:

$$Q_f = ADT(FTG) \tag{3.31}$$

where

$Q_f$ = total number of vehicles over the design period

*ADT* = average daily traffic

*FTG* = future total growth factor

$$FTG = \frac{365[(1+i)^n - 1]}{ln(1+i)} \quad 3.32$$

Where*i* = growth rate

The future traffic is distributed by direction and lanes for the purpose of design. It has been found in Nigeria that the direction distribution factors (DDF) are between forty and sixty percent (Claros et al., 1986). For multilane facilities, the controlling lane is generally the outside lane. A lane distribution factor (LDF) is applied depending on the number of lanes e.g. for 2 lanes both direction LDF = 1.0 is used.

The design traffic is therefore calculated as number of equivalent single axle load (ESAL) expected to be carried on the design lane over the design period. The design traffic (n) is calculated by applying a directional distribution factor (DDF), a lane distribution factor (LDF), the percent truck factor ($P_t$), and an average 8, 200 kg single axle load equivalent factor to the total number of vehicles over design period. The equation to calculate the design traffic is:

$$n = Q_f(DDF)(LDF)(P_t)(F_{avg}) \quad 3.33$$

where

*n* = number of cumulative ESALs to be carried by critical lane over design period

$Q_f$= total number of estimated future vehicles during the design period, in both directions

*DDF* = directional distribution factor (between 0.4 and 0.6)

*LDF* = lane distribution factor

$P_t$= percent trucks, and

$F_{avg}$= average 8, 200 kg single axle load equivalence factor from the TRUKWT program.

## 3.7 MATERIAL CHARACTERIZATION

### i. Asphalt concrete material

The required asphalt concrete material properties are the Poisson‟ s ratio and dynamic modulus of elasticity. While modulus of elasticity values must be estimated, Poisson‟ s ratio values are assumed constant.

The dynamic modulus of the asphalt concrete can be measured in the lab using indirect tensile test (ASTM d-4123). In order to characterize asphalt mix for new pavement the asphalt mix design for new pavement is computed and six samples material can be molded to design density and tested in the dynamic indirect tensile device to obtain the resilient modulus of elasticity ($E_R$) at room temperature. Then $E_R$ is corrected to the temperature condition in the field.

### ii. **Bases and sub-bases**

For unbound bases and sub-bases, the resilient modulus $M_R$ can be estimated from in-situ CBR test using the following relationships developed for Nigerian soils (Claros et al., 1986), which now expressed in S.I. units are presented below:

For base layers

$$M_{RB} = 10{,}920 \times FLDCBR_B \qquad 3.34$$

$M_{RB}$ = Resilient modulus of Base layer *kPa*

*FLDCRB* = Field *CRB* of the Base material

For Sub base Layers

$$M_{RSB} = 6890 \times FLDCBR_B \qquad 3.35$$

$M_{RSB}$ = Resilient modulus of Sub Base layer *kPa*

$FLDCBR_{SB}$ = Field *CBR* in the Sub Base material

Sub grade Material: Usually samples are tested in the lab for resilient modulus ($M_R$).

**Table 3.5 Summary of Variability of Design Input Parameters**

| Property | Previous Investigatio | |
|---|---|---|
| | Range of COV (%) | Type of Distribution |
| AC Thickness ($T_{AC}$) | 3 – 12 | Normal |
| | 3 – 12 | Normal |
| AC Modulus ($E_{AC}$) | 10 – 40 | Lognormal |
| | 10 –20 | Normal |
| Base Modulus ($E_{Base}$) | 10 – 30 | Normal |
| | 5 – 60 | Lognormal |
| Subbase Modulus ($E_{Subbase}$) | 10 – 30 | Normal |
| | 5 – 60 | Lognormal |
| Subgrade Modulus ($E_{SG}$) | 10 – 30 | Normal |
| | 20 – 45 | Lognormal |
| Traffic (N) | 42 | Lognormal |
| | - | Extreme Value Type I |
| Professional Factor (P) | 20 | Normal |

Source: Kim and Buch (2003)

**Table 3.6 Typical Poisson ratio values**

| Material | General range | Remarks | Typical value |
|---|---|---|---|
| Portland Cement concrete | 0.10 – 0.45 | | |
| Asphalt Concrete/ Asphalt Treated Bases | 0.15 – 0.45 | Highly dependent upon temperature; use low value for cold temperatures (less than 30$^{o}$F) and high value (0.45) for warm pavement (120$^{o}$F plus) | 0.35 |
| Cement Stabilized Bases | 0.15 – 0.30 | Degree of cracking in stabilized layer tends to increase value towards 0.30 from sound (crack free) value of 0.15 | 0.20 |
| Granular Base/ Sub-base | 0.30 – 0.40 | Use lower value for crushed material and high value for unprocessed rounded gravels/sands | 0.40 |
| Sub-grades | 0.30 – 0.50 | Value dependent upon type of subgrade soil. For cohesionless soils, use value near 0.30. A value of 0.50 is approached for very plastic clays (cohesive soils). | 0.45 |

Source: Claros et.al. (1986)

**Table 3.7 Variability of Design Input Parameters**

| Variable description | Distribution type | Mean | Standard deviation |
|---|---|---|---|
| Annual Daily Traffic | Lognormal | 1818 | 75.81 |
| Asphalt stiffness | Lognormal | 4827MPa | 482.7MPa |
| Horizontal tensile strain | Normal | Varies | Varies |
| Vertical compressive strain | Normal | Varies | Varies |
| Truck percentage | Lognormal | 27.4 | 0.17 |
| Load equivalence factor | Normal | 3.35 | 0 |
| Lane distribution factor | Deterministic | 1.0 | 0 |
| Directional distribution factor | Deterministic | 0.5 | 0.6% |
| Traffic growth rate | Lognormal | 5% | |

## CHAPTER FOUR

## ANALYSIS AND DISCUSSION OF RESULTS

The investigation focused on a typical four-layer pavement system consisting of asphalt concrete over granular base and sub-base on top of a sub-grade soil. The data for the pavement structure has been indicated in Chapter three. Tables below show the results of the study:

# 4.1 FATIGUEFAILURE

$$N_F=1.66X10^{-10}\ (E_t)^{-4.32} \quad (4.1)$$

NEMPAD distress sub-model

Season – I (*Hunturu*)
Duration – 74 – days (1st week Dec-2nd week Feb.)

Table 4.1: Analysis Steps in Empirical-Mechanistic Design Procedure in season-I(Fatigue) COV=25%

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** | **5th** |
| $E_t$ | 3.48E-05 | 3.40E-05 | 2.98E-05 | 2.91E-05 | 2.53E-05 |

| | | | | | |
|---|---|---|---|---|---|
| $N_F$ | 3.02E+09 | 3.34E+09 | 5.91E+09 | 6.55E+09 | 1.20E+10 |
| n | $1.36x10^6$ | $1.36x10^6$ | $1.36x10^6$ | $1.36x10^6$ | $1.36x10^6$ |
| $D_i$ (DAMAGE) | 0.001 | 0.004 | 0.0002 | 0.0002 | 0.0001 |
| $\beta_1$(n,& NF,ARENORMAL DISTRIBUTION) RELIABILITY INDEX | 5.63 | 5.63 | 5.63 | 5.63 | 5.63 |
| $\beta_2$(n,& NF,ARELOG-NORMAL DISTRIBUTION) RELIABILITY INDEX | 6.18 | 6.18 | 6.18 | 6.18 | 6.18 |
| $\beta_3$(n,& NF,AREGUMBEL DISTRIBUTION) RELIABILITY INDEX | 7.15 | 7.15 | 7.15 | 7.15 | 7.15 |

Table 4.2: Analysis Steps in Empirical-Mechanistic Design Procedure in season-I(Fatigue) COV=42%

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** | **5th** |
| $E_t$ | 3.48E-05 | 3.40E-05 | 2.98E-05 | 2.91E-05 | 2.53E-05 |
| $N_F$ | 3.02E+09 | 3.34E+09 | 5.91E+09 | 6.55E+09 | 1.20E+10 |
| n | $1.36x10^6$ | $1.36x10^6$ | $1.36x10^6$ | $1.36x10^6$ | $1.36x10^6$ |

| $D_i$ (DAMAGE) | 0.001 | 0.004 | 0.0002 | 0.0002 | 0.0001 |
|---|---|---|---|---|---|
| $\beta_1$(n,& NF,ARENORMAL DISTRIBUTION)<br>RELIABILITY<br>INDEX | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 |
| $\beta_2$(n,& NF,ARELOG-NORMAL DISTRIBUTION)<br>RELIABILITY<br>INDEX | 3.44 | 3.44 | 3.44 | 3.44 | 3.44 |
| $\beta_3$(n,& NF,AREGUMBEL DISTRIBUTION)<br>RELIABILITY<br>INDEX | 4.55 | 4.55 | 4.55 | 4.55 | 4.55 |

$$Di = \frac{ni}{Nfi} < 1.0 \quad (4.2)$$

Season II– (*Damina*)

Duration – 141 – days ($2^{nd}$ week May-$1^{st}$ week Oct.)

Table 4.3: Analysis Steps in Empirical-Mechanistic Design Procedure in season-II(Fatigue),COV=25%

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **$1^{st}$** | **$2^{nd}$** | **$3^{rd}$** | **$4^{th}$** | **$5^{th}$** |
| $E_t$ | 1.33E-04 | 1.29E-04 | 1.05E-04 | 1.03E-04 | 8.46E-05 |
| $N_F$ | 9.23E+06 | 1.05E+07 | 2.56E+07 | 2.78E+07 | 6.51E+07 |
| n | $2.6x10^6$ | $2.6x10^6$ | $2.6x10^6$ | $2.6x10^6$ | $2.6x10^6$ |
| $D_i$ (DAMAGE) | 0.28 | 0.25 | 0.10 | 0.09 | 0.04 |
| $\beta_1$(n,& NF,ARENORMAL DISTRIBUTION) RELIABILITY INDEX | 3.16 | 3.40 | 4.60 | 4.67 | 5.20 |
| $\beta_2$(n,& NF,ARELOG-NORMAL DISTRIBUTION) RELIABILITY INDEX | 3.46 | 3.73 | 5.04 | 5.12 | 5.71 |
| $\beta_3$(n,& NF,AREGUMBEL DISTRIBUTION) RELIABILITY | 4.01 | 4.32 | 5.83 | 5.93 | 6.60 |

| | | | | | |
|---|---|---|---|---|---|
| INDEX | | | | | |

Table 4.4: Analysis Steps in Empirical-Mechanistic Design Procedure in season-II(Fatigue),COV=42%

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** | **5th** |
| $E_t$ | 1.33E-04 | 1.29E-04 | 1.05E-04 | 1.03E-04 | 8.46E-05 |
| $N_F$ | 9.23E+06 | 1.05E+07 | 2.56E+07 | 2.78E+07 | 6.51E+07 |
| n | $2.6x10^6$ | $2.6x10^6$ | $2.6x10^6$ | $2.6x10^6$ | $2.6x10^6$ |
| $D_i$ (DAMAGE) | 0.28 | 0.25 | 0.10 | 0.09 | 0.04 |
| $\beta_1$(n,& NF,ARENORMAL DISTRIBUTION)<br>RELIABILITY<br>INDEX | 1.88 | 2.02 | 2.74 | 2.78 | 3.10 |
| $\beta_2$(n,& NF,ARELOG-NORMAL DISTRIBUTION)<br>RELIABILITY<br>INDEX | 1.93 | 2.08 | 2.81 | 2.85 | 3.18 |
| $\beta_3$(n,& NF,AREGUMBEL DISTRIBUTION)<br>RELIABILITY<br>INDEX | 2.55 | 2.75 | 3.71 | 3.77 | 4.20 |

Season – III (*Bazara*)
Duration – 90 – days ($2^{nd}$ week Feb-$2^{nd}$ Week May)

Table 4.5: Analysis Steps in Empirical-Mechanistic Design Procedure in season-III (Fatigue),COV=25%

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **$1^{st}$** | **$2^{nd}$** | **$3^{rd}$** | **$4^{th}$** | **$5^{th}$** |
| $E_t$ | 1.69E-04 | 1.66E-04 | 1.54E-04 | 1.51E-04 | 1.36E-04 |
| $N_F$ | 3.28E+06 | 3.54E+06 | 4.90E+06 | 5.33E+06 | 8.38E+06 |
| n | $1.66x10^6$ | $1.66x10^6$ | $1.66x10^6$ | $1.66x10^6$ | $1.66x10^6$ |
| $D_i$ (DAMAGE) | 0.51 | 0.47 | 0.34 | 0.31 | 0.20 |
| $\beta_1$(n,& NF,ARE NORMAL DISTRIBUTION) RELIABILITY INDEX | 1.85 | 2.04 | 2.78 | 2.96 | 3.77 |
| $\beta_2$(n,& NF, ARELOG-NORMAL DISTRIBUTION) RELIABILITY INDEX | 2.02 | 2.23 | 3.05 | 3.23 | 4.14 |
| $\beta_3$(n, &NF,AREGUMBEL DISTRIBUTION) RELIABILITY INDEX | 2.34 | 2.59 | 3.53 | 3.76 | 4.79 |

Table 4.6: Analysis Steps in Empirical-Mechanistic Design Procedure in season-III (Fatigue),COV=42%

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** | **5th** |
| $E_t$ | 1.69E-04 | 1.66E-04 | 1.54E-04 | 1.51E-04 | 1.36E-04 |
| $N_F$ | 3.28E+06 | 3.54E+06 | 4.90E+06 | 5.33E+06 | 8.38E+06 |
| n | $1.66x10^6$ | $1.66x10^6$ | $1.66x10^6$ | $1.66x10^6$ | $1.66x10^6$ |
| $D_i$ (DAMAGE) | 0.51 | 0.47 | 0.34 | 0.31 | 0.20 |
| $\beta_1$(n,& NF,ARE NORMAL DISTRIBUTION) RELIABILITY INDEX | 1.10 | 1.21 | 1.66 | 1.76 | 2.24 |
| $\beta_2$(n,& NF, ARELOG-NORMAL DISTRIBUTION) RELIABILITY INDEX | 1.13 | 1.24 | 1.70 | 1.81 | 2.30 |
| $\beta_3$(n, &NF,AREGUMBEL DISTRIBUTION) RELIABILITY INDEX | 1.49 | 1.65 | 2.25 | 2.39 | 3.05 |

Season – IV (*Kaka*)
Duration – 60 – days (1st Week Oct-1st Week Dec.)

Table 4.7: Analysis Steps in Empirical-Mechanistic Design Procedure in season-IV (Fatigue),COV=25%

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** | **5th** |
| $E_t$ | 1.44E-04 | 1.40E-04 | 1.24E-04 | 1.22E-04 | 1.06E-04 |
| $N_F$ | 6.55E+06 | 7.40E+06 | 1.2E+07 | 1.34E+07 | 2.45E+07 |
| n | $1.11x10^6$ | $1.11x10^6$ | $1.11x10^6$ | $1.11x10^6$ | $1.11x10^6$ |
| $D_i$ (DAMAGE) | 0.17 | 0.15 | 0.09 | 0.08 | 0.05 |
| $\beta_1$(n, &NF, ARE NORMAL DISTRIBUTION) RELIABILITY INDEX | 4.00 | 4.17 | 4.72 | 4.77 | 5.15 |
| $\beta_2$(n, &NF, ARE LOG-NORMAL DISTRIBUTION) RELIABILITY INDEX | 4.39 | 4.57 | 5.17 | 5.24 | 5.65 |
| $\beta_3$(n,& NF, ARE GUMBEL DISTRIBUTION) RELIABILITY INDEX | 5.08 | 5.29 | 5.99 | 6.06 | 6.54 |

Table 4.8: Analysis Steps in Empirical-Mechanistic Design Procedure in season-IV (Fatigue),COV=42%

| **Analysis** | **NO OF TRIALS** |
|---|---|

| | 1st | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|---|
| $E_t$ | 1.44E-04 | 1.40E-04 | 1.24E-04 | 1.22E-04 | 1.06E-04 |
| $N_F$ | 6.55E+06 | 7.40E+06 | 1.2E+07 | 1.34E+07 | 2.45E+07 |
| n | $1.11x10^6$ | $1.11x10^6$ | $1.11x10^6$ | $1.11x10^6$ | $1.11x10^6$ |
| $D_i$ (DAMAGE) | 0.17 | 0.15 | 0.09 | 0.08 | 0.05 |
| $\beta_1$(n, &NF, ARE NORMAL DISTRIBUTION) RELIABILITY INDEX | 2.38 | 2.48 | 2.81 | 2.84 | 3.06 |
| $\beta_2$(n, &NF, ARE LOG-NORMAL DISTRIBUTION) RELIABILITY INDEX | 2.45 | 2.55 | 2.88 | 2.92 | 3.15 |
| $\beta_3$(n,& NF, ARE GUMBEL DISTRIBUTION) RELIABILITY INDEX | 3.24 | 3.37 | 3.81 | 3.86 | 4.16 |

Table 4.9:computation 0fFatigue accumulated damage for all seasons

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** | **5th** |
| Season 1 | 0.0010 | 0.0004 | 0.0002 | 0.0002 | 0.0001 |
| Season 2 | 0.2800 | 0.2500 | 0.1000 | 0.0900 | 0.0400 |

| | | | | | |
|---|---|---|---|---|---|
| Season 3 | 0.5100 | 0.4700 | 0.3400 | 0.3100 | 0.2000 |
| Season 4 | 0.1700 | 0.1500 | 0.0900 | 0.0800 | 0.0500 |
| Fatigue total Damage Dj | 0.9600 | 0.8700 | 0.5300 | 0.4800 | 0.2900 |

$$Dj = \sum_{i=1}^{i} \frac{ni}{NF} \quad (4.3)$$

## 4.2RUTTING FAILURE

$$NR = 2.56 \times 10^{-8} (Ev)^{-4.5337} \quad (4.4)$$

NEMPAD Distress sub-Model

Season – I (*Hunturu*)

Duration – 74 – days (1st Week Dec-2nd Week Feb.)

Table 4.10: Analysis Steps in Empirical-Mechanistic Design Procedure in season-I (Rutting),COV=25%

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** | **5th** |
| $E_v$ | -5.20E-05 | -3.83E-05 | -3.29E-05 | -2.73E-05 | -2.40E-05 |
| $N_R$ | 6.77E+11 | 2.71E+12 | 5.40E+12 | 1.26E+13 | 2.25E+13 |
| n | $1.36x10^6$ | $1.36x10^6$ | $1.36x10^6$ | $1.36x10^6$ | $1.36x10^6$ |
| $D_i$ (DAMAGE) | 0.000002 | 0.0000007 | 0.0000003 | 0.0000001 | 0.00000006 |
| $\beta_1$(n, &NR, ARE NORMAL | 5.63 | 5.63 | 5.63 | 5.63 | 5.63 |

| | | | | | |
|---|---|---|---|---|---|
| DISTRIBUTION)<br>RELIABILITY<br>INDEX | | | | | |
| $\beta_2$(n, &NR, ARE LOG-NORMAL DISTRIBUTION)<br>RELIABILITY<br>INDEX | 6.18 | 6.18 | 6.18 | 6.18 | 6.18 |
| $\beta_3$(n, &NR, ARE GUMBEL DISTRIBUTION)<br>RELIABILITY<br>INDEX | 7.15 | 7.15 | 7.15 | 7.15 | 7.15 |

Table 4.11: Analysis Steps in Empirical-Mechanistic Design Procedure in season-I (Rutting),COV=42%

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** | **5th** |
| $E_v$ | -5.20E-05 | -3.83E-05 | -3.29E-05 | -2.73E-05 | -2.40E-05 |
| $N_R$ | 6.77E+11 | 2.71E+12 | 5.40E+12 | 1.26E+13 | 2.25E+13 |
| n | $1.36x10^6$ | $1.36x10^6$ | $1.36x10^6$ | $1.36x10^6$ | $1.36x10^6$ |
| $D_i$ (DAMAGE) | 0.000002 | 0.0000007 | 0.0000003 | 0.0000001 | 0.00000006 |
| $\beta_1$(n, &NR, ARE NORMAL DISTRIBUTION) | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 |

| | | | | | |
|---|---|---|---|---|---|
| RELIABILITY INDEX | | | | | |
| $\beta_2$(n, &NR, ARE LOG-NORMAL DISTRIBUTION) RELIABILITY INDEX | 3.44 | 3.44 | 3.44 | 3.44 | 3.44 |
| $\beta_3$(n, &NR, ARE GUMBEL DISTRIBUTION) RELIABILITY INDEX | 4.55 | 4.55 | 4.55 | 4.55 | 4.55 |

Season – II (*Damina*)

Duration – 141– days (2nd Week May-1st Week Oct.)

Table 4.12: Analysis Steps in Empirical-Mechanistic Design Procedure in season-II (Rutting),COV=25%

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** | **5th** |
| $E_v$ | -2.39E-04 | -1.84E-04 | -1.50E-04 | -1.28E-04 | -1.08E-04 |
| $N_R$ | 6.72E+08 | 2.20E+09 | 5.56E+09 | 1.14E+10 | 2.46E+10 |
| n | 2. $6x10^6$ | $2.6x10^6$ | $2.6x10^6$ | $2.6x10^6$ | $2.6x10^6$ |
| $D_i$ (DAMAGE) | 0.004 | 0.001 | 0.0005 | 0.0002 | 0.0001 |

| | | | | | |
|---|---|---|---|---|---|
| $\beta_1$(n, &NR, ARE NORMAL DISTRIBUTION) RELIABILITY INDEX | 5.59 | 5.62 | 5.63 | 5.63 | 5.63 |
| $\beta_2$(n, &NR, ARE LOG-NORMAL DISTRIBUTION) RELIABILITY INDEX | 6.13 | 6.17 | 6.17 | 6.18 | 6.18 |
| $\beta_3$(n, &NR, ARE GUMBEL DISTRIBUTION) RELIABILITY INDEX | 7.10 | 7.14 | 7.14 | 7.15 | 7.15 |

Table 4.13: Analysis Steps in Empirical-Mechanistic Design Procedure in season-II (Rutting),COV=42%

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** | **5th** |
| $E_v$ | -2.39E-04 | -1.84E-04 | -1.50E-04 | -1.28E-04 | -1.08E-04 |
| $N_R$ | 6.72E+08 | 2.20E+09 | 5.56E+09 | 1.14E+10 | 2.46E+10 |
| n | 2. $6x10^6$ | $2.6x10^6$ | $2.6x10^6$ | $2.6x10^6$ | $2.6x10^6$ |
| $D_i$ (DAMAGE) | 0.004 | 0.001 | 0.0005 | 0.0002 | 0.0001 |
| $\beta_1$(n, &NR, ARE NORMAL DISTRIBUTION) RELIABILITY | 3.33 | 3.35 | 3.35 | 3.35 | 3.35 |

| | | | | | |
|---|---|---|---|---|---|
| INDEX | | | | | |
| $\beta_2$(n, &NR, ARE LOG-NORMAL DISTRIBUTION)<br>RELIABILITY<br>INDEX | 3.42 | 3.43 | 3.44 | 3.45 | 3.45 |
| $\beta_3$(n, &NR, ARE GUMBEL DISTRIBUTION)<br>RELIABILITY<br>INDEX | 4.52 | 4.54 | 4.55 | 4.55 | 4.55 |

Season – III (*Bazara*)
Duration – 90 – days (2nd Week Feb-2nd Week May.)

Table 4.14: Analysis Steps in Empirical-Mechanistic Design Procedure in season-III (Rutting)

COV=25%

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** | **5th** |
| $E_v$ | -2.29E-04 | -1.65E-04 | -1.45E-04 | -1.18E-04 | -1.06E-04 |
| $N_R$ | 8.16E+08 | 3.61E+09 | 6.48E+09 | 1.65E+10 | 2.68E+10 |
| n | $1.66x10^6$ | $1.66x10^6$ | $1.66x10^6$ | $1.66x10^6$ | $1.66x10^6$ |

| | | | | | |
|---|---|---|---|---|---|
| $D_i$ (DAMAGE) | 0.002 | 0.0005 | 0.0005 | 0.0001 | 0.00006 |
| $\beta_1$(n, &NR, ARE NORMAL DISTRIBUTION) RELIABILITY INDEX | 5.61 | 5.63 | 5.63 | 5.63 | 5.63 |
| $\beta_2$(n, &NR, ARE LOG- NORMAL DISTRIBUTION) RELIABILITY INDEX | 6.16 | 6.18 | 6.18 | 6.18 | 6.18 |
| $\beta_3$(n, &NR, ARE GUMBEL DISTRIBUTION) RELIABILITY INDEX | 7.12 | 7.15 | 7.15 | 7.15 | 7.15 |

Table4.15: Analysis Steps in Empirical-Mechanistic Design Procedure in season-III (Rutting),COV=42%

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** | **5th** |
| $E_v$ | -2.29E-04 | -1.65E-04 | -1.45E-04 | -1.18E-04 | -1.06E-04 |
| $N_R$ | 8.16E+08 | 3.61E+09 | 6.48E+09 | 1.65E+10 | 2.68E+10 |
| n | $1.66x10^6$ | $1.66x10^6$ | $1.66x10^6$ | $1.66x10^6$ | $1.66x10^6$ |
| $D_i$ (DAMAGE) | 0.002 | 0.0005 | 0.0005 | 0.0001 | 0.00006 |
| $\beta_1$(n, &NR, ARE NORMAL | 3.34 | 3.35 | 3.35 | 3.35 | 3.35 |

| | | | | | |
|---|---|---|---|---|---|
| DISTRIBUTION)<br>RELIABILITY<br>INDEX | | | | | |
| $\beta_2$(n, &NR, ARE LOG- NORMAL DISTRIBUTION)<br>RELIABILITY<br>INDEX | 3.43 | 3.44 | 3.45 | 4.45 | 4.45 |
| $\beta_3$(n, &NR, ARE GUMBEL DISTRIBUTION)<br>RELIABILITY<br>INDEX | 4.53 | 4.55 | 4.55 | 4.55 | 4.55 |

Season – IV (*Kaka*)
Duration – 60 – days (1st Week Oct-1st Week Dec.)

Table 4.16: Analysis Steps in Empirical-Mechanistic Design Procedure in season-IV (Rutting),COV=25%

| **Analysis** | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** | **5th** |
| $E_v$ | -2.01E-04 | -1.46E-04 | -1.27E-04 | -1.05E-04 | -9.21E-05 |
| $N_R$ | 1.47E+09 | 6.28E+09 | 1.18E+10 | 2.80E+10 | 5.07E+10 |
| n | $1.11X10^6$ | $1.11X10^6$ | $1.11X10^6$ | $1.11X10^6$ | $1.11X10^6$ |
| $D_i$ (DAMAGE) | 0.0008 | 0.0002 | 0.00009 | 0.00005 | 0.00002 |
| $\beta_1$(n, &NR, ARE NORMAL DISTRIBUTION)<br>RELIABILITY<br>INDEX | 5.63 | 5.63 | 5.63 | 5.63 | 5.63 |

| | | | | | |
|---|---|---|---|---|---|
| $\beta_2$(n, &NR, ARE LOG-NORMAL DISTRIBUTION) RELIABILITY INDEX | 6.18 | 6.18 | 6.18 | 6.18 | 6.18 |
| $\beta_3$(n, &NR, ARE GUMBEL DISTRIBUTION) RELIABILITY INDEX | 7.15 | 7.15 | 7.15 | 7.15 | 7.15 |

Table 4.17: Analysis Steps in Empirical-Mechanistic Design Procedure in season-IV (Rutting),COV=42%

| Analysis | **NO OF TRIALS** | | | | |
|---|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** | **5th** |
| $E_v$ | -2.01E-04 | -1.46E-04 | -1.27E-04 | -1.05E-04 | -9.21E-05 |
| $N_R$ | 1.47E+09 | 6.28E+09 | 1.18E+10 | 2.80E+10 | 5.07E+10 |
| n | $1.11X10^6$ | $1.11X10^6$ | $1.11X10^6$ | $1.11X10^6$ | $1.11X10^6$ |
| $D_i$ (DAMAGE) | 0.0008 | 0.0002 | 0.00009 | 0.00005 | 0.00002 |
| $\beta_1$(n, &NR, ARE NORMAL DISTRIBUTION) RELIABILITY INDEX | 3.35 | 3.35 | 3.35 | 3.35 | 3.35 |
| $\beta_2$(n, &NR, ARE | 3.44 | 3.44 | 3.44 | 3.44 | 3.44 |

| | | | | | |
|---|---|---|---|---|---|
| LOG-NORMAL DISTRIBUTION)<br>RELIABILITY<br>INDEX | | | | | |
| $\beta_3$(n, &NR, ARE GUMBEL DISTRIBUTION)<br>RELIABILITY<br>INDEX | 4.55 | 4.55 | 4.55 | 4.55 | 4.55 |

Table 4.18: computation 0f rutting accumulated damage for all seasons

| Season | 1st | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|---|
| Season 1 | 0.00002 | 0.0000007 | 0.0000003 | 0.0000001 | 0.00000006 |
| Season 2 | 0.00400 | 0.0010000 | 0.0005000 | 0.0002000 | 0.00010000 |
| Season 3 | 0.00200 | 0.0005000 | 0.0003000 | 0.0001000 | 0.00006000 |
| Season 4 | 0.00080 | 0.0002000 | 0.0000900 | 0.0000500 | 0.00002000 |
| Rutting Total Damage $D_i$ | 0.00700 | 0.0020000 | 0.0010000 | 0.0000000 | 0.00000000 |

$$Dj = \sum_{i=1}^{j} \frac{ni}{NR} \quad (4.5)$$

Table 4.19: Fatigue System reliability index within the seasons(Per annum),COV=25%

| | 1st | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|---|
| $\beta_1$(n, &NR, ARE NORMAL DISTRIBUTION) RELIABILITY INDEX | 1.84 | 2.04 | 2.78 | 2.96 | 3.77 |
| $\beta_2$(n, &NR, ARE LOG-NORMAL DISTRIBUTION) RELIABILITY INDEX | 2.02 | 2.23 | 3.06 | 3.23 | 4.15 |
| $\beta_3$(n, &NR, ARE GUMBEL DISTRIBUTION) RELIABILITY INDEX | 2.34 | 2.59 | 3.53 | 3.76 | 4.8 |

Table 4.20: Fatigue System reliability index within the seasons(Per annum),COV=42%

| | 1st | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|---|
| $\beta_1$(n, &NR, ARE NORMAL DISTRIBUTION) RELIABILITY INDEX | 0.98 | 1.11 | 1.62 | 1.71 | 2.18 |
| $\beta_2$(n, &NR, ARE LOG-NORMAL DISTRIBUTION) RELIABILITY INDEX | 1.03 | 1.15 | 1.66 | 1.77 | 2.25 |

| | | | | | |
|---|---|---|---|---|---|
| $\beta_3$(n, &NR, ARE GUMBEL DISTRIBUTION) RELIABILITY INDEX | 1.46 | 1.61 | 2.25 | 2.39 | 3.06 |

Table 4.21: Rutting System reliability index within the seasons(Per annum),COV=25%

| | 1st | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|---|
| $\beta_1$(n, &NR, ARE NORMAL DISTRIBUTION) RELIABILITY INDEX | 5.40 | 5.45 | 5.45 | 5.45 | 5.45 |
| $\beta_2$(n, &NR, ARE LOG-NORMAL DISTRIBUTION) RELIABILITY INDEX | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 |
| $\beta_3$(n, &NR, ARE GUMBEL DISTRIBUTION) | 7.00 | 7.10 | 7.10 | 7.10 | 7.10 |

| | | | | | |
|---|---|---|---|---|---|
| RELIABILITY<br><br>INDEX | | | | | |

Table 4.22: Rutting System reliability index within the seasons(Per annum),COV=42%

| | 1st | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|---|
| $\beta_1$(n, &NR, ARE NORMAL DISTRIBUTION)<br><br>RELIABILITY<br><br>INDEX | 2.94 | 2.95 | 2.95 | 2.95 | 2.95 |
| $\beta_2$(n, &NR, ARE LOG-NORMAL DISTRIBUTION)<br><br>RELIABILITY<br><br>INDEX | 3.05 | 3.06 | 3.06 | 3.07 | 3.07 |
| $\beta_3$(n, &NR, ARE GUMBEL DISTRIBUTION)<br><br>RELIABILITY<br><br>INDEX | 4.25 | 4.25 | 4.25 | 4.25 | 4.25 |

Table 4.23: Overall System reliability index/probability of failure between the two failure modes(Fatigue and Rutting),COV=25%

| | 1st | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|---|
| $\beta_1$(n, &NR, ARE NORMAL DISTRIBUTION) RELIABILITY INDEX | 1.84 | 2.04 | 2.78 | 2.96 | 3.77 |
| PROBABILITY OF FAILURE ($P_F$) | 0.45 | 0.28 | 0.14 | 0.08 | 0.05 |
| $\beta_2$(n, &NR, ARE LOG-NORMAL DISTRIBUTION) RELIABILITY INDEX | 2.02 | 2.23 | 3.07 | 3.23 | 4.15 |
| PROBABILITY OF FAILURE ($P_F$) | 0.29 | 0.17 | 0.06 | 0.11 | 0.01 |
| $\beta_3$(n, &NR, ARE GUMBEL DISTRIBUTION) RELIABILITY INDEX | 2.34 | 2.59 | 3.53 | 3.76 | 4.80 |
| PROBABILITY OF FAILURE ($P_F$) | 0.48 | 0.24 | 0.04 | 0.06 | 7.2X10^-3 |

Table 4.24: Overall System reliability index/probability of failure between the two failure modes(Fatigue and Rutting),COV=42%

| | 1st | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|---|
| $\beta_1$(n, &NR, ARE NORMAL DISTRIBUTION) RELIABILITY INDEX | 0.98 | 1.11 | 1.61 | 1.70 | 2.14 |
| PROBABILITY OF FAILURE ($P_F$) | 0.61 | 0.50 | 0.27 | 0.21 | 0.18 |
| $\beta_2$(n, &NR, ARE LOG-NORMAL DISTRIBUTION) RELIABILITY INDEX | 1.04 | 1.15 | 1.65 | 1.76 | 2.22 |
| PROBABILITY OF FAILURE ($P_F$) | 0.56 | 0.46 | 0.25 | 0.31 | 0.07 |
| $\beta_3$(n, &NR, ARE GUMBEL DISTRIBUTION) RELIABILITY INDEX | 1.46 | 1.61 | 2.25 | 2.39 | 3.07 |
| PROBABILITY OF FAILURE ($P_F$) | 0.98 | 0.73 | 0.17 | 0.42 | 0.03 |

The results shownin the tables above confirmed the recommendation made in Murana(2010) that:

- Transport and Road Research Laboratory pavement performance model for fatigue's equation (NEMPADS Fatigue Distress sub model), and Indian pavement

performance model equation for Rutting (NEMPADS Rutting Distress sub model)are good predictorsfor 'NEMPADS'

Table4.25:Analysis Steps in Empirical-Mechanistic Design Procedure

| Design alternative | Surfacing mm | Base mm | Sub-base mm | $\varepsilon_t \times 10^{-6}$ | $\varepsilon_v \times 10^{-6}$ | $D_F$ | $D_R$ |
|---|---|---|---|---|---|---|---|
| 1 | 100 | 165 | 180 | 144 | 201 | 2.36 | 0.02 |
| 2 | 100 | 200 | 250 | 141 | 147 | 2.20 | 0.0 |
| 3 | 125 | 200 | 250 | 124 | 127 | 1.44 | 0.0 |
| 4 | 125 | 250 | 275 | 122 | 122 | 1.37 | 0.0 |
| 5 | 150 | 250 | 275 | 106 | 92.6 | 0.86 | 0.0 |

Source:Olowosulu(2005)

Table 4.26: Fatigue accumulated damage

| | | | | | |
|---|---|---|---|---|---|
| $D_F$ | 0.96 | 0.87 | 0.53 | 0.48 | 0.29 |

Table 4.27: rutting accumulated damage

| | | | | | |
|---|---|---|---|---|---|
| $D_R$ | 0.007 | 0.002 | 0.001 | 0.00 | 0.00 |

Table 4.1 and 4.2 reflected the effect of coefficient of variation( COV),when the COV. was changed from 25% to 42% and keeping all other parameter constant, the component reliability index (β) for fatigue decreased significantly, which showed that COV. affects the reliability index.

Table 4.2 to 4.8 represent component reliability analysis procedure for fatigue failure, through four different seasons, using five different trial layer thickness (table 3.4), with 25% and 42% COV respectively, from the results we found out that when the expected number of equivalent single axle load (ESALS) ,n, is small the computed component reliability through out the season is not sensitive.

Also, season I (*HUNTURU)* has recorded the highest component reliability index for fatigue (table 4.1 and 4.2). This is as a result of the effect of low temperature on the pavement modulus of elasticity, that makes it very stiff (table 3.1), which also tallied with our result for accumulated damage within this season (table 4.9). Similarly, season III (*BAZARA)* has recorded the lowest component reliability index for fatigue (table 4.5 and 4.6), which is as a result of the effect of high temperature on the pavement surface modulus of elasticity which makes it weak. This has also tallied with our result for accumulated damage within the season (table 4.9)

The effect of choice of probability distribution of random variables was also reflected in the tables for both component and system reliability index computation, where Gumbel produced higher reliability index, followed by Log-Normal, while Normal produced lowest reliability index.

Table 4.10 to 4.17 represent component reliability analysis for rutting failure, through four different seasons, using five different trial layer thickness,with 25% and 42% COV respectively. Season II (*DAMINA*) has recorded the lowest component reliability index (β) for rutting ( table 4.12 and 4.13) which is as a result of the effect of moisture on the pavement subgrade material resilient modulus that makes it very weak. This also tallied with the result of accumulated damage within the season (table 4.18). Table 4.23 and 4.24 represent the overall system reliability/probability of failure analysis procedure between the two failure mode ( fatigue and rutting) in a year, using five different trial layer thickness (table 3.4),with 25% and 42% COV respectively. The result indicated that Gumbel distribution

produced highest overall system reliability index, followed by Log-Normal, while Normal distribution provided the lowest reliability index.

Fig 4.5 represent a comparism between Deterministic(Olowosulu,2005) and Reliability method (Muhammed,2014) in terms of accumulated fatigue damage, using five different trial layer thickness (table 3.4). From the results we found out that there is great savings in accumulated damage as reflected in Muhammed (2014) which means the design pavement layer thickness were reduced drastically, this confirmed the deterministic method to be very conservative. Fig 4.6 to 4.9 represent a plot of Hasofer-Lind reliability index (β), and allowable ESALS application (NF) for fatigue at 25% COV through four different seasons.

Table 4.25: analysis steps in Empirical-Mechanistic design procedure, using Fatigue and Rutting distress model equations (claros*et al* 1986) inOlowosulu(2005), and neglecting climatic effect on the material properties. On the other hand, Tables 4.26, and 4.27show the fatigue and rutting accumulated damage respectively, computed using the recommended NEMPAD distress models in Murana(2010),and considering climatic effects in Yakubu(2011).It is important to mention that at the trial thickness of 150mm of surfacing,250mm of Base course, and 275mm of sub base ,in Olowosulu(2005)a value of 0.86 was gotten as accumulated damage neglecting climatic effect, while in Yakubu(2011) a value of 0.67 was gotten as the accumulated damage considering climatic effect,in this project (Table 4.26) a value of 0.29 was gotten using "NEMPADfatigue Distress model" and considering climatic effect.

The accumulated damage values for Fatigue and Rutting,and Reliability index for different Seasons and different trial layers thicknesses produced the following Figures.

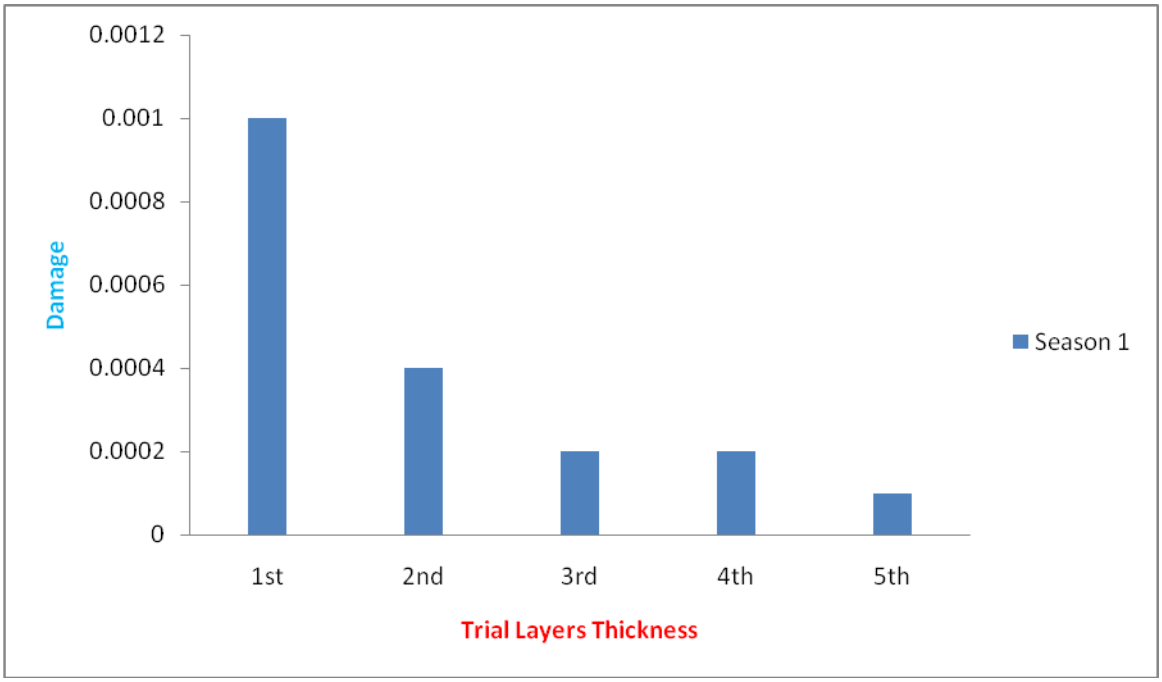



Fig. 4.1: (Fatigue Damage Vs Trial Layers Thickness

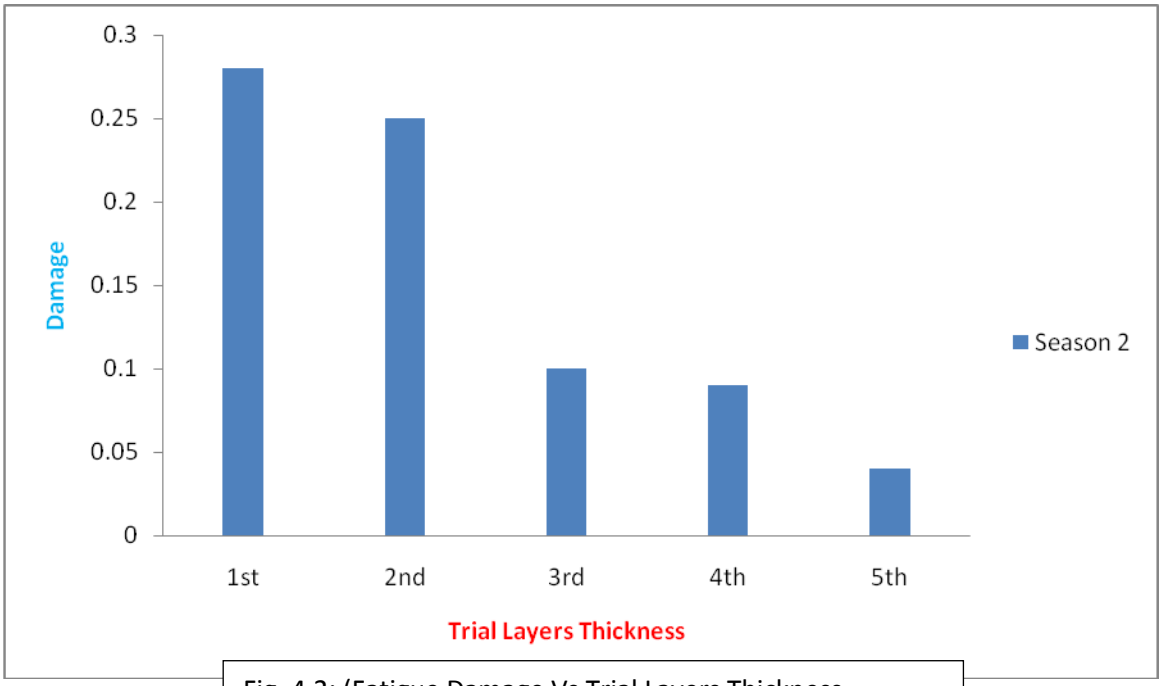



Fig. 4.2: (Fatigue Damage Vs Trial Layers Thickness

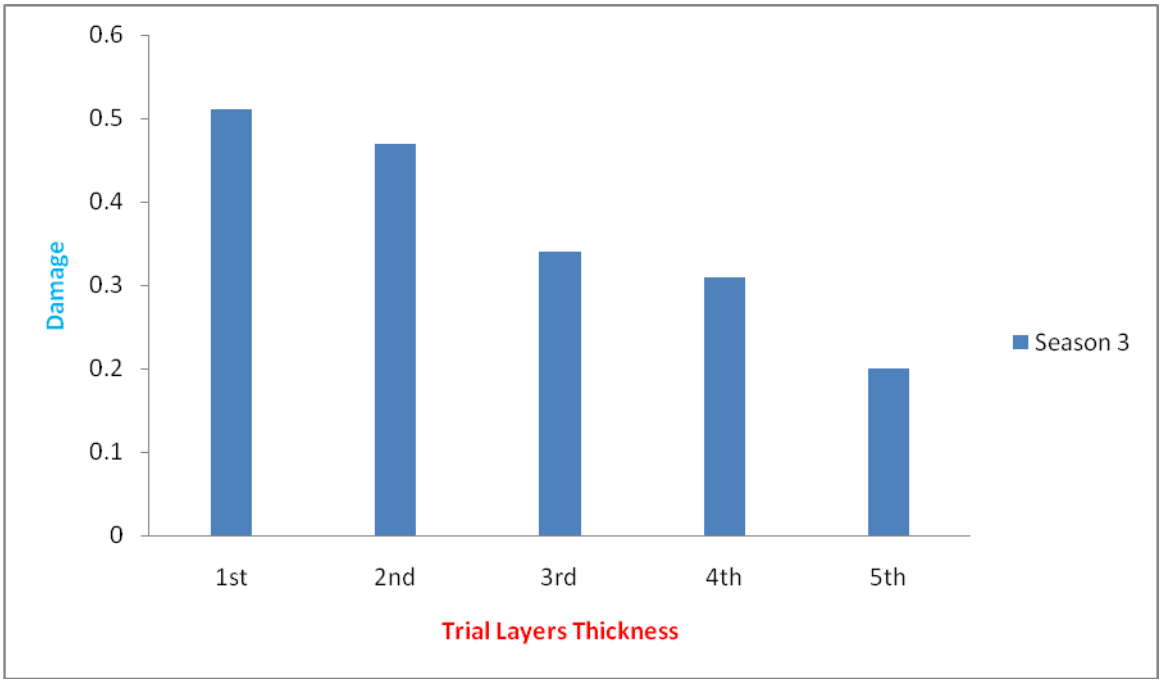



Fig. 4.3: (Fatigue Damage Vs Trial Layers Thickness

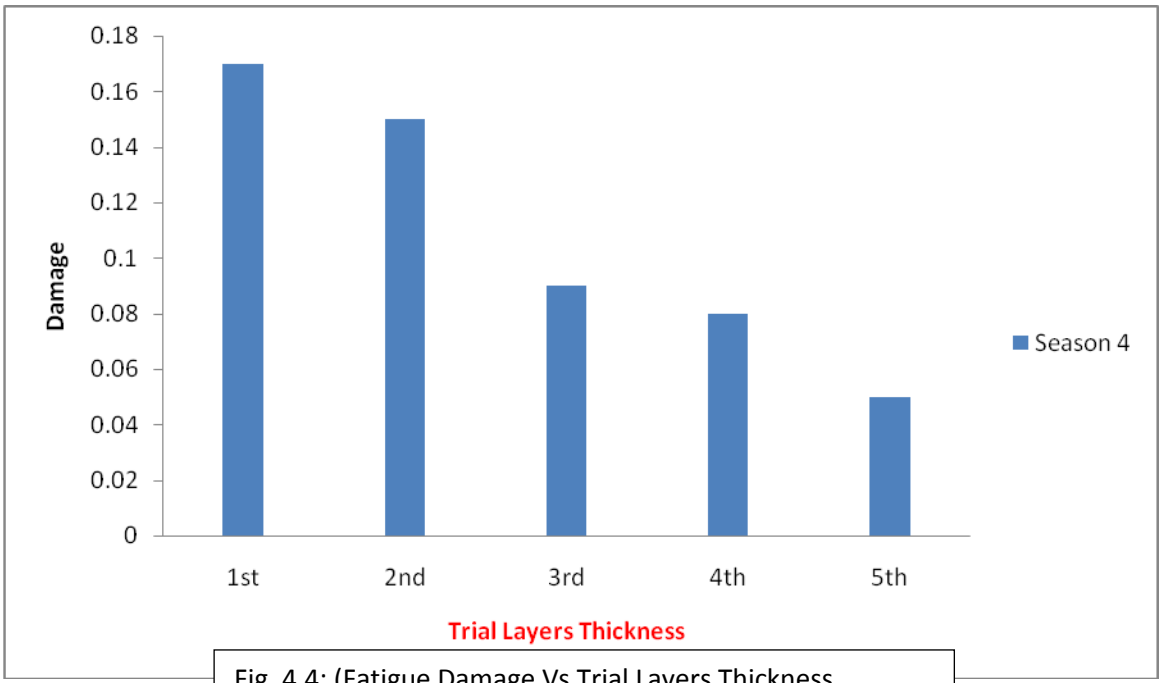



Fig. 4.4: (Fatigue Damage Vs Trial Layers Thickness

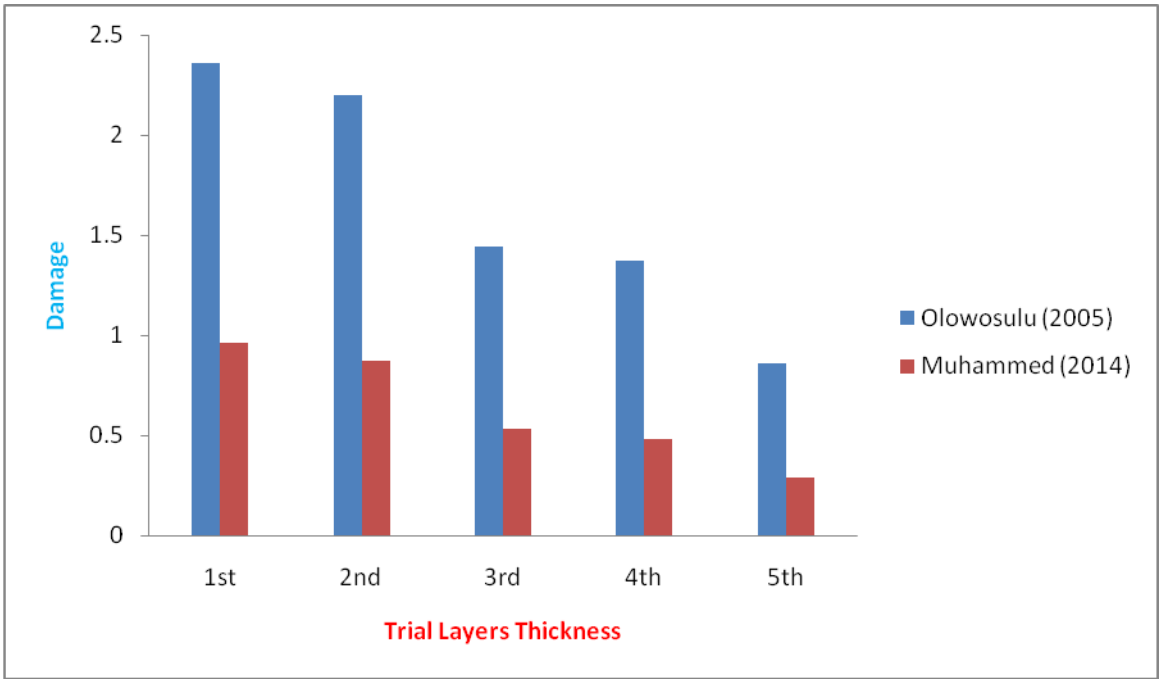



Fig. 4.5: (Comparism of Cumulative Damage Vs Trial Layers Thickness

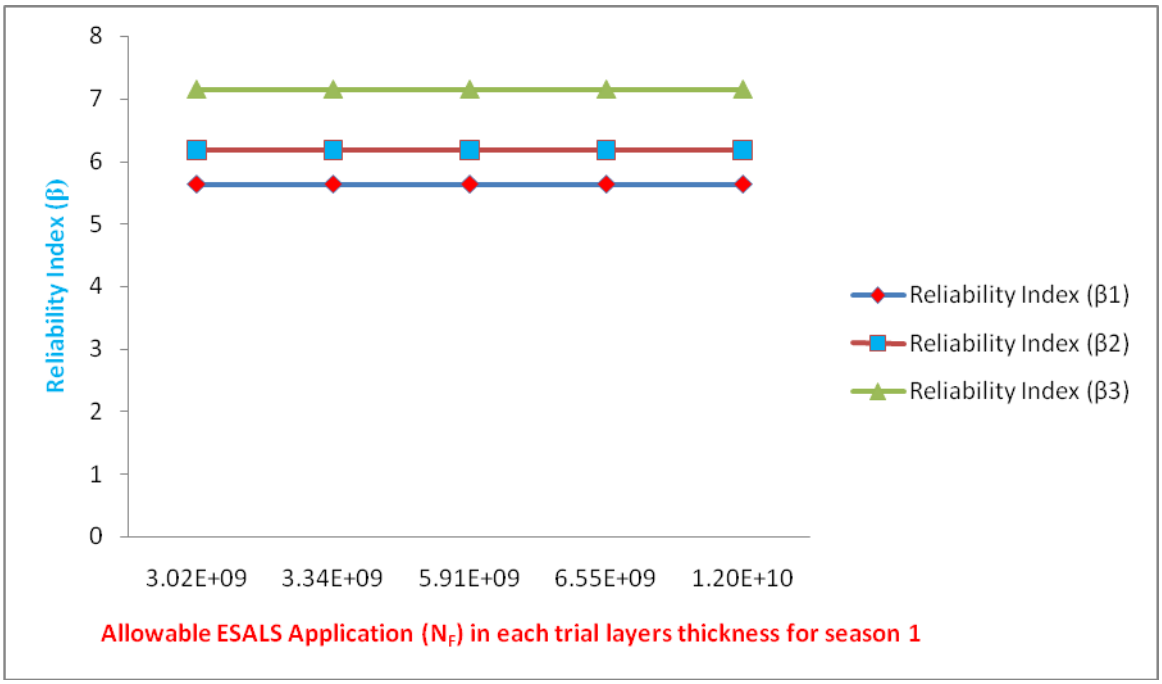



Fig. 4.6: (Reliability Index (β) Vs Allowable ESALS Application ($N_F$),using COV of 25%

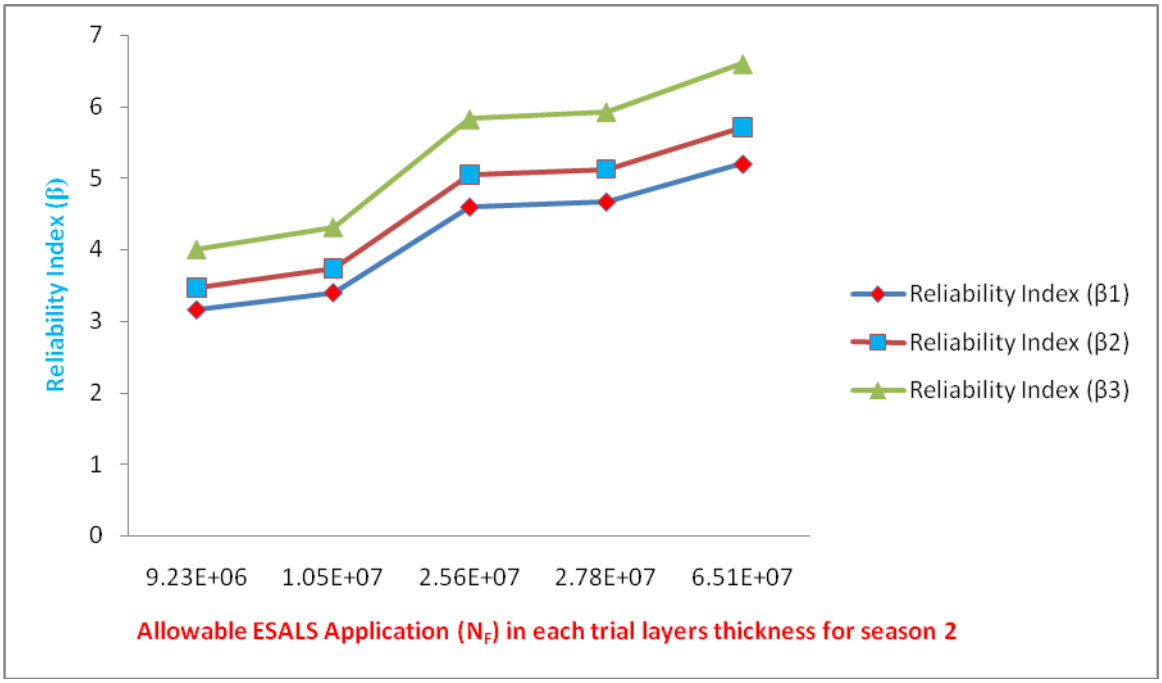



Fig. 4.7: (Reliability Index (β) Vs Allowable ESALS Application ($N_F$),using COV of 25%

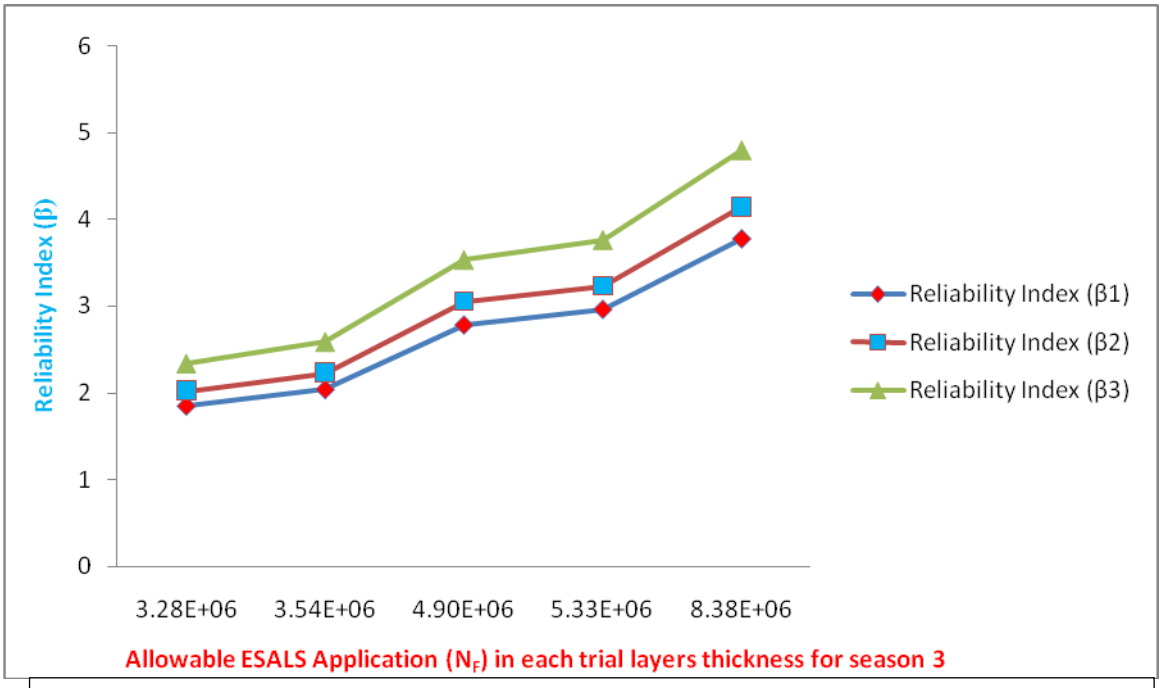



Fig. 4.8: (Reliability Index (β) Vs Allowable Esals Application ($N_F$),using COV of 25%

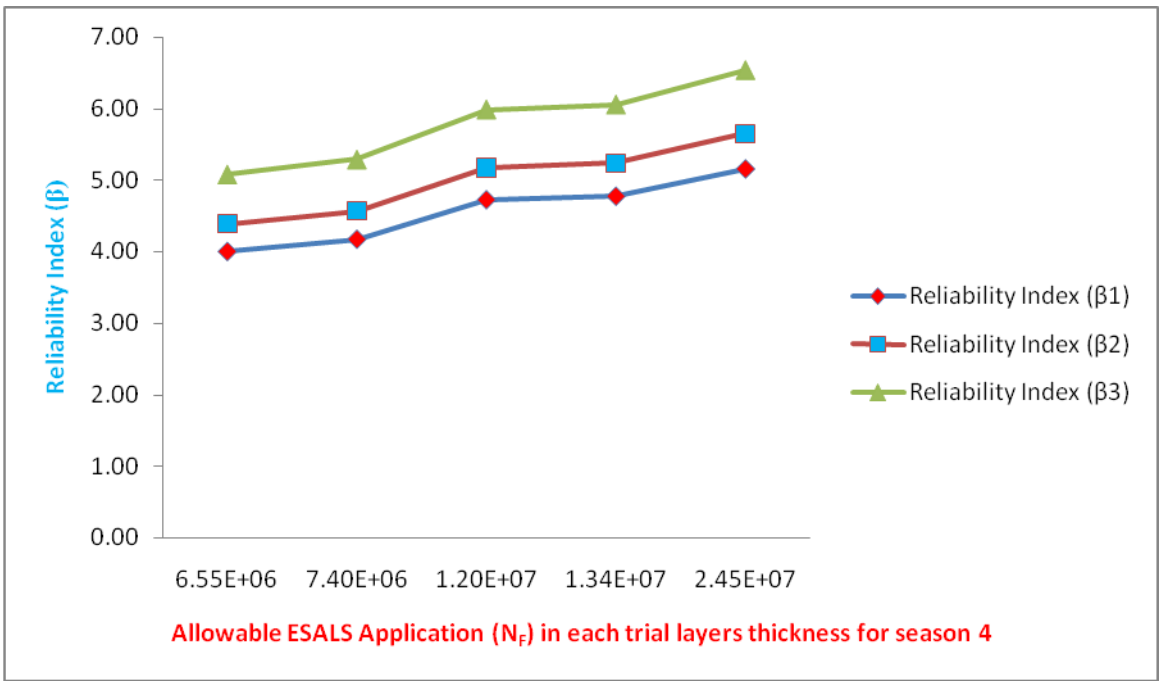



Fig. 4.9: (Reliability Index (β) Vs Allowable Esals Application ($N_F$),using COV of 25%

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATION

## 5.1CONCLUSION

The damage of a pavement section is caused by load applications. Total equivalent damage due to all the load repetitions has been calculated with the results of multi layer analysis of the pavement. Therefore, a pavement design is safe when the allowable number of standard axle repetitions (the fatigue and rutting life) is greater than applied standard axle repetitions (Expected traffic) during the design period. In general, these values exhibit significant variability due to uncertainties of input parameters. Therefore pavement can be designed for a

given safety, known as reliability. Thus for a given reliability, mean allowable standard axle repetitions can be found for an expected future traffic.

It is important to mention that at the trial thickness of 150mm thickness of Asphaltic surfacing,250mm of Base course, and 275mm of sub base ($5^{th}$ trial thickness) Table 3.4,a value of 0.86 was obtained as accumulated damage neglecting climatic effect, while a value of 0.67 was obtained as the accumulated damage considering climatic effect, in this project (Table 4.26) a value of 0.29 was obtained using "NEMPADfatigue Distress sub-model" and considering climatic effect.This project show us the effect of seasonal factors, and NEMPAD distress sub-model equations in our design, as we can observe that all the first 4-trial layer thicknesses have failed, only the $5^{th}$ one passed the design, when seasonal factors, variabilities of random variables were not considered, while in this thesis all the 5-trial layer thicknesses passed the design when seasonal factors and variability of random variables were considered at 25% COV , and the last 4-trial layer thickness passed the design when COV was changed to 42 % .

The following conclusions are also observed:

**1**.The lowest level of damage with respect to both Fatigue and Rutting failure is recorded during '*Hunturu'*season.

**2**.The highest level of damagewith respect to Fatigue is recorded during 'Bazara ' season.

**3**.The highest level of damagewith respect to Rutting is recorded during'Damina' season.

## 5.2 RECOMMENDATIONS

Based on the results obtained in this study, the following recommendations are made:

1. Since the material properties ofPavement are highly uncertain, there is the need to integrate reliability-based designed criteria in the design of pavement structures in order to fully accommodate the uncertainties.
2. The process used in this study could be used in other regions for the Mechanistic empiricalreliability based design of flexible pavement.
3. The Mechanistic empirical reliability based design of flexible pavement should be based on system reliability between the two failure mode(Fatigue and Rutting) and not component reliability.
4. The Log-Normal distribution should be used as probability distribution for both the applied and allowable ESALS application for being considered as Load variables and not Resistance.

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# APPENDIX-A

## ELSYM-5OUTPUT(SHOWING STRESSES AND STRAINS)

**ELSYM-5**

```
1     EEEEE L     SSSSS Y   Y M   M    55555
      E     L     S      Y Y  MMMM    5
      EEE   L     SSSSS   Y   M MM    5555
      E     L         S   Y   M   M        5
      EEEEE LLLLL SSSSS   Y   M   M    5555
```

FIVE LAYER ELASTIC SYSTEM RESPONSE PROGRAM - VERSION 11/84-1

```
      ADAPTED FOR MICRO COMPUTER APPLICATION BY
      ARE INC - ENGINEERING CONSULTANTS
FROM ORIGINAL VERSION 3/72 - 3. DEVELOPED BYGALE AHLBORN,
      UNIVERSITY OF CALIFORNIA AT BERKELEY
1     ELSYM5 - FIVE LAYERED ELASTIC SYSTEM - VERSION 4.0
      LATEST REVISION: 77/12/19 - J C OQUIN, S B SEEDS
                                  P R JORDAHL, R CATALANO
      AUSTIN RESEARCH ENGINEERS,INC.

      SYSTEM NUMBER  0

      EXAMPLE PROBLEM

      NUMBER OF ELASTIC LAYERS =  4
      NUMBER OF LOAD LOCATIONS =  1
      NUMBER OF X-Y RESULTS =     1
      NUMBER OF Z DEPTHS =        2

                ELASTIC   POISSONS
LAYER     MODULUS    RATIO      THICKNESS (IN.)
1      3080044.     .350        3.940
2       333165.     .400        6.500
3       142501.     .400        7.090
4       154289.     .450      300.000

      LOAD DESCRIPTION:

      LOAD FORCE =        9000.
      TIRE PRESSURE =       80.
      LOAD RADIUS =        5.98

          LOADS LOCATED AT:
      LOAD     X        Y
        1     .000     .000

      RESULTS REQUESTED FOR SYSTEM LOCATION(S)

        X-Y POINT(S)
         X      Y
         .00   .00

        DEPTHS =   3.94  17.50
1      ELSYM-5  FIVE LAYERED ELASTIC SYSTEM RESPONSE
      PROGRAM - VERSION 11/84-1
      LATEST REVISION: ARE INC - ENGINEERING CONSULTANTS

      SYSTEM NUMBER  0

      EXAMPLE PROBLEM
0   X     Y     Z    ---------PRINCIPAL STRESSES--------- ----------
PRINCIPAL STRAINS----------
                           1           2           3           1
2           3
    .00   .00  3.94     .145E+03    .145E+03   -.378E+02    .348E-04
.348E-04   -.452E-04
```

```
    .00   .00 17.50    -.169E+00   -.169E+00   -.754E+01    .205E-04
.205E-04   -.520E-04
```

---

```
1     EEEEE L     SSSSS Y   Y M   M    55555
      E     L     S      Y Y  MMMM    5
      EEE   L     SSSSS   Y   M MM    5555
      E     L         S   Y   M   M        5
      EEEEE LLLLL SSSSS   Y   M   M    5555


      FIVE LAYER ELASTIC SYSTEM RESPONSE PROGRAM - VERSION 11/84-1
      ADAPTED FOR MICRO COMPUTER APPLICATION BY
      ARE INC - ENGINEERING CONSULTANTS
FROM ORIGINAL VERSION 3/72 - 3. DEVELOPED BYGALE AHLBORN,
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1    ELSYM5 - FIVE LAYERED ELASTIC SYSTEM - VERSION 4.0
     LATEST REVISION: 77/12/19 - J C OQUIN, S B SEEDS
                                 P R JORDAHL, R CATALANO
     AUSTIN RESEARCH ENGINEERS,INC.

     SYSTEM NUMBER  0

     EXAMPLE PROBLEM

     NUMBER OF ELASTIC LAYERS =  4
     NUMBER OF LOAD LOCATIONS =  1
     NUMBER OF X-Y RESULTS =     1
     NUMBER OF Z DEPTHS =        2

               ELASTIC   POISSONS
LAYER     MODULUS    RATIO      THICKNESS (IN.)
1      3080044.     .350        3.940
2       333165.     .400        7.870
3       142501.     .400        9.840
4       154289.     .450      300.000

     LOAD DESCRIPTION:

     LOAD FORCE =        9000.
     TIRE PRESSURE =       80.
     LOAD RADIUS =        5.98

         LOADS LOCATED AT:
     LOAD     X        Y
       1     .000     .000

     RESULTS REQUESTED FOR SYSTEM LOCATION(S)

       X-Y POINT(S)
        X      Y
        .00   .00

       DEPTHS =   3.94  21.60
1     ELSYM-5  FIVE LAYERED ELASTIC SYSTEM RESPONSE
```

```
     PROGRAM - VERSION 11/84-1
     LATEST REVISION: ARE INC - ENGINEERING CONSULTANTS

     SYSTEM NUMBER  0

     EXAMPLE PROBLEM
0   X     Y     Z    ---------PRINCIPAL STRESSES--------- ----------
PRINCIPAL STRAINS----------
                          1           2           3           1
2           3
    .00   .00  3.94     .140E+03    .140E+03   -.387E+02    .340E-04
.340E-04   -.444E-04
    .00   .00 21.60    -.582E-01   -.582E-01   -.550E+01    .152E-04
.152E-04   -.383E-04
```

---

```
1     EEEEE L     SSSSS Y   Y M   M    55555
      E     L     S      Y Y  MMMM    5
      EEE   L     SSSSS   Y   M MM    5555
      E     L         S   Y   M   M        5
      EEEEE LLLLL SSSSS   Y   M   M    5555


      FIVE LAYER ELASTIC SYSTEM RESPONSE PROGRAM - VERSION 11/84-1
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                                  P R JORDAHL, R CATALANO
      AUSTIN RESEARCH ENGINEERS,INC.

      SYSTEM NUMBER  0

      EXAMPLE PROBLEM

      NUMBER OF ELASTIC LAYERS =  4
      NUMBER OF LOAD LOCATIONS =  1
      NUMBER OF X-Y RESULTS =     1
      NUMBER OF Z DEPTHS =        2

                ELASTIC   POISSONS
LAYER     MODULUS    RATIO      THICKNESS (IN.)
1      3080044.     .350        4.920
2       333165.     .400        7.870
3       142501.     .400        9.840
4       154289.     .450      300.000

      LOAD DESCRIPTION:

      LOAD FORCE =        9000.
      TIRE PRESSURE =       80.
      LOAD RADIUS =        5.98
```

```
         LOADS LOCATED AT:
     LOAD     X         Y
       1     .000      .000

     RESULTS REQUESTED FOR SYSTEM LOCATION(S)

       X-Y POINT(S)
        X      Y
        .00   .00

       DEPTHS =   4.92  22.60
1     ELSYM-5  FIVE LAYERED ELASTIC SYSTEM RESPONSE
     PROGRAM - VERSION 11/84-1
     LATEST REVISION: ARE INC - ENGINEERING CONSULTANTS

     SYSTEM NUMBER  0

     EXAMPLE PROBLEM
0   X     Y     Z    ---------PRINCIPAL STRESSES--------- ----------
PRINCIPAL STRAINS----------
                          1           2           3           1
2           3
    .00   .00  4.92     .125E+03    .125E+03   -.297E+02    .298E-04
.298E-04   -.382E-04
    .00   .00 22.60    -.754E-01   -.754E-01   -.476E+01    .130E-04
.130E-04   -.329E-04
```

---

```
1     EEEEE L     SSSSS Y   Y M   M    55555
      E     L     S      Y Y  MMMM    5
      EEE   L     SSSSS   Y   M MM    5555
      E     L         S   Y   M   M        5
      EEEEE LLLLL SSSSS   Y   M   M    5555


      FIVE LAYER ELASTIC SYSTEM RESPONSE PROGRAM - VERSION 11/84-1
      ADAPTED FOR MICRO COMPUTER APPLICATION BY
      ARE INC - ENGINEERING CONSULTANTS
FROM ORIGINAL VERSION 3/72 - 3. DEVELOPED BYGALE AHLBORN,
      UNIVERSITY OF CALIFORNIA AT BERKELEY
1     ELSYM5 - FIVE LAYERED ELASTIC SYSTEM - VERSION 4.0
     LATEST REVISION: 77/12/19 - J C OQUIN, S B SEEDS
                                 P R JORDAHL, R CATALANO
     AUSTIN RESEARCH ENGINEERS,INC.

     SYSTEM NUMBER  0

     EXAMPLE PROBLEM

     NUMBER OF ELASTIC LAYERS =  4
     NUMBER OF LOAD LOCATIONS =  1
     NUMBER OF X-Y RESULTS =     1
     NUMBER OF Z DEPTHS =        2

               ELASTIC   POISSONS
```

```
LAYER     MODULUS    RATIO      THICKNESS (IN.)
1      3080044.     .350        4.920
2       333165.     .400        9.840
3       142501.     .400       10.800
4       154289.     .450      300.000

     LOAD DESCRIPTION:

     LOAD FORCE =        9000.
     TIRE PRESSURE =       80.
     LOAD RADIUS =        5.98

         LOADS LOCATED AT:
     LOAD     X        Y
       1     .000     .000

     RESULTS REQUESTED FOR SYSTEM LOCATION(S)

       X-Y POINT(S)
        X      Y
        .00   .00

       DEPTHS =   4.92  25.50
1     ELSYM-5  FIVE LAYERED ELASTIC SYSTEM RESPONSE
     PROGRAM - VERSION 11/84-1
     LATEST REVISION: ARE INC - ENGINEERING CONSULTANTS

     SYSTEM NUMBER  0

     EXAMPLE PROBLEM
0   X     Y     Z    ---------PRINCIPAL STRESSES--------- ----------
PRINCIPAL STRAINS----------
                          1           2           3           1
2           3
    .00   .00  4.92     .122E+03    .122E+03   -.305E+02    .291E-04
.291E-04   -.376E-04
    .00   .00 25.50    -.303E-01   -.303E-01   -.392E+01    .109E-04
.109E-04   -.273E-04
```

# APPENDIX-B

## MATLAB OUT PUT(SHOWING RELIABILITY INDEX AND PROBABILITY OF FAILURE)

# MATLAB OUTPUT

```
THE INPUT DATA FOR FATIGUE MODE OF FAILURE


HORIZONTAL TENSILE STRAIN
3.48e-005

DIRECTIONAL DISTRIBUTION FACTOR
      0.50

LANE DISTRIBUTION FACTOR
      1.00

PERCENTAGE OF TRUCKS
      0.27

AVERAGE LOAD EQUIVALENCE FACTOR
      3.35

AVERAGE DAILY TRAFFIC
   1818.00

NUMBER OF DAYS PER SEASON
     74.00

COEFFICIENT OF VARIATION OF Nf IN PERCENTAGE
     25.00

COEFFICIENT OF VARIATION OF n IN PERCENTAGE
     25.00



THE OUTPUT FOR FATIGUE MODE OF FAILURE

NUMBER OF CUMULATIVE ESALS
1365394.91

ALLOWABLE 8200kg ESAL APPLICATION WITH RESPECT TO FATIGUE
3023331397.00

TOTAL NUMBER OF ESTIMATED FUTURE VEHICLES
2975040.65

FUTURE TOTAL GROWTH FACTOR
   1636.44

Nf DISTRIBUTION MODEL IS NORMAL AND THE
n DISTRIBUTION MODEL IS NORMAL
```

RELIABILITY/SAFETY INDEX
 5.63

THE INPUT DATA FOR FATIGUE MODE OF FAILURE

HORIZONTAL TENSILE STRAIN
3.40e-005

DIRECTIONAL DISTRIBUTION FACTOR
      0.50

LANE DISTRIBUTION FACTOR
      1.00

PERCENTAGE OF TRUCKS
      0.27

AVERAGE LOAD EQUIVALENCE FACTOR
      3.35

AVERAGE DAILY TRAFFIC
   1818.00

NUMBER OF DAYS PER SEASON
     74.00

COEFFICIENT OF VARIATION OF Nf IN PERCENTAGE
     25.00

COEFFICIENT OF VARIATION OF n IN PERCENTAGE
     25.00

THE OUTPUT FOR FATIGUE MODE OF FAILURE

NUMBER OF CUMULATIVE ESALS
1365394.91

ALLOWABLE 8200kg ESAL APPLICATION WITH RESPECT TO FATIGUE
3342867526.58

TOTAL NUMBER OF ESTIMATED FUTURE VEHICLES
2975040.65

FUTURE TOTAL GROWTH FACTOR
   1636.44

Nf DISTRIBUTION MODEL IS NORMAL AND THE

n DISTRIBUTION MODEL IS NORMAL

RELIABILITY/SAFETY INDEX
 5.63

THE INPUT DATA FOR FATIGUE MODE OF FAILURE

HORIZONTAL TENSILE STRAIN
2.98e-005

DIRECTIONAL DISTRIBUTION FACTOR
      0.50

LANE DISTRIBUTION FACTOR
      1.00

PERCENTAGE OF TRUCKS
      0.27

AVERAGE LOAD EQUIVALENCE FACTOR
      3.35

AVERAGE DAILY TRAFFIC
   1818.00

NUMBER OF DAYS PER SEASON
     74.00

COEFFICIENT OF VARIATION OF Nf IN PERCENTAGE
     25.00

COEFFICIENT OF VARIATION OF n IN PERCENTAGE
     25.00

THE OUTPUT FOR FATIGUE MODE OF FAILURE

NUMBER OF CUMULATIVE ESALS
1365394.91

ALLOWABLE 8200kg ESAL APPLICATION WITH RESPECT TO FATIGUE
5908725672.50

TOTAL NUMBER OF ESTIMATED FUTURE VEHICLES
2975040.65

FUTURE TOTAL GROWTH FACTOR
   1636.44

Nf DISTRIBUTION MODEL IS NORMAL AND THE
n DISTRIBUTION MODEL IS NORMAL

RELIABILITY/SAFETY INDEX
 5.63

THE INPUT DATA FOR FATIGUE MODE OF FAILURE

HORIZONTAL TENSILE STRAIN
2.91e-005

DIRECTIONAL DISTRIBUTION FACTOR
      0.50

LANE DISTRIBUTION FACTOR
      1.00

PERCENTAGE OF TRUCKS
      0.27

AVERAGE LOAD EQUIVALENCE FACTOR
      3.35

AVERAGE DAILY TRAFFIC
   1818.00

NUMBER OF DAYS PER SEASON
     74.00

COEFFICIENT OF VARIATION OF Nf IN PERCENTAGE
     25.00

COEFFICIENT OF VARIATION OF n IN PERCENTAGE
     25.00

THE OUTPUT FOR FATIGUE MODE OF FAILURE

NUMBER OF CUMULATIVE ESALS
1365394.91

ALLOWABLE 8200kg ESAL APPLICATION WITH RESPECT TO FATIGUE
6547724164.32

TOTAL NUMBER OF ESTIMATED FUTURE VEHICLES
2975040.65

FUTURE TOTAL GROWTH FACTOR
1636.44

Nf DISTRIBUTION MODEL IS NORMAL AND THE
n DISTRIBUTION MODEL IS NORMAL

RELIABILITY/SAFETY INDEX
5.63

THE INPUT DATA FOR FATIGUE MODE OF FAILURE

HORIZONTAL TENSILE STRAIN
2.53e-005

DIRECTIONAL DISTRIBUTION FACTOR
0.50

LANE DISTRIBUTION FACTOR
1.00

PERCENTAGE OF TRUCKS
0.27

AVERAGE LOAD EQUIVALENCE FACTOR
3.35

AVERAGE DAILY TRAFFIC
1818.00

NUMBER OF DAYS PER SEASON
74.00

COEFFICIENT OF VARIATION OF Nf IN PERCENTAGE
25.00

COEFFICIENT OF VARIATION OF n IN PERCENTAGE
25.00

THE OUTPUT FOR FATIGUE MODE OF FAILURE

NUMBER OF CUMULATIVE ESALS
1365394.91

ALLOWABLE 8200kg ESAL APPLICATION WITH RESPECT TO FATIGUE
11984707430.93

TOTAL NUMBER OF ESTIMATED FUTURE VEHICLES

2975040.65

FUTURE TOTAL GROWTH FACTOR
1636.44

Nf DISTRIBUTION MODEL IS NORMAL AND THE
n DISTRIBUTION MODEL IS NORMAL

RELIABILITY/SAFETY INDEX
5.63

THE INPUT DATA FOR FATIGUE MODE OF FAILURE

HORIZONTAL TENSILE STRAIN
3.48e-005

DIRECTIONAL DISTRIBUTION FACTOR
0.50

LANE DISTRIBUTION FACTOR
1.00

PERCENTAGE OF TRUCKS
0.27

AVERAGE LOAD EQUIVALENCE FACTOR
3.35

AVERAGE DAILY TRAFFIC
1818.00

NUMBER OF DAYS PER SEASON
74.00

COEFFICIENT OF VARIATION OF Nf IN PERCENTAGE
42.00

COEFFICIENT OF VARIATION OF n IN PERCENTAGE
42.00

THE OUTPUT FOR FATIGUE MODE OF FAILURE

NUMBER OF CUMULATIVE ESALS
1365394.91

ALLOWABLE 8200kg ESAL APPLICATION WITH RESPECT TO FATIGUE
3023331397.00

TOTAL NUMBER OF ESTIMATED FUTURE VEHICLES
2975040.65

FUTURE TOTAL GROWTH FACTOR
1636.44

Nf DISTRIBUTION MODEL IS NORMAL AND THE
n DISTRIBUTION MODEL IS NORMAL

RELIABILITY/SAFETY INDEX
3.35

THE INPUT DATA FOR FATIGUE MODE OF FAILURE

HORIZONTAL TENSILE STRAIN
3.48e-005

DIRECTIONAL DISTRIBUTION FACTOR
0.50

LANE DISTRIBUTION FACTOR
1.00

PERCENTAGE OF TRUCKS
0.27

AVERAGE LOAD EQUIVALENCE FACTOR
3.35

AVERAGE DAILY TRAFFIC
1818.00

NUMBER OF DAYS PER SEASON
74.00

COEFFICIENT OF VARIATION OF Nf IN PERCENTAGE
42.00

COEFFICIENT OF VARIATION OF n IN PERCENTAGE
42.00

THE OUTPUT FOR FATIGUE MODE OF FAILURE

NUMBER OF CUMULATIVE ESALS
1365394.91

ALLOWABLE 8200kg ESAL APPLICATION WITH RESPECT TO FATIGUE
3023331397.00

TOTAL NUMBER OF ESTIMATED FUTURE VEHICLES
2975040.65

FUTURE TOTAL GROWTH FACTOR
1636.44

Nf DISTRIBUTION MODEL IS LOGNORMAL AND THE
n DISTRIBUTION MODEL IS LOGNORMAL

RELIABILITY/SAFETY INDEX
3.44

THE INPUT DATA FOR FATIGUE MODE OF FAILURE

HORIZONTAL TENSILE STRAIN
3.48e-005

DIRECTIONAL DISTRIBUTION FACTOR
0.50

LANE DISTRIBUTION FACTOR
1.00

PERCENTAGE OF TRUCKS
0.27

AVERAGE LOAD EQUIVALENCE FACTOR
3.35

AVERAGE DAILY TRAFFIC
1818.00

NUMBER OF DAYS PER SEASON
74.00

COEFFICIENT OF VARIATION OF Nf IN PERCENTAGE
42.00

COEFFICIENT OF VARIATION OF n IN PERCENTAGE
42.00

THE OUTPUT FOR FATIGUE MODE OF FAILURE

NUMBER OF CUMULATIVE ESALS
1365394.91

ALLOWABLE 8200kg ESAL APPLICATION WITH RESPECT TO FATIGUE
3023331397.00

TOTAL NUMBER OF ESTIMATED FUTURE VEHICLES
2975040.65

FUTURE TOTAL GROWTH FACTOR
   1636.44

Nf DISTRIBUTION MODEL IS GUMBEL AND THE
n DISTRIBUTION MODEL IS GUMBEL

RELIABILITY/SAFETY INDEX
 4.55

1.   SYSTEM PROBABILITY OF FAILURE(using  C0V=25%)
0.05

SYSTEM SAFETY INDEX
3.77

2.   SYSTEM PROBABILITY OF FAILURE(using  C0V=25%)
0.01

SYSTEM SAFETY INDEX
 4.15

3.   SYSTEM PROBABILITY OF FAILURE(using  C0V=25%)
0.007

SYSTEM SAFETY INDEX
 4.80

1.   SYSTEM PROBABILITY OF FAILURE(using  C0V=42%)
0.18

SYSTEM SAFETY INDEX
 2.14

2.   SYSTEM PROBABILITY OF FAILURE(using  C0V=42%)
0.07

```
SYSTEM SAFETY INDEX
 2.22

3.   SYSTEM PROBABILITY OF FAILURE(using  C0V=42%)
0.03

SYSTEM SAFETY INDEX
 3.07
```