CRC for Construction Innovation (2005) *Report : stochastic analysis of road asset data for maintenance cost prediction.* CRC for Construction Innovation, Brisbane.

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Report
Stochastic Analysis of Road Asset Data for Maintenance Cost Prediction

Research Project No: 2003-029-C-03

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Research Program: C
Delivery and Management of Built Assets

Project: 2003-029-C
Maintenance Cost Prediction for Roads

Date: September 2005

Leaders in Construction and Property Research

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PREFACE

The report is part of CRC CI research project 2003-029-C “Maintenance Cost Prediction for Roads”. The aim of this research project is to develop a method for assessing reliable budget/cost estimates for road maintenance and rehabilitation investment. The method takes into account the variability of critical input parameters including road asset conditions and annual average daily traffic in the analysis.

The authors wish to acknowledge the Cooperative Research Centre for Construction Innovation (CRC CI) for their financial support. The authors also wish to thank Mr. John Spathonis of Queensland Department of Main Roads, and Mr. Dale Gilbert of Queensland Department of Public Works for their constant support and feedback.

EXECUTIVE SUMMARY

Reliable budget/cost estimates for road maintenance and rehabilitation are subjected to uncertainties and variability in road asset condition and characteristics of road users. The CRC CI research project 2003-029-C 'Maintenance Cost Prediction for Road' developed a method for assessing variation and reliability in budget/cost estimates for road maintenance and rehabilitation. The method is based on probability-based reliable theory and statistical method. The next stage of the current project is to apply the developed method to predict maintenance/rehabilitation budgets/costs of large networks for strategic investment. The first task is to assess the variability of road data. This report presents initial results of the analysis in assessing the variability of road data. A case study of the analysis for dry non reactive soil is presented to demonstrate the concept in analysing the variability of road data for large road networks. In assessing the variability of road data, large road networks were categorised into categories with common characteristics according to soil and climatic conditions, pavement conditions, pavement types, surface types and annual average daily traffic. The probability distributions, statistical means, and standard deviation values of asset conditions and annual average daily traffic for each type were quantified. The probability distributions and the statistical information obtained in this analysis will be used to asset the variation and reliability in budget/cost estimates in later stage.

Generally, we usually used mean values of asset data of each category as input values for investment analysis. The variability of asset data in each category is not taken into account. This analysis method demonstrated that it can be used for practical application taking into account the variability of road data in analysing large road networks for maintenance/rehabilitation investment analysis.

1. Introduction

The Cooperative Research Centre for Construction Innovation (CRC CI) in Australia led by RMIT University has developed a method for assessing variation and reliability in budget/cost estimates for road maintenance and rehabilitation. This method is based on probability-based reliability theory and statistical method. Details of the methodology are given in CRC-CI Report 2003-029-C-002 ‘Development of a Methodology for Assessing Variation in Maintenance and Rehabilitation Costs’.

The aim of the research work is to apply the method to assess variation and reliability in budget/cost estimates for maintenance and rehabilitation for large road networks. Figure 1 shows a framework of this research study.

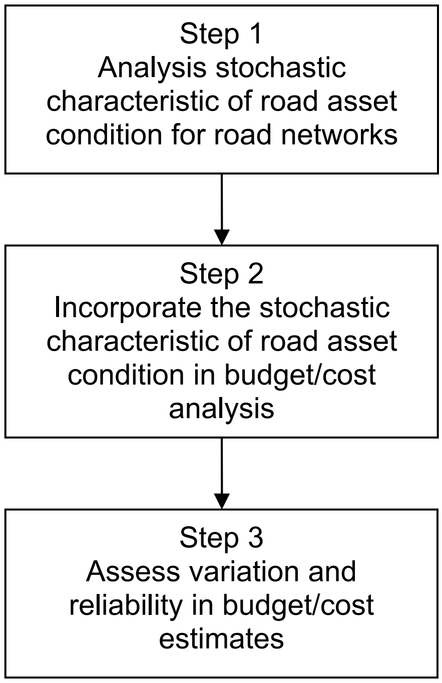

Figure 1 Framework of study

The first task in the cost/budget analysis is to assess the variability or the stochastic characteristics of the road network. The report presents results of the stochastic analysis of road asset condition of a large road network located in the state of Queensland. To demonstrate the concept, national highways located in dry non reactive soils were used in the analysis. The analysis method is based on categorising road networks into categories of common characteristics. The stochastic characteristic of road asset condition and road vehicles for each category is statistically quantified. The overall categories and their associated road condition stochastic characteristics will eventually be used in Step 2 (in the above figure) for assessing the variation in budget/cost estimates.

2. Method of Stochastic Analysis of Road Asset Condition

Road asset condition may include road pavement strength, pavement roughness, rutting of pavement surface, cracking, pothole and so forth. Factors that affect road asset condition may include road vehicles, climatic condition, soil condition, etc. Piyatrapoomi et al (2005) identified that pavement strength, roughness, rutting and road user traffic made significant contribution to variation and reliability in budget/cost estimates. In this study, pavement roughness, rut depth and average annual daily traffic were extracted from Queensland Government Department of Main Road's database. Pavement strength data will be collected in later stage. The steps of the analysis include;

1) Categorise road network into different categories, which each category has common characteristics.
2) Statistically quantify pavement roughness, rut depth, annual average daily traffic and pavement strength for each category.

3. Categorisation of Road Pavement

Categorisation criteria of road network are based on annual average daily traffic, pavement roughness conditions, climatic zones, soil conditions, surface types and base types. In this study two types of surface types including bitumen and asphalt concrete were used. Three types of pavement bases including flexible, semi rigid and full depth asphalt were used. Seven levels of annual average daily traffics were used including annual average daily traffic of less than 500, 501-1500, 1501-3000, 3001-5000, 5001-10000, 10001-25000, and greater than 25000. Three pavement roughness conditions were used including good in which international roughness index (IRI) is less than 2.31, fair in which IRI is greater than 2.31 and less than 4.2, and poor in which IRI is greater than 4.2. Four climatic and soil conditions were used including wet non reactive soils, dry and non reactive soils, wet reactive soil and dry reactive soils. Figure 2 shows climatic and soil conditions classified by Queensland Department of Main Roads for road asset management purposes. Green colour (G) represents wet non reactive soils, blue (B) represents dry reactive soils while red (R) represent dry non reactive soils, yellow represents wet reactive soil. Table 1 summaries the categorisation criteria used in the analysis.

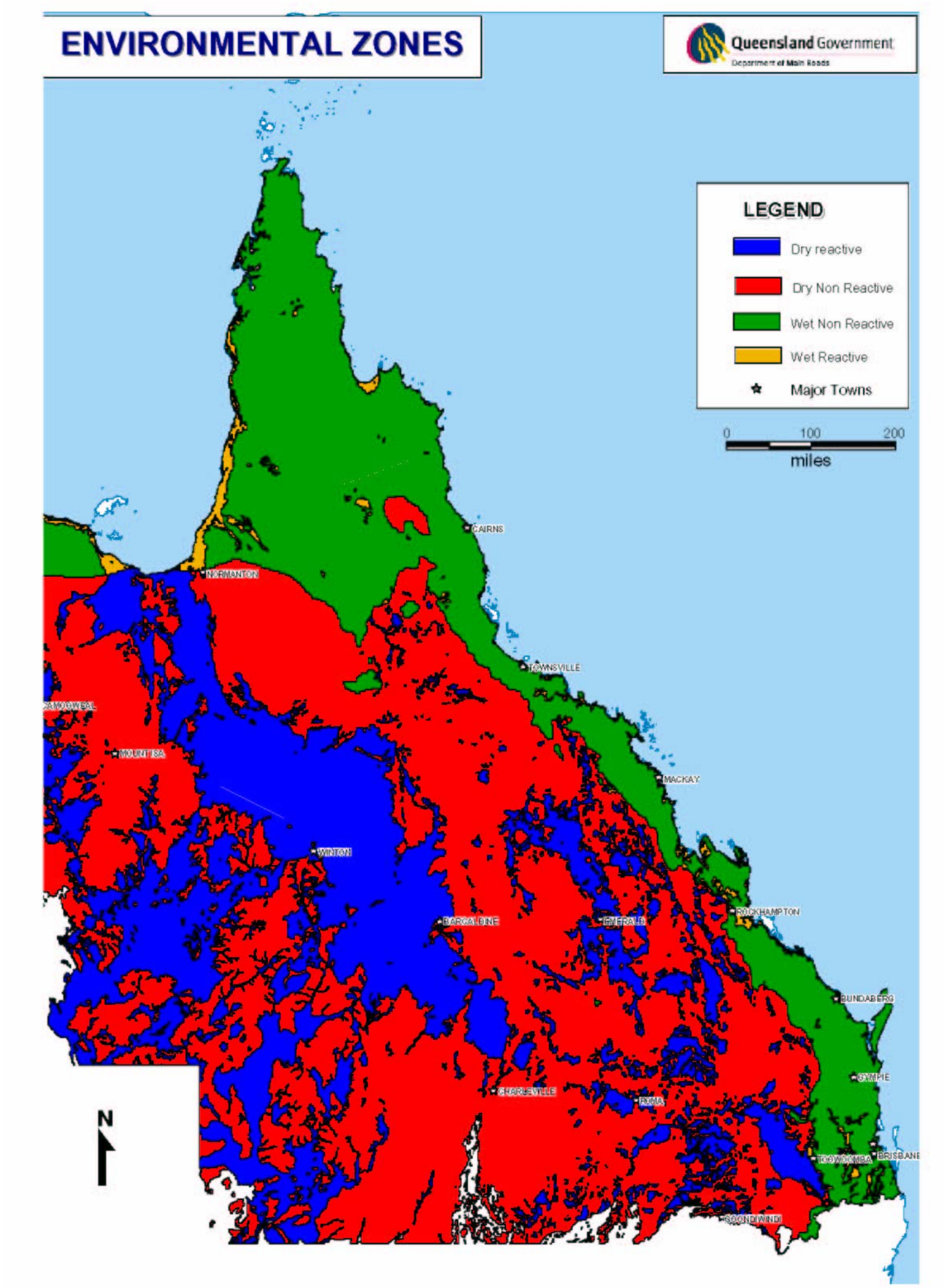

Figure 2 Climatic zones and soil conditions

Table 1 Criteria used for categorising road pavements

Annual Average Daily Traffic	Pavement Roughness (IRI)	Surface Types	Base Types	Climatic and Soil Types
< 500	Good (IRI<2.31)	Bitumen	Flexible	Wet non Reactive soil
501-1500	Fair (2.31<IRI>4.2)	Asphalt concrete (AC)	Semi Rigid	Dry non Reactive Soil
1501-5000	Poor (IRI>4.2)		Full Depth Asphalt	Wet Reactive Soil
5001-10000				Dry Reactive Soil
10001-25000				
>25000				

For simplicity in identifying road categories, generic identifications were developed. Descriptions of the generic identifications are described as follows:

For soil and Climatic conditions

WNR = wet non reactive soil
DR = Dry reactive soil
DNR = Dry non reactive soil

For pavement roughness conditions

Poor = IRI > 4.2
Fair = 2.31 < IRI < 4.2
Good = IRI <2.31

Note: IRI refers to International Roughness Index

For Pavement Surface Types

AC = Asphalt concrete surfacing
Bt = Bitumen surfacing

For Pavement Types

Flx = Flexible pavement
SR = Semi rigid
FDA = Full depth asphalt

For Annual Average Daily Traffic (AADT)

< 0.5k = AADT less than 500
0.5k-1.5k = AADT between 501-1500
1.5k-3k = AADT between 1501-3000
3k-5k = AADT between 3001-5000
5k-10k = AADT between 5001-10000
10k-25k = AADT between 10001-25000
> 25k = AADT greater than 25000

Road Category Identification

Identification of a road category may be written as follows:

'WNR-Good-Bt-Flx-(1.5k-3k)'

which is referred to a road category located in wet non reactive soil, IRI < 2.31, bitumen surfacing, flexible pavement type, ADDT between 1501-3000, respectively.

National highways located in dry non reactive soil were used to demonstrate the analysis concept. The national highways were categorised according to the criteria given in Table 1. Eighteen categories were obtained from the categorisation. It must be noted that only the categories that have data were obtained. Tables 2 give categories of the national located in dry non reactive soil.

In 'ID' column of Table 2, R1-R18 represents road categories in red areas (i.e. dry non reactive soil). As described above, In 'Description' column of Tables 2, 'DNR' stand for dry non reactive soil. 'Good' means roughness of IRI less than 2.31. 'Fair' is IRI is greater than 2.31 but less than 4.2, while 'Poor' means IRI is greater than 4.2. 'Bt' stands for bitumen surfacing while 'AC' stands for asphalt concrete. 'Flx' means flexible pavement, SR refers to semi rigid pavement. The terms '0.5k, 1.5k, 3k, 5k, 10k, 25k' refer to annual average daily traffic of 500, 1500, 3000, 5000, 10000 and 25000, respectively.

Table 2 Road Categories for Dry Non Reactive Soil

No	ID	Description	Climatic Zone	Surface Type	Pavement Type	Roughness IRI	AADT
1	R1	DNR-Good-Bt-Flx-(<0.5k)	Dry Non Reactive	Bitumen	Flexible	< 2.31	<500
2	R2	DNR-Good-Bt-Flx-(0.5k-1.5k)	Dry Non Reactive	Bitumen	Flexible	< 2.31	501-1500
3	R3	DNR-Good-Bt-Flx-(1.5k-3k)	Dry Non Reactive	Bitumen	Flexible	< 2.31	1501-3000
4	R4	DNR-Good-Bt-Flx-(3k-5k)	Dry Non Reactive	Bitumen	Flexible	< 2.31	3001-5000
5	R5	DNR-Good-Bt-Flx-(5k -10k)	Dry Non Reactive	Bitumen	Flexible	< 2.31	5001-10000
6	R6	DNR-Good-Bt-Flx-(10k-25k)	Dry Non Reactive	Bitumen	Flexible	< 2.31	10001-25000
7	R7	DNR-Fair-Bt-Flx-(<0.5k)	Dry Non Reactive	Bitumen	Flexible	2.31-4.2	<500
8	R8	DNR-Fair-Bt-Flx-(0.5k-1.5k)	Dry Non Reactive	Bitumen	Flexible	2.31-4.2	501-1500
9	R9	DNR-Fair-Bt-Flx-(1.5k-3k)	Dry Non Reactive	Bitumen	Flexible	2.31-4.2	1501-3000
10	R10	DNR-Fair-Bt-Flx-(3k-5k)	Dry Non Reactive	Bitumen	Flexible	2.31-4.2	3001-5000

Table 2 Road Categories for Dry Non Reactive Soil /Continued.

No	ID	Description	Climatic Zone	Surface Type	Pavement Type	Roughness IRI	AADT
11	R11	DNR-Fair-Bt-Flx-(5k-10k)	Dry Non Reactive	Bitumen	Flexible	2.31-4.2	5001-10000
12	R12	DNR-Fair-Bt-Flx-(10k-25k)	Dry Non Reactive	Bitumen	Flexible	2.31-4.2	10001-25000
13	R13	DNR-Poor-Bt-Flx-(<0.5k)	Dry Non Reactive	Bitumen	Flexible	>4.2	<500
14	R14	DNR-Poor-Bt-Flx-(0.5k-1.5k)	Dry Non Reactive	Bitumen	Flexible	>4.2	501-1500
15	R15	DNR-Good-AC-Flx-(0.5k-1.5k)	Dry Non Reactive	AC	Flexible	<2.31	501-1500
16	R16	DNR-Good-AC-Flx-(1.5k-3k)	Dry Non Reactive	AC	Flexible	<2.31	1501-3000
17	R17	DNR-Fair-AC-Flx-(0.5k-1.5k)	Dry Non Reactive	AC	Flexible	2.31-4.2	501-1500
18	R18	DNR-Good-Bt-SR-(0.5k -1.5k)	Dry Non Reactive	Bitumen	Semi Rigid	< 2.31	501-1500

4. Statistical Analysis

This section presents results of statistical analysis of road asset condition and annual average daily traffic for each category. As mentioned, Piyatrapoomi et al (2005) found that pavement strength, roughness, rut depth and annual average daily traffic were significant contributions in the variation in budget/cost estimates. Probability distributions, means and standard deviation values of pavement roughness, average rut depth and annual average daily traffic were quantified. Pavement strength information will be collected and presented at a later stage.

Table 3 presents probability distributions, means and standard deviation values of pavement roughness, average rut depth and annual average daily traffic of the identified eighteen categories. Appendix shows theoretical cumulative probability distributions that are in good-fit with the road data for dry non reactive soils. For roughness, the majority of probability distributions of the eighteen categories were found to have good-fit with beta general distributions. Logistic, log normal and normal distributions were also found to be in good-fit with the data in some categories. For average rut depth, the most common probability distributions that are in good-fit with the data were found to be log normal distributions. For annual average daily traffic, the data were not in good-fit with any probability distributions. This may be due to the fact that the annual average daily traffic data were collected at certain locations and in some cases via weigh in motion (WIM) at some locations. Thus, the data were dictated by locations of collection. However, the data show some trend in good fit with triangular and exponential distributions.

In Appendix, details of statistical parameters of the probability distributions are given below:

- BetaGeneral($\alpha1$,$\alpha2$, min, max): Beta General probability distribution is specified with shape parameters, $\alpha1$,$\alpha2$, minimum and maximum values.
- Expon(β): Exponential distribution is specified with a decay constant β.
- Logistic(α, β): Logistic distribution is specified with a location parameter, α, and a scale parameter, β.
- Loglogistic(γ, α, β): Log logistic distribution is specified with a location parameter, γ, a shape parameter, α, and a scale parameter, β.
- Lognorm(μ, σ): Lognormal distribution is specified with mean, μ, and standard deviation, σ.
- Normal(μ, σ): Normal distribution is specified with mean, μ, and standard deviation, σ.
- Triang(mim, most likely, max): Triangular distribution is specified with a minimum value, most likely and a maximum value.

Table 3 Probability Distributions, Means and Standard Deviation Values of Road Categories for Dry Non Reactive Soil

ID	Description	Roughness (IRI)			Rut Depth (mm)			AADT		
		Mean	SD	Probability Distribution	Mean	SD	Probability Distribution	Mean	SD	Probability Distribution
R1	DNR-Good-Bt-Flx-(<0.5k)	2.32	0.39	Beta General	4.52	1.97	Log Normal	322	52	Triangular
R2	DNR-Good-Bt-Flx-(0.5k-1.5k)	1.70	0.35	Beta General	4.54	2.37	Log Normal	970	244	Normal
R3	DNR-Good-Bt-Flx-(1.5k-3k)	1.72	0.36	Beta General	4.20	2.29	Log Normal	1990	337	Exponential
R4	DNR-Good-Bt-Flx-(3k-5k)	1.82	0.34	Beta General	4.24	2.61	Log Normal	3420	386	Exponential
R5	DNR-Good-Bt-Flx-(5k -10k)	1.80	0.37	Beta General	3.43	1.72	Log Normal	6154	424	Exponential
R6	DNR-Good-Bt-Flx-(10k-25k)	1.70	0.31	Beta General	4.60	1.53	Normal	10035	-	-
R7	DNR-Fair-Bt-Flx-(<0.5k)	2.30	0.48	Beta General	6.14	3.06	Log Normal	311	54	Triangular
R8	DNR-Fair-Bt-Flx-(0.5k-1.5k)	2.90	0.46	Beta General	5.88	2.74	Log Normal	953	210	Triangular
R9	DNR-Fair-Bt-Flx-(1.5k-3k)	2.96	0.47	Beta General	5.53	2.75	Log Normal	1940	428	Exponential
R10	DNR-Fair-Bt-Flx-(3k-5k)	2.89	0.43	Beta General	4.55	2.46	Log Normal	3300	267	Exponential

Table 3 Probability Distributions, Means and Standard Deviation Values of Road Categories for Dry Non Reactive Soil /Continued.

ID	Description	Roughness (IRI)			Rut Depth (mm)			AADT		
		Mean	SD	Probability Distribution	Mean	SD	Probability Distribution	Mean	SD	Probability Distribution
R11	DNR-Fair-Bt-Flx-(5k-10k)	2.90	0.46	Beta General	4.35	1.33	Log Normal	6063	152	Exponential
R12	DNR-Fair-Bt-Flx-(10k-25k)	2.64	0.37	Log Normal	5.40	1.29	Log Normal	10035	-	-
R13	DNR-Poor-Bt-Flx-(<0.5k)	5.07	2.0	Log Normal	6.91	4.0	Log Normal	299	64	Exponential
R14	DNR-Poor-Bt-Flx-(0.5k-1.5k)	4.98	1.92	Log Normal	6.13	2.98	Log Normal	960	205	Triangular
R15	DNR-Good-AC-Flx-(0.5k-1.5k)	1.57	0.36	Log Normal	6.04	1.67	Normal	795	159	Triangular
R16	DNR-Good-AC-Flx-(1.5k-3k)	1.60	0.34	Log Normal	2.47	0.97	Log Normal	2211	345	Triangular
R17	DNR-Fair-AC-Flx-(0.5k-1.5k)	1.83	0.33	Normal	4.01	1.34	Log Normal	720	233	Exponential
R18	DNR-Good-Bt-SR-(0.5k -1.5k)	1.32	0.27	Log Logistic	3.48	1.54	Log Normal	940	-	-

5. Conclusions

This report presents a stochastic analysis of road asset condition and annual averaged daily traffic for large road network. National highways located in dry non reactive soils were used in the analysis to demonstrate the concept. The national highways can be grouped into eighteen categories with common characteristics of soil and climatic conditions, road pavement conditions, pavement types, surface types, annual average daily traffic. The probability distributions and statistical means and standard deviation values of roughness, average rut depth and annual average daily traffic were quantified for each category.

The result of the analysis indicated that beta general distributions were found to give good-fit to the cumulative probability distribution of roughness data. Log normal distributions were found to be in good-fit with the average rut depth data, while triangular and exponential distributions could be used to model the probability distributions of annual average daily traffic. For annual average daily traffic, analysts need to observe the distribution of the data before deciding whether the triangular or exponential distributions should be used.

The probability distribution, mean and standard deviation obtained in this analysis will be used for assessing variation and reliability in budget estimates for road maintenance and rehabilitation.

Auslink network of 4,500 km was selected as a case study for maintenance/rehabilitation investment analysis. A complete analysis of the stochastic characteristic of the 4,500 km Austlink network will be presented in CRC CI Report 2003-029-C/04 (December 2005).

Appendix

This appendix presents comparisons between theoretical cumulative probability distributions and cumulative distributions of data for roughness, average rut depth and annual average daily traffic for dry non reactive soils. Figures (A1-R1) to (A18-R18) show the comparison of the theoretical cumulative probability distributions and cumulative distribution of roughness. Figures (B1-R1) to (B18-R18) show the comparisons of the theoretical cumulative probability distributions and cumulative probability distributions of average rut depth. Figures (C1-R1) to (C15-R17) show the comparisons of the theoretical cumulative distributions and cumulative distributions of annual average daily traffic.

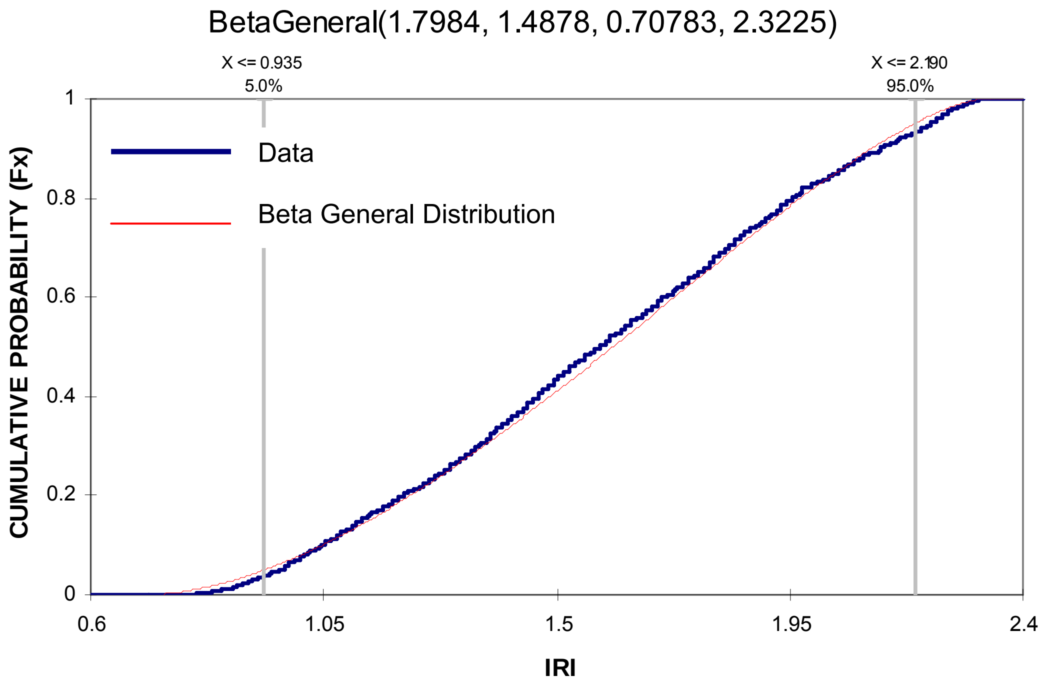

Figure A1-R1. Cumulative probability distributions of roughness for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT<500 (DNR-Good-Bt-Flx-(<0.5k)

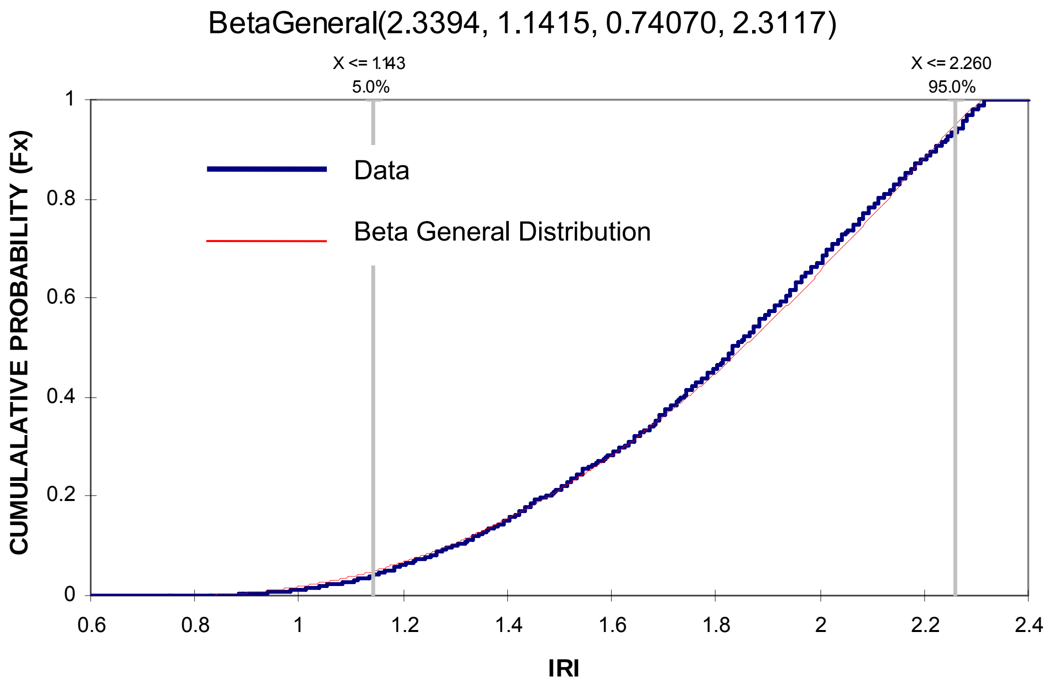

Figure A2-R2. Cumulative probability distributions of roughness for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT=501-1500 (DNR-Good-Bt-Flx-(0.5k-1.5k)

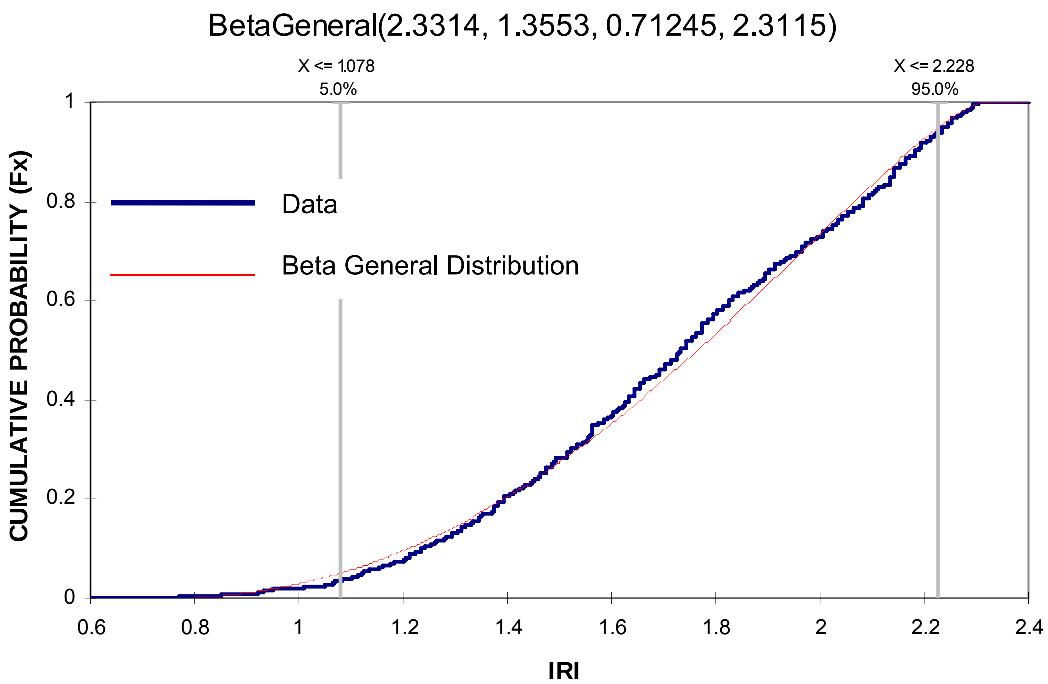

Figure A3-R3. Cumulative probability distributions of roughness for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT=1501-3000 (DNR-Good-Bt-Flx-(1.5k-3k)

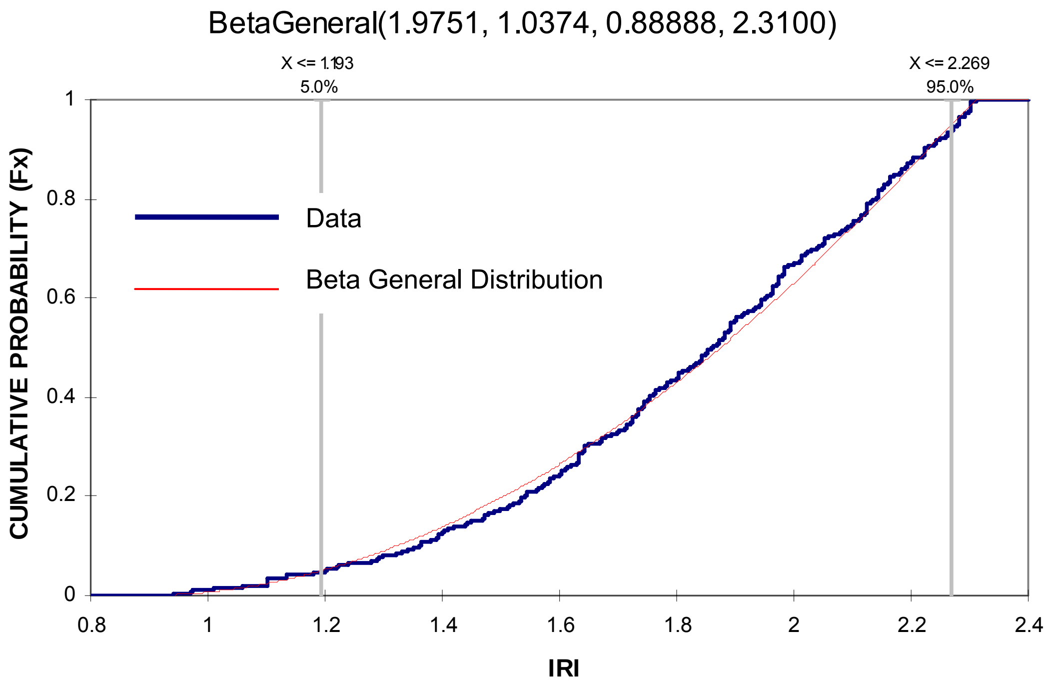

Figure A4-R4. Cumulative probability distributions of roughness for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT=3001-5000 (DNR-Good-Bt-Flx-(3k-5k)

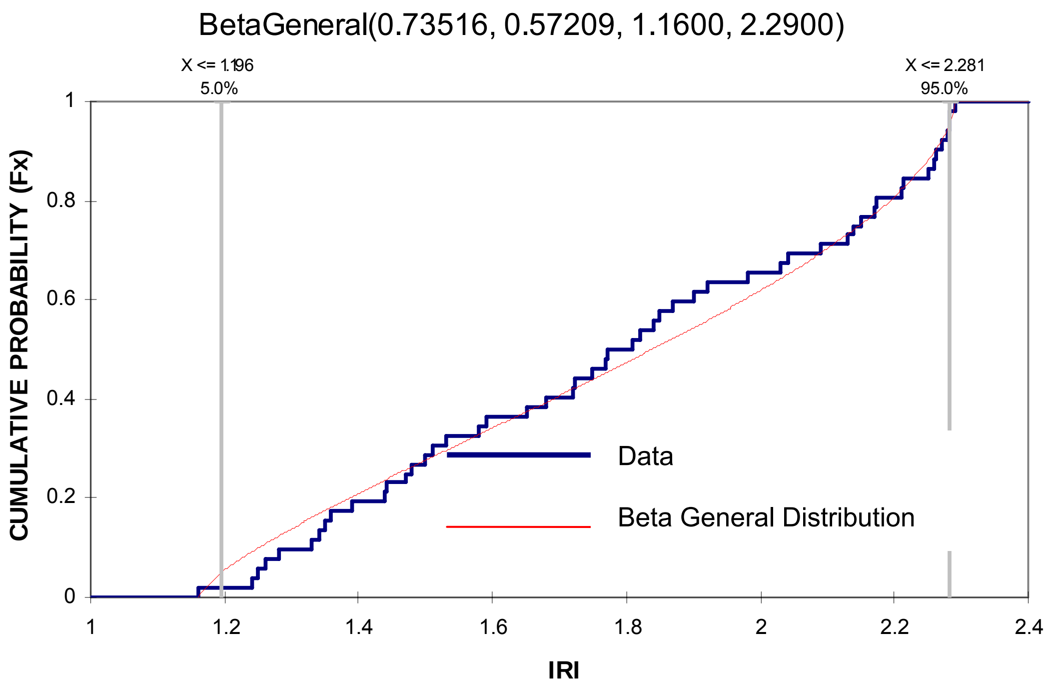

Figure A5-R5. Cumulative probability distributions of roughness for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT=5001-10000 (DNR-Good-Bt-Flx-(5k-10k)

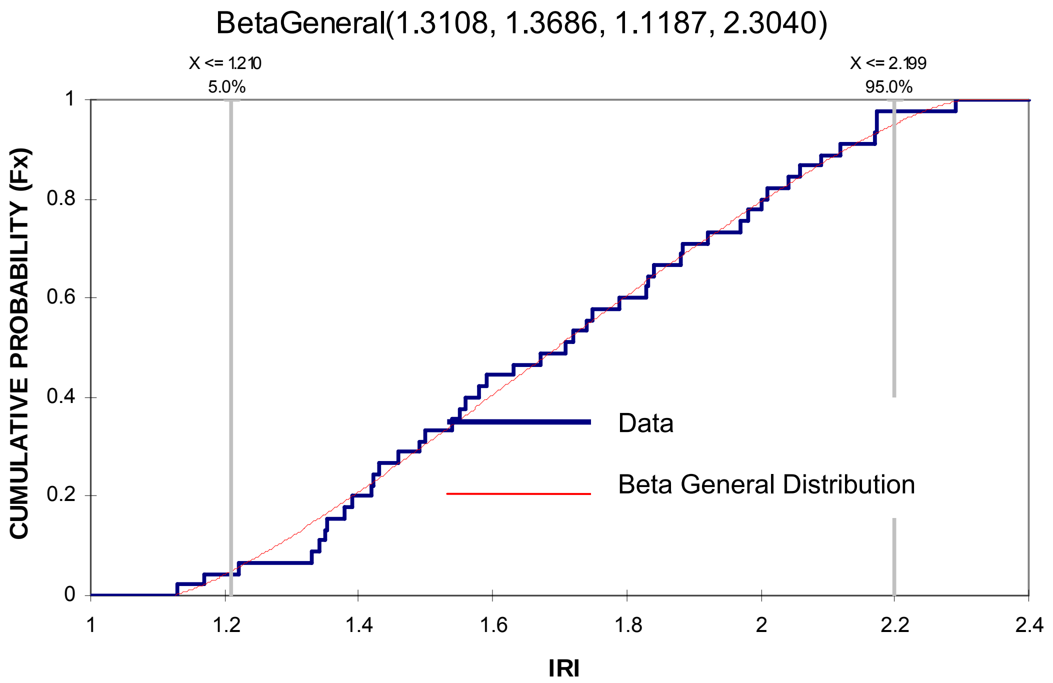

Figure A6-R6. Cumulative probability distributions of roughness for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT=10001-25000 (DNR-Good-Bt-Flx-(10k-25k)

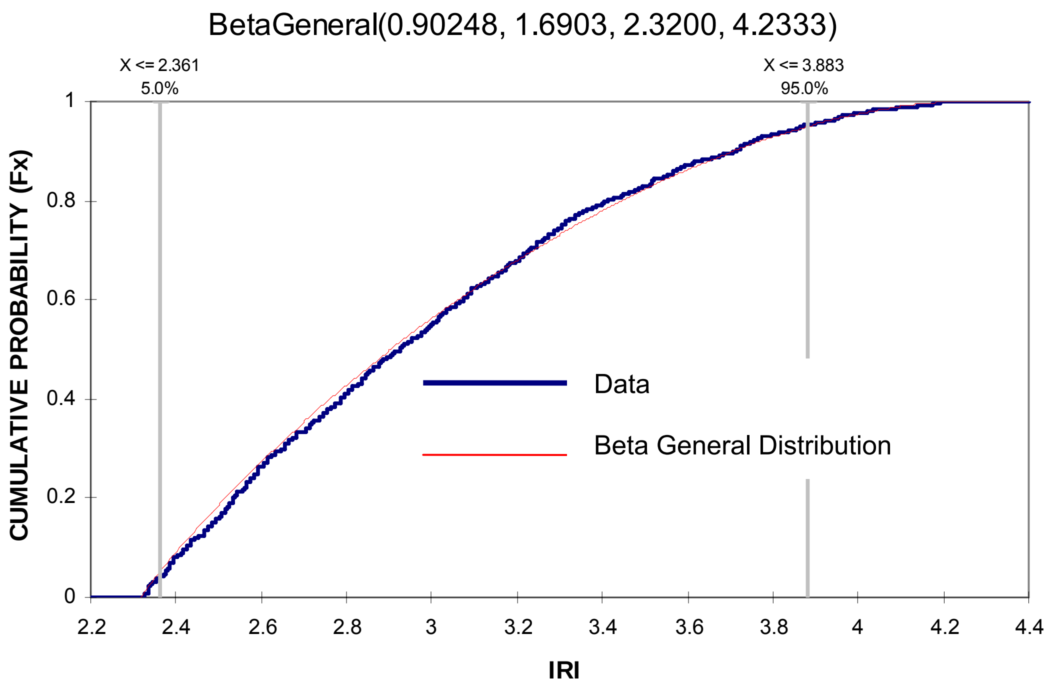

Figure A7-R7. Cumulative probability distributions of roughness for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT<500 (DNR-Fair-Bt-Flx-(>0.5k)

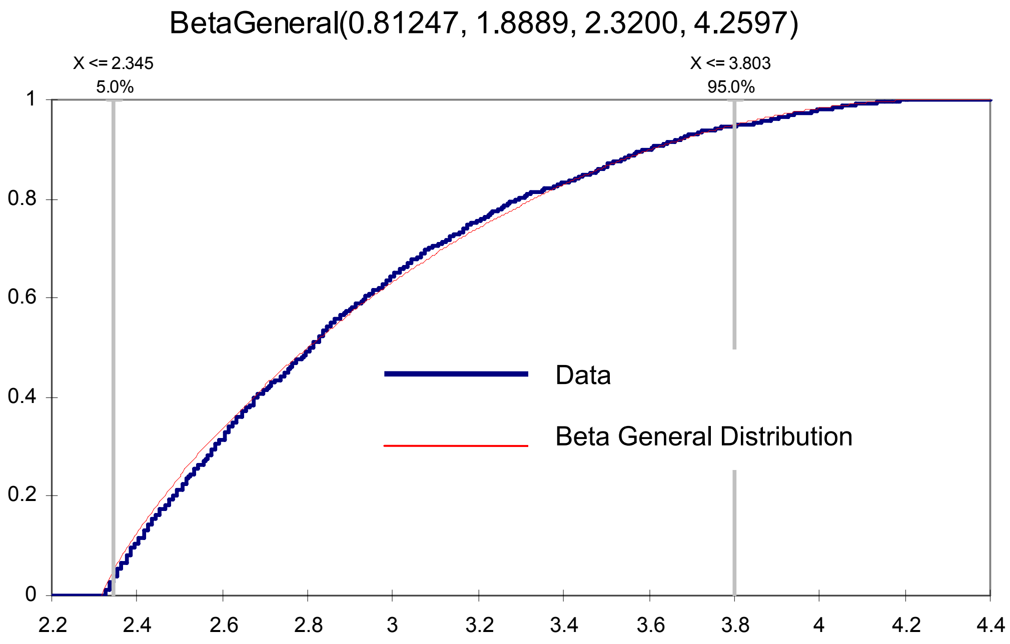

Figure A8-R8. Cumulative probability distributions of roughness for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT=501-1500 (DNR-Fair-Bt-Flx-(0.5k-1.5k)

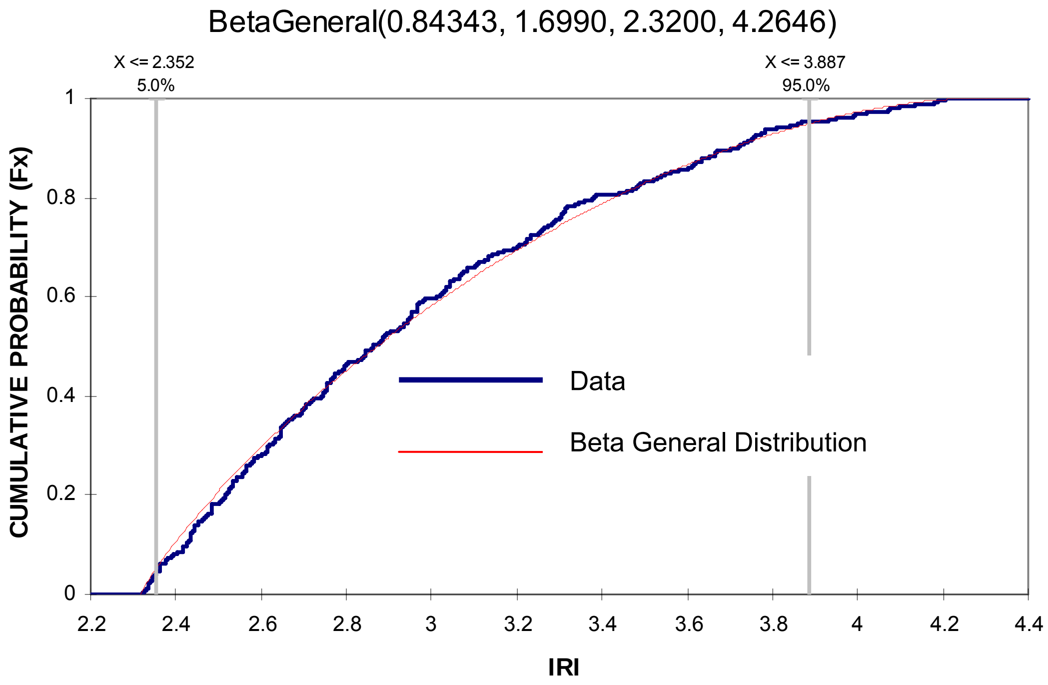

Figure A9-R9. Cumulative probability distributions of roughness for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT=1501-3000 (DNR-Fair-Bt-Flx-(1.5k-3k)

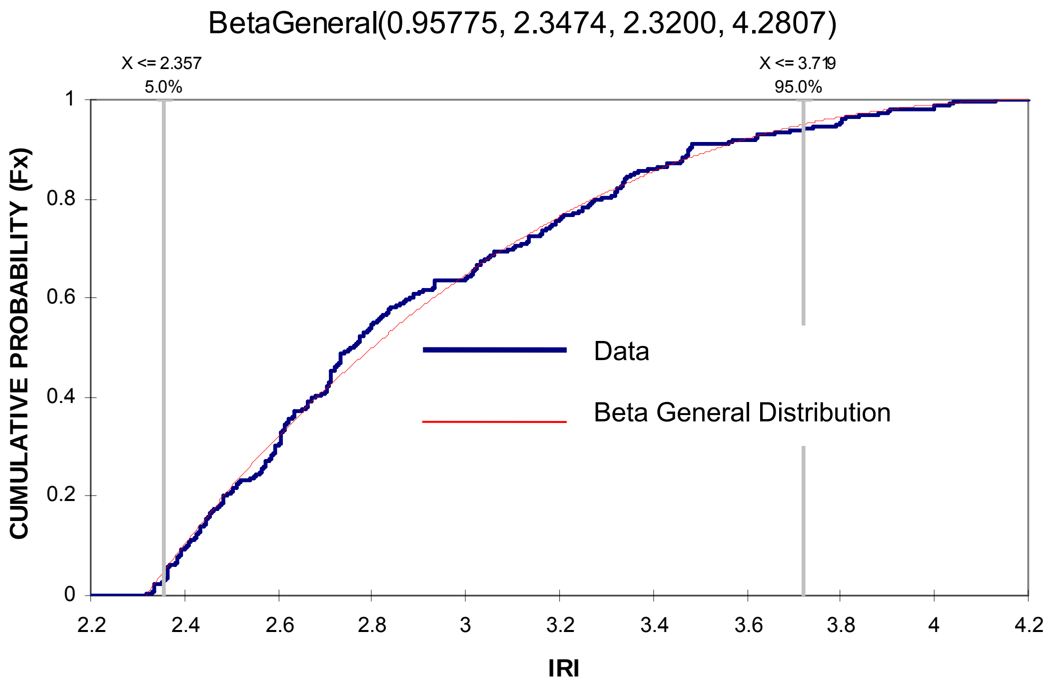

Figure A10-R10. Cumulative probability distributions of roughness for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT=3001-5000 (DNR-Fair-Bt-Flx-(3k-5k)

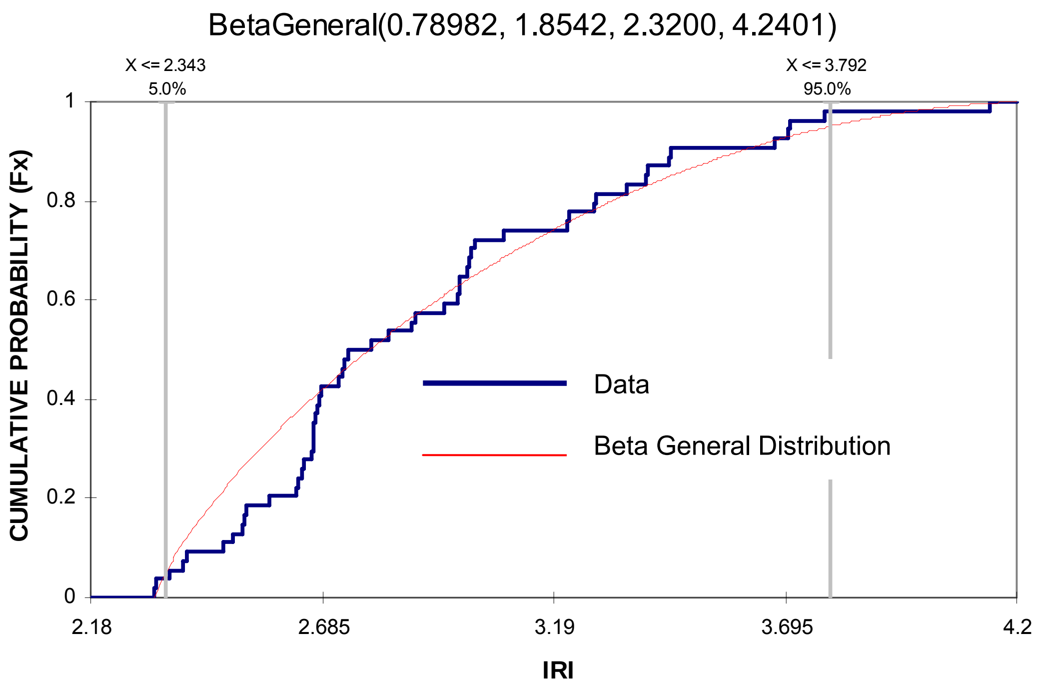

Figure A11-R11. Cumulative probability distributions of roughness for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT=5001-10000 (DNR-Fair-Bt-Flx-(5k-10k)

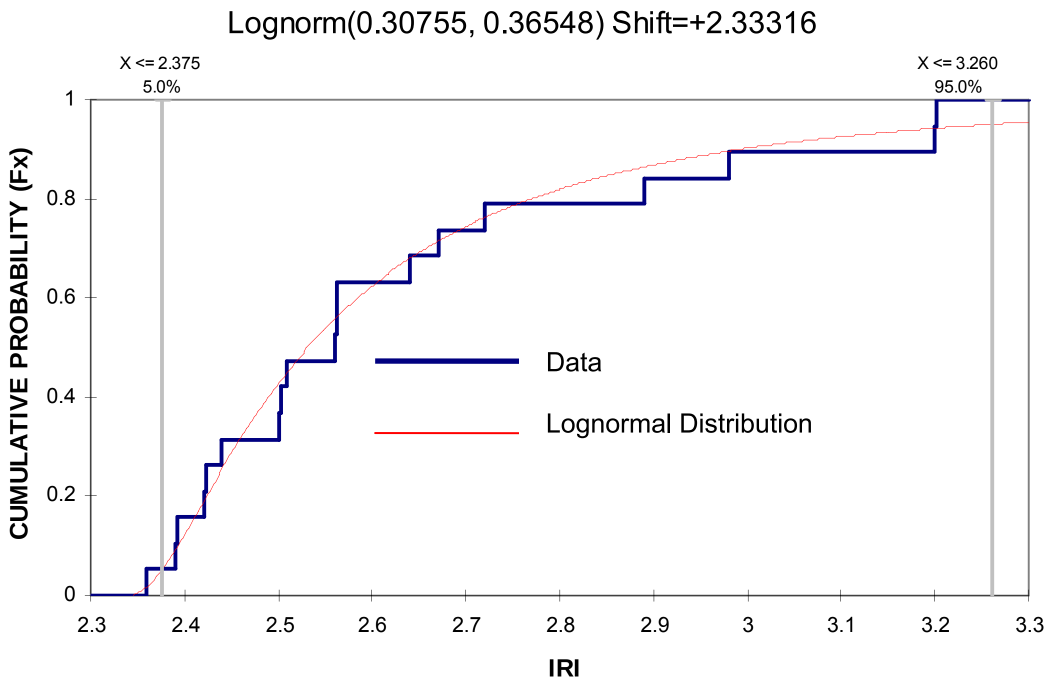

Figure A12-R12. Cumulative probability distributions of roughness for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT=10001-25000 (DNR-Fair-Bt-Flx-(10k-25k)

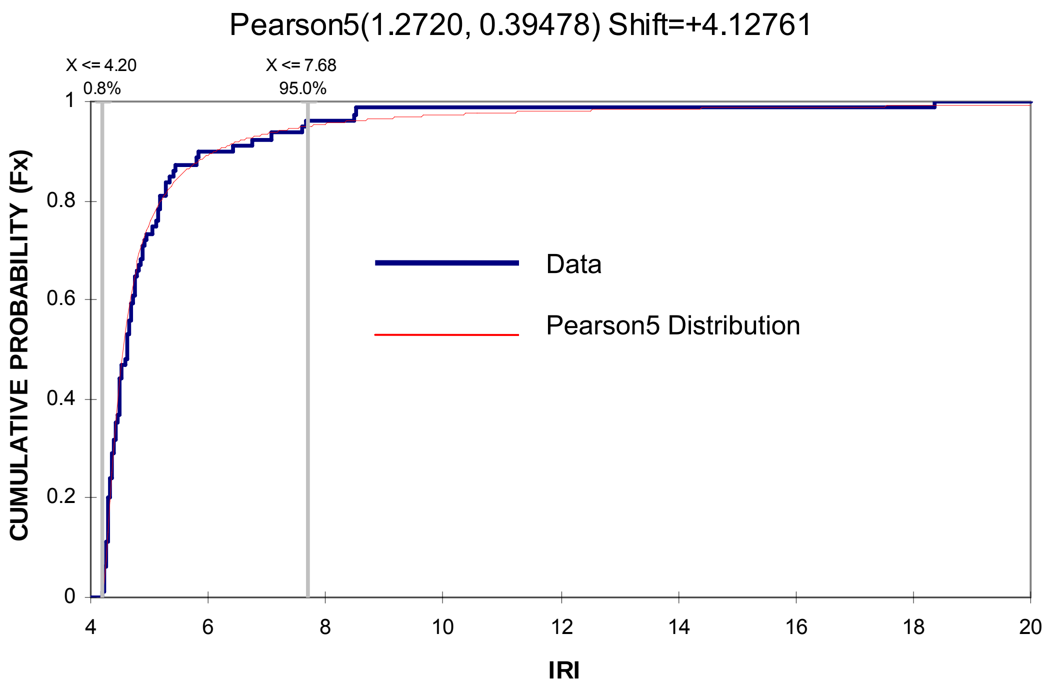

Figure A13-R13. Cumulative probability distributions of roughness for dry non reactive soil, bitumen surfacing, flexible pavement, IRI >4.2, AADT<501 (DNR-Poor-Bt-Flx-(<0.5k)

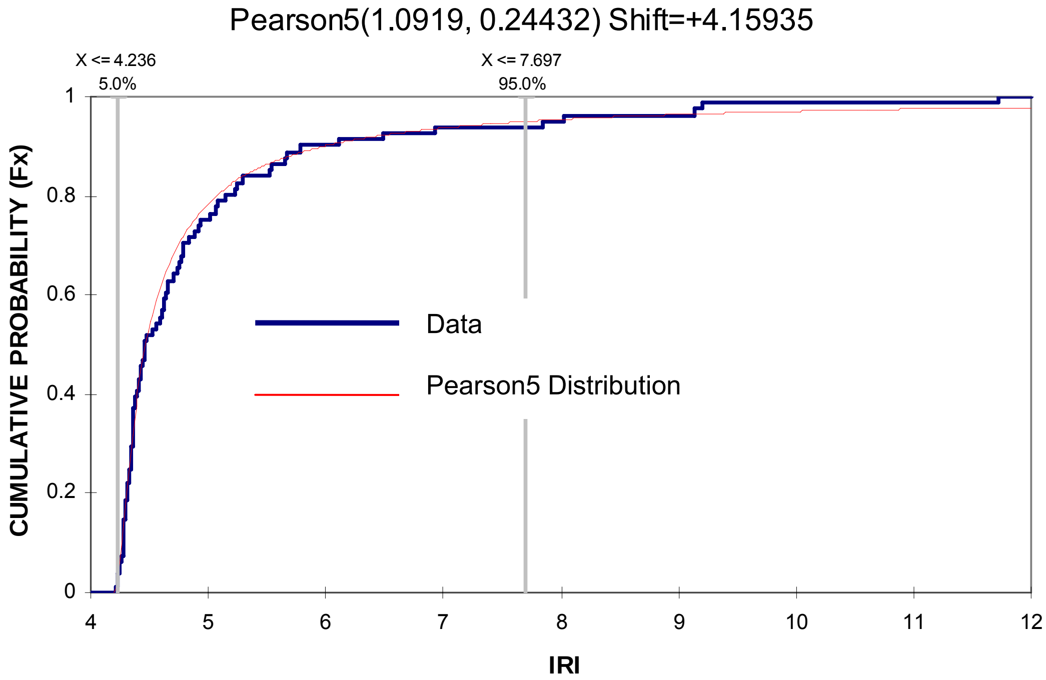

Figure A14-R14. Cumulative probability distributions of roughness for dry non reactive soil, bitumen surfacing, flexible pavement, IRI >4.2, AADT=501-1500 (DNR-Poor-Bt-Flx-(0.5k-1.5k)

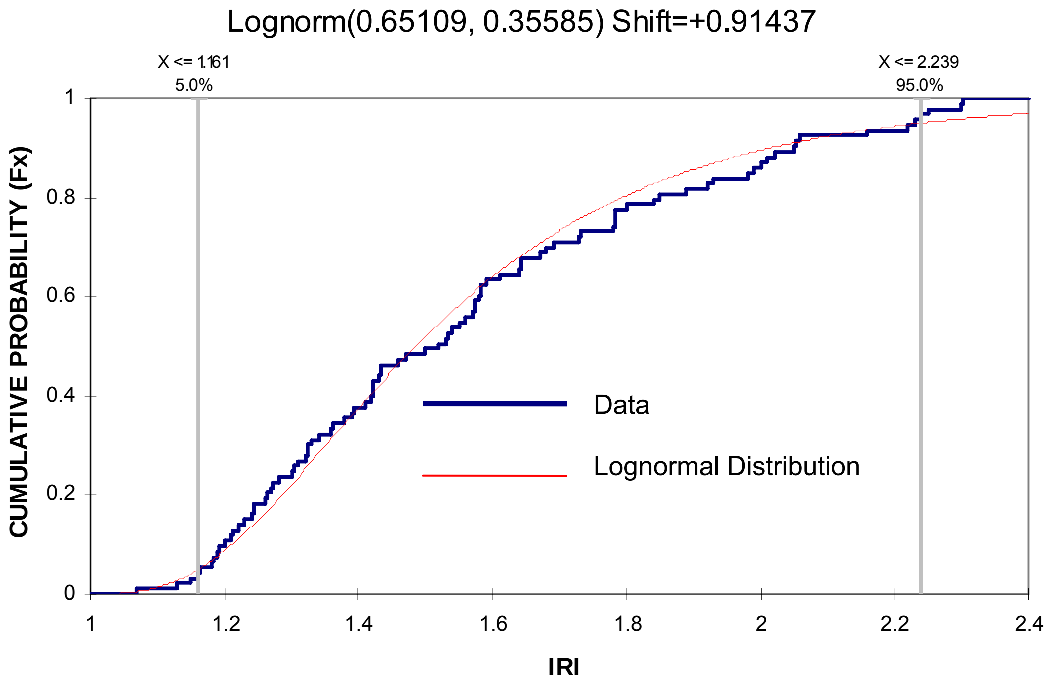

Figure A15-R15. Cumulative probability distributions of roughness for dry non reactive soil, asphalt concrete surfacing, flexible pavement, IRI <2.31, AADT=501-1500 (DNR-Good-AC-Flx-(0.5k-1.5k)

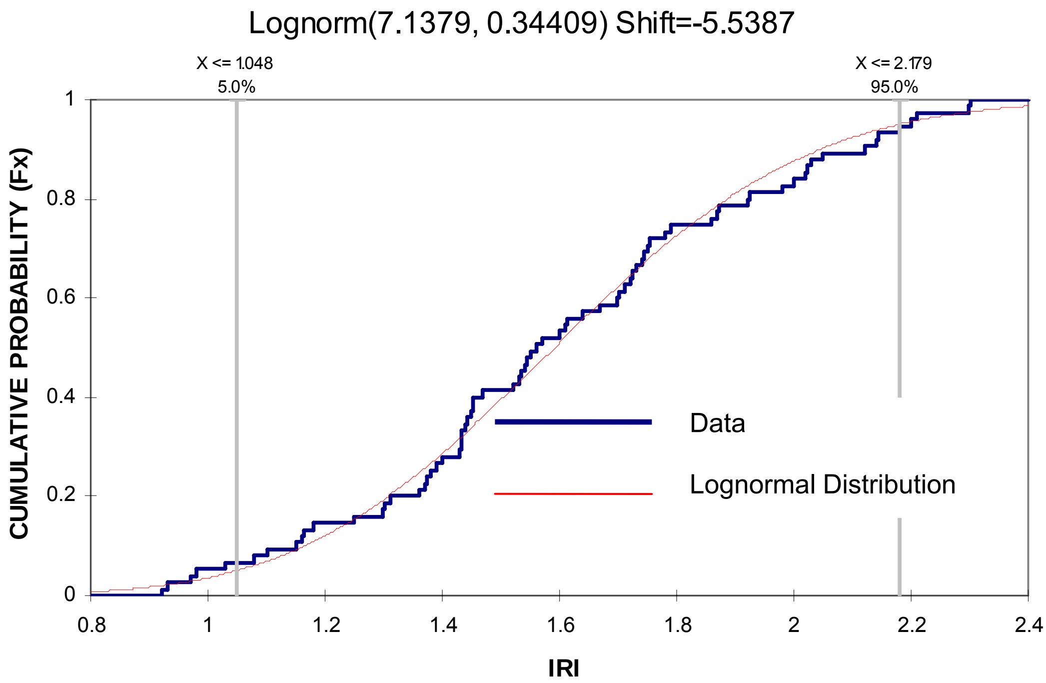

Figure A16-R16. Cumulative probability distributions of roughness for dry non reactive soil, asphalt concrete surfacing, flexible pavement, IRI <2.31, AADT=1501-3000 (DNR-Good-AC-Flx-(1.5k-3k)

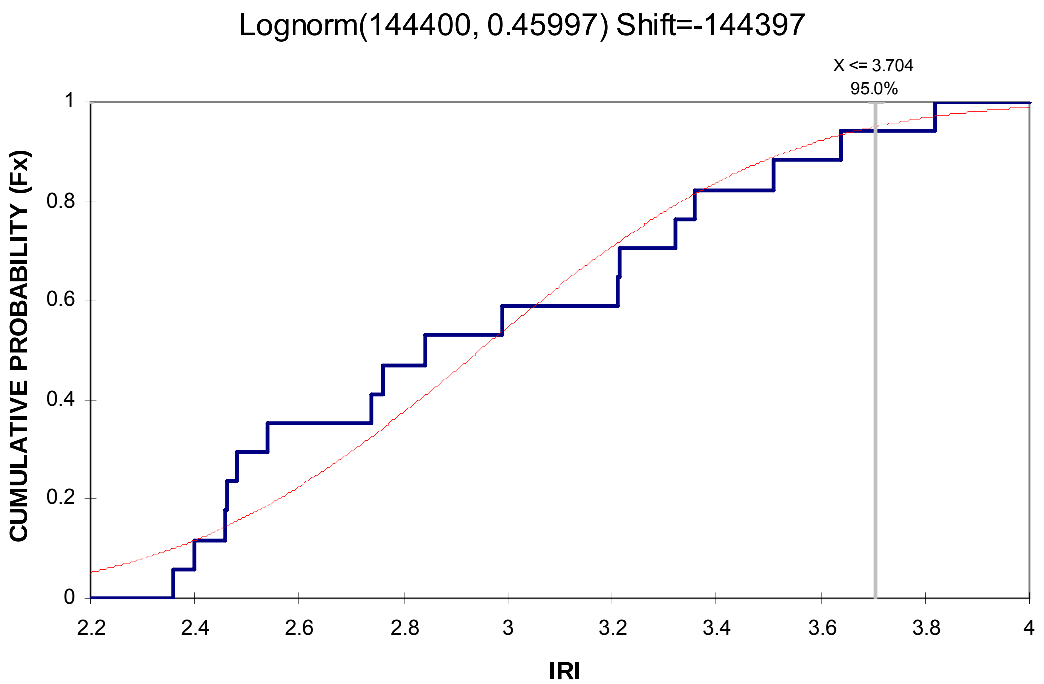

Figure A17-R17. Cumulative probability distributions of roughness for dry non reactive soil, asphalt concrete surfacing, flexible pavement, 2.31< IRI <4.2, AADT=501-1500 (DNR-Fair-AC-Flx-(0.5k-1.5k)

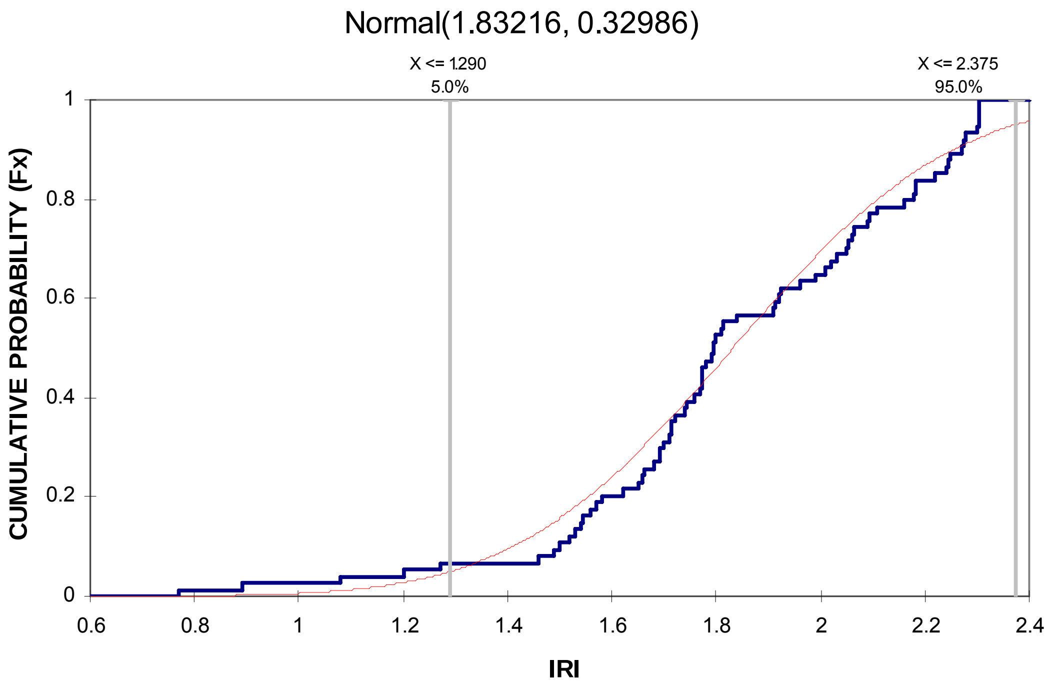

Figure A18-R18. Cumulative probability distributions of roughness for dry non reactive soil, asphalt concrete surfacing, semi rigid pavement, IRI <2.31, AADT=501-1500 (DNR-Good-AC-SR-(0.5k-1.5k)

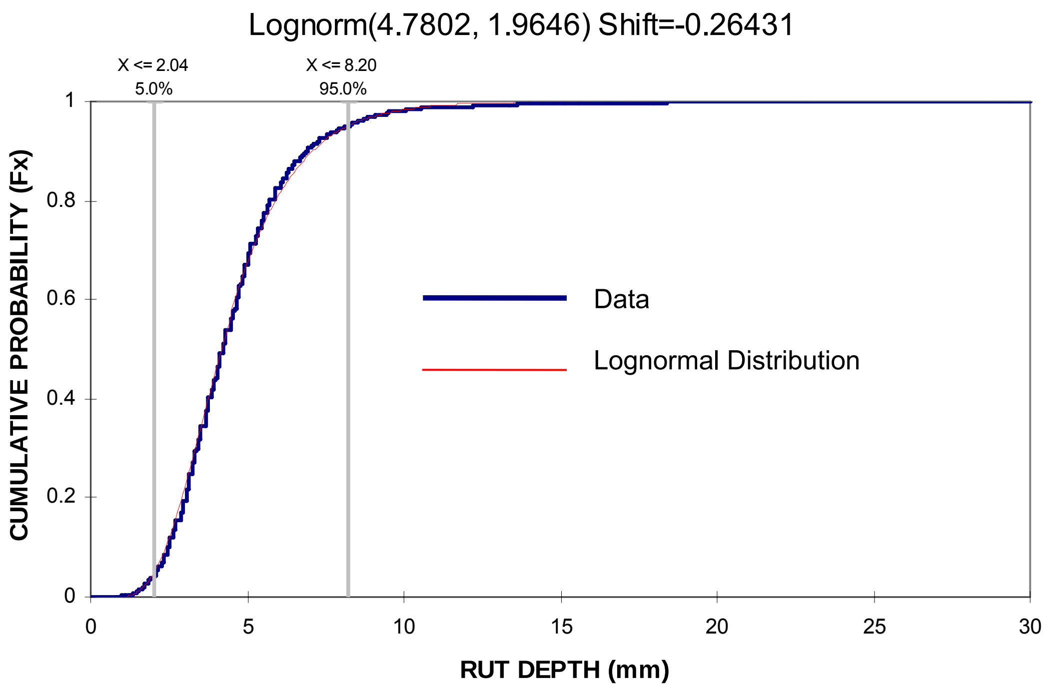

Figure B1-R1. Cumulative probability distributions of average rut depth for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT<500 (DNR-Good-Bt-Flx-(<0.5k)

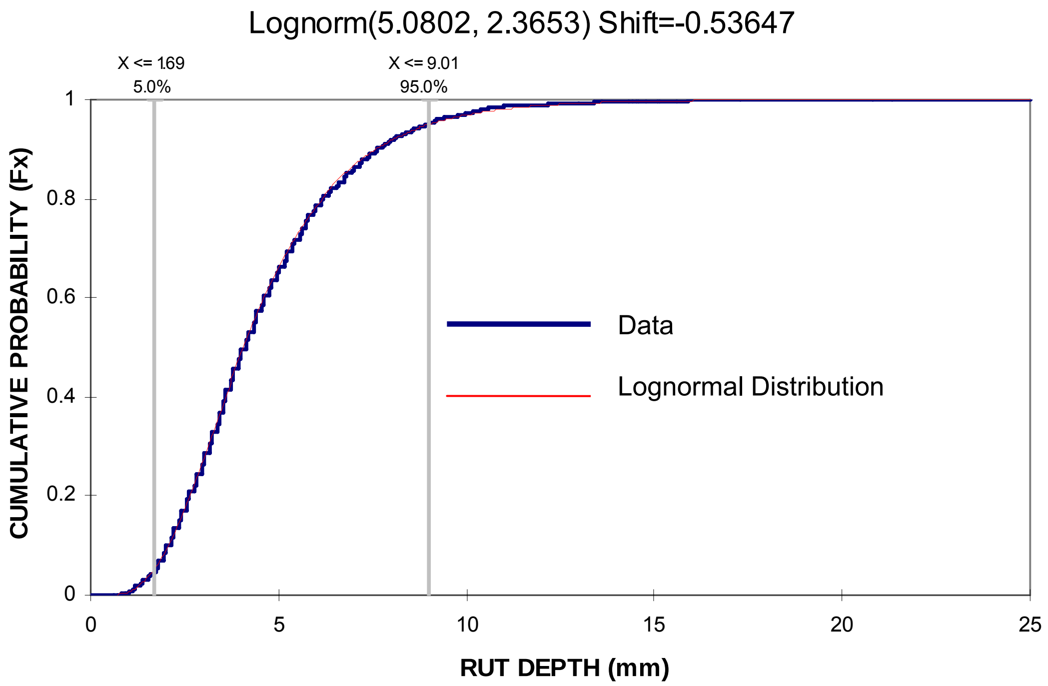

Figure B2-R2. Cumulative probability distributions of average rut depth for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT=501-1500 (DNR-Good-Bt-Flx-(0.5k-1.5k)

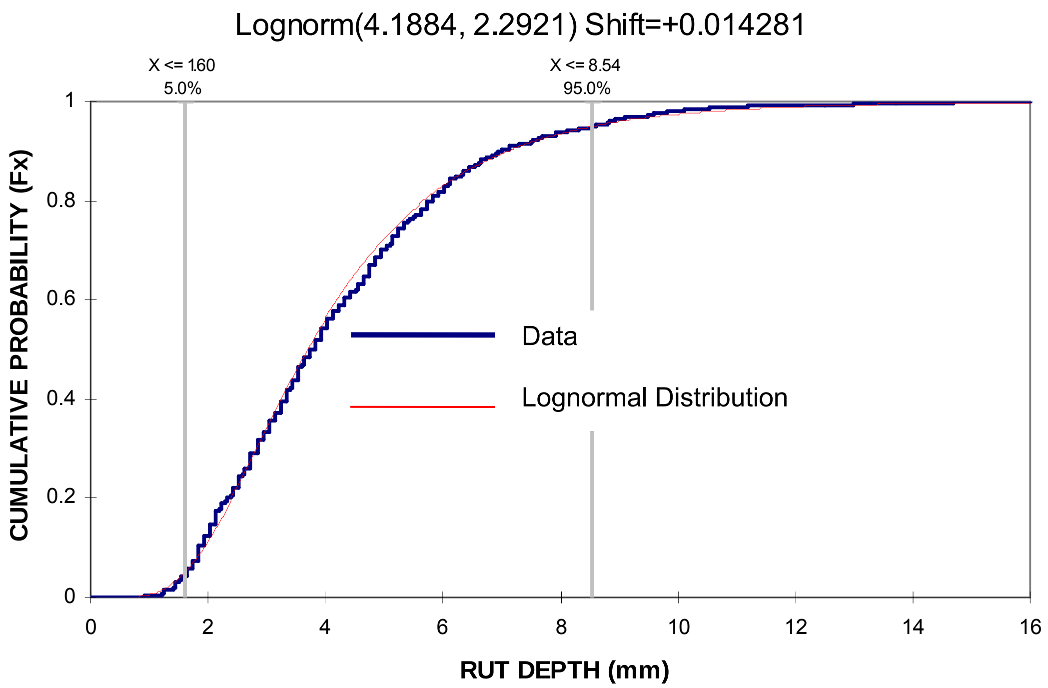

Figure B3-R3. Cumulative probability distributions of average rut depth for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT=1501-3000 (DNR-Good-Bt-Flx-(1.5k-3k)

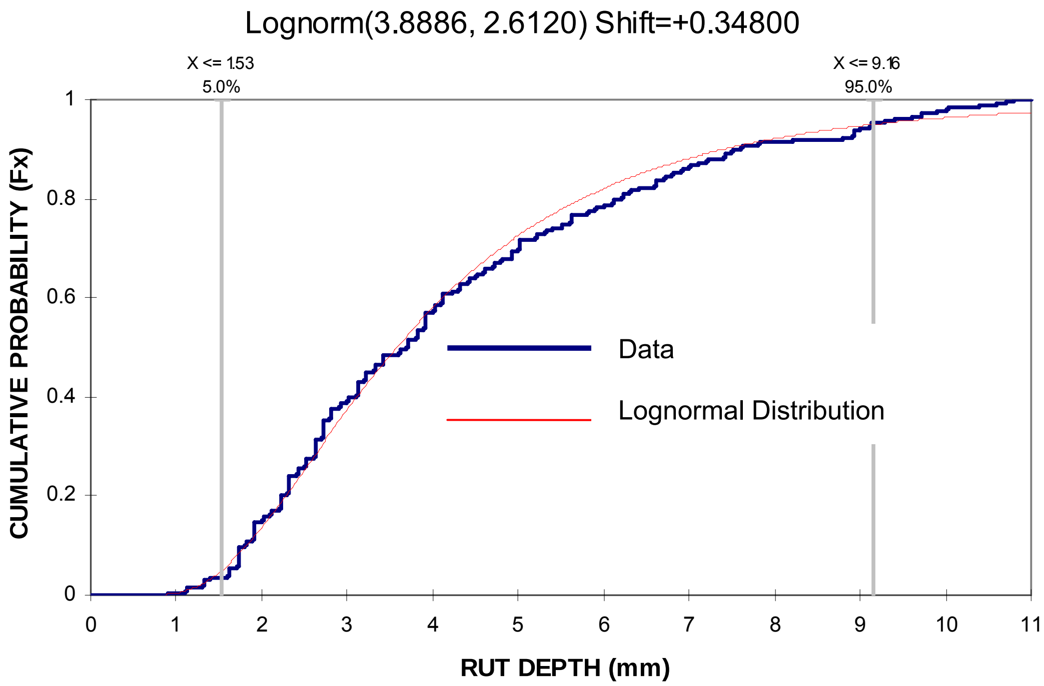

Figure B4-R4. Cumulative probability distributions of average rut depth for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT=3001-5000 (DNR-Good-Bt-Flx-(3k-5k)

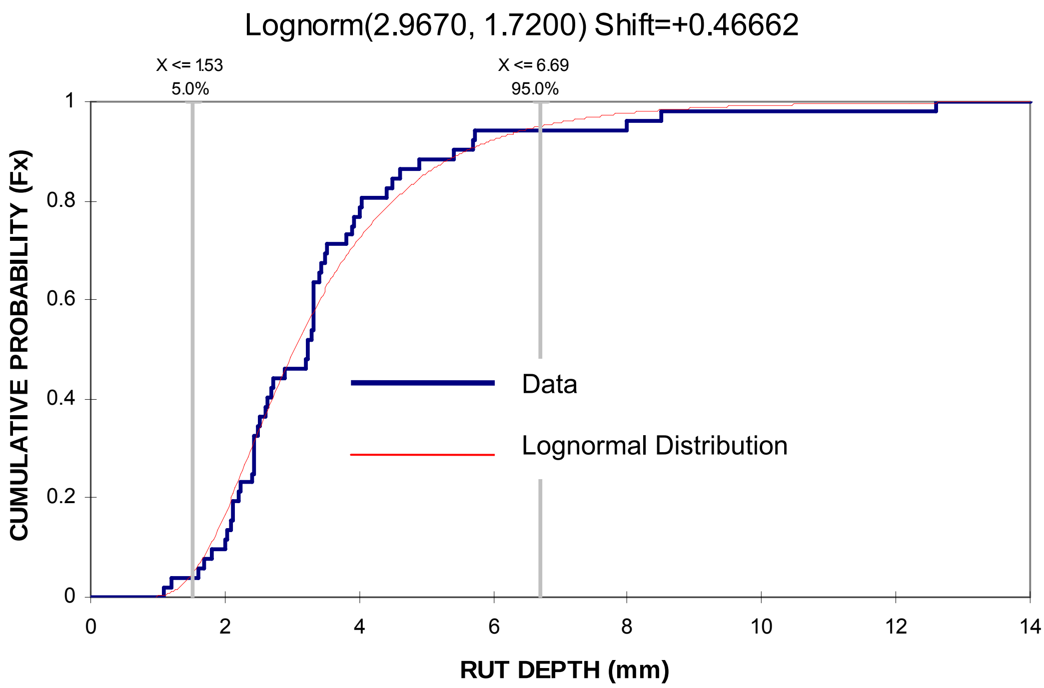

Figure B5-R5. Cumulative probability distributions of average rut depth for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT=5001-10000 (DNR-Good-Bt-Flx-(5k-10k)

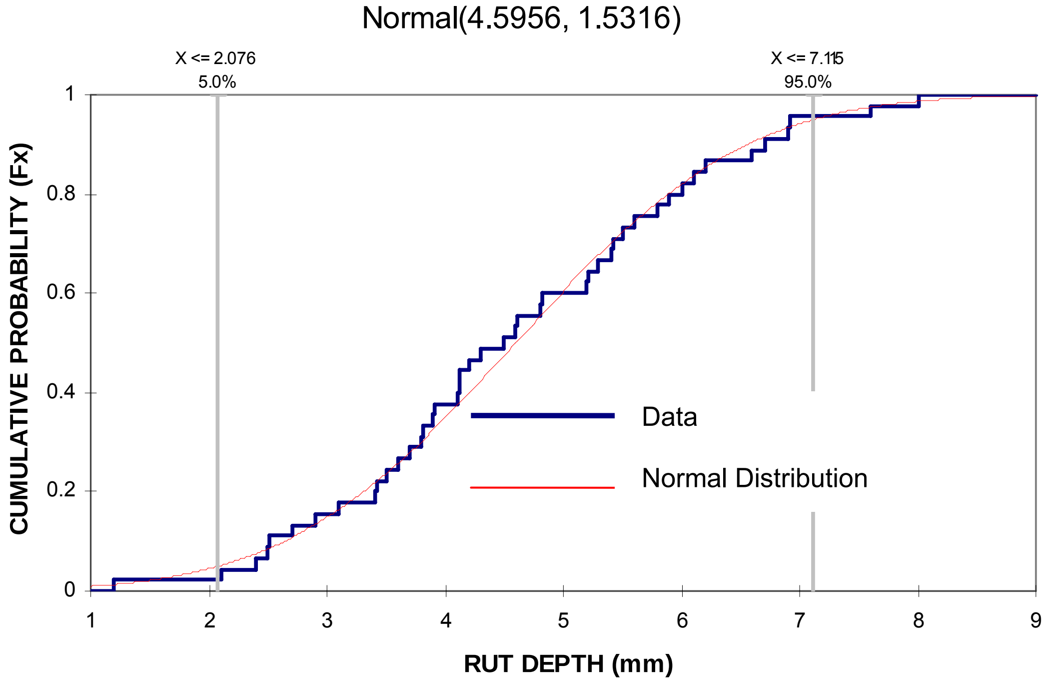

Figure B6-R6. Cumulative probability distributions of average rut depth for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT=10001-25000 (DNR-Good-Bt-Flx-(10k-25k)

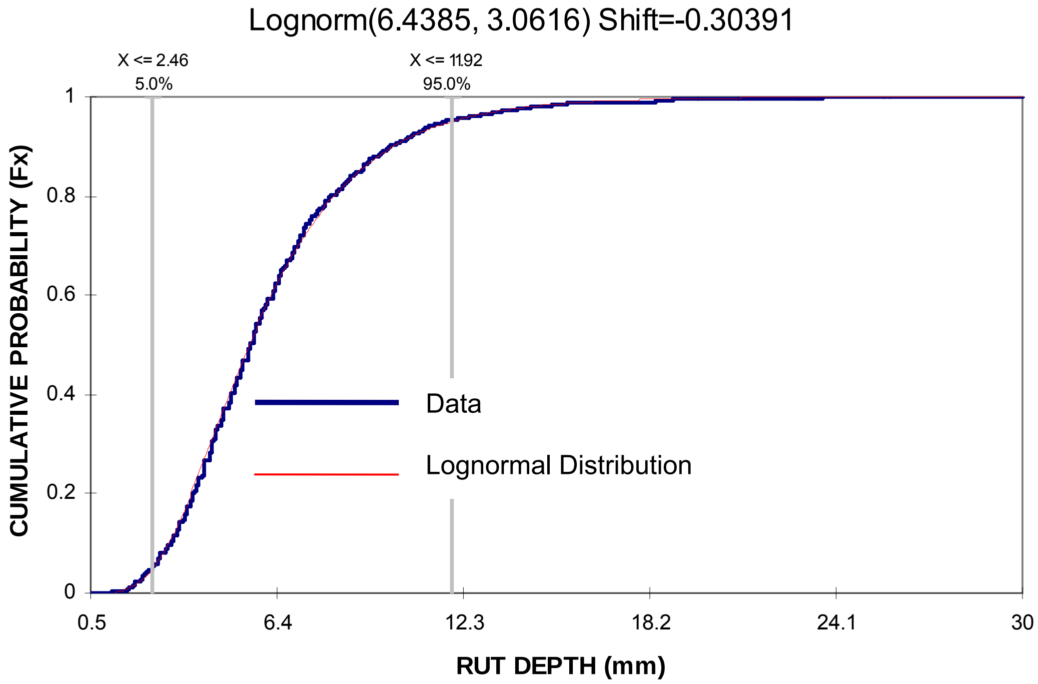

Figure B7-R7. Cumulative probability distributions of average rut depth for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT<500 (DNR-Fair-Bt-Flx-(>0.5k)

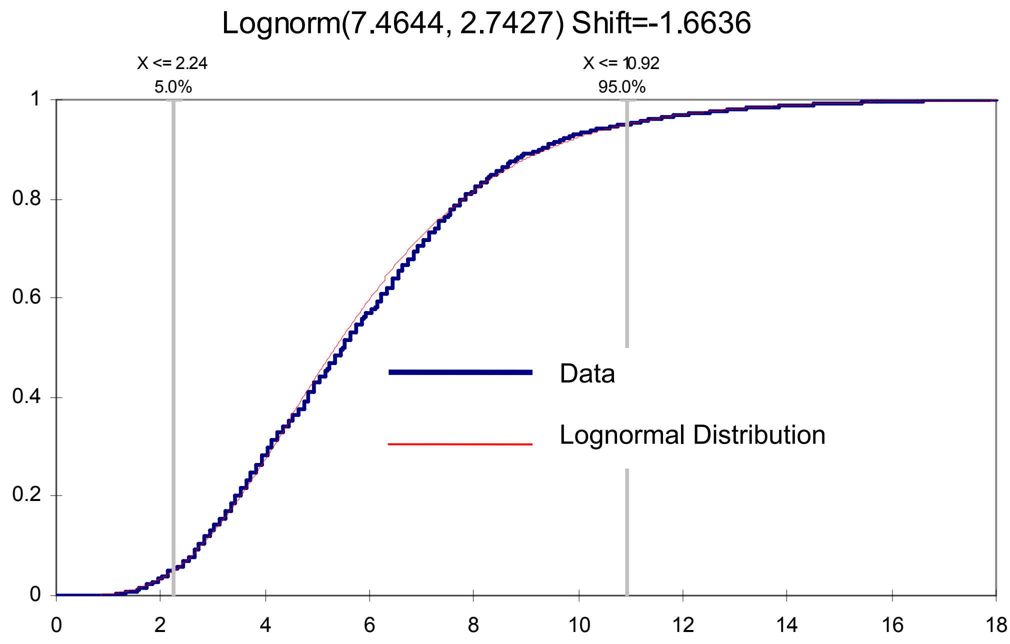

Figure B8-R8. Cumulative probability distributions of average rut depth for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT=501-1500 (DNR-Fair-Bt-Flx-(0.5k-1.5k)

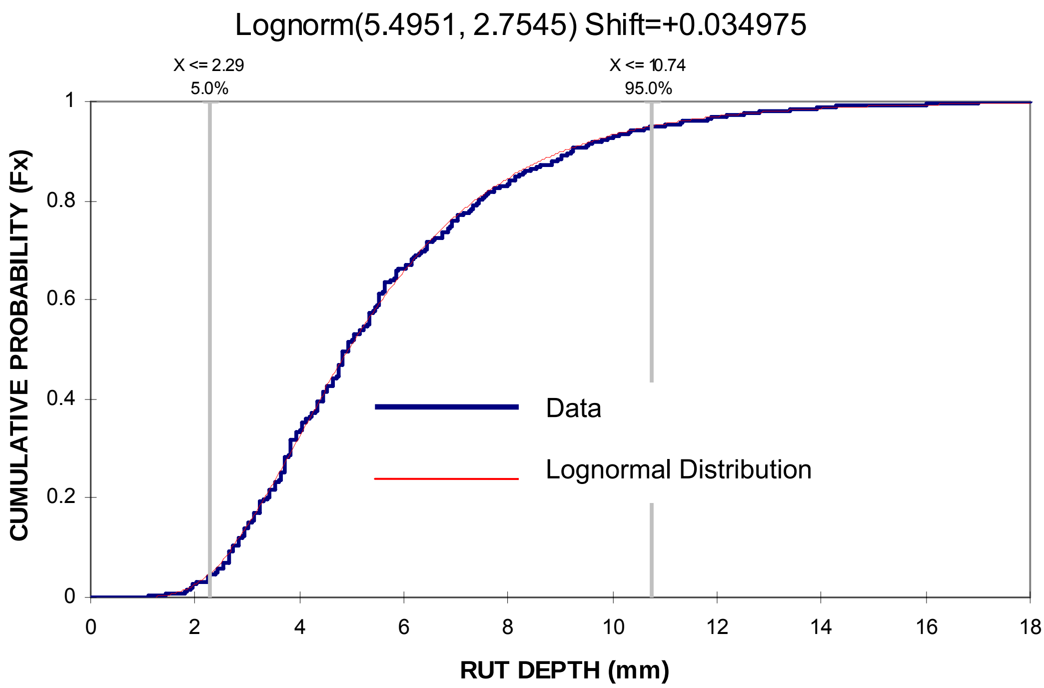

Figure B9-R9. Cumulative probability distributions of average rut depth for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT=1501-3000 (DNR-Fair-Bt-Flx-(1.5k-3k)

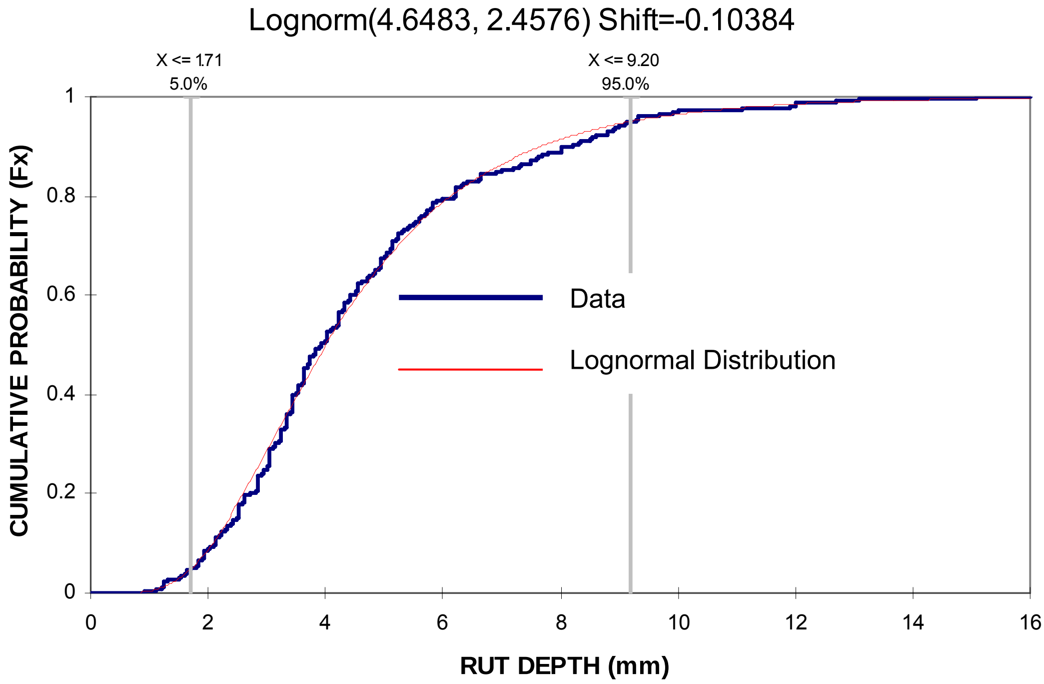

Figure B10-R10. Cumulative probability distributions of average rut depth for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT=3001-5000 (DNR-Fair-Bt-Flx-(3k-5k)

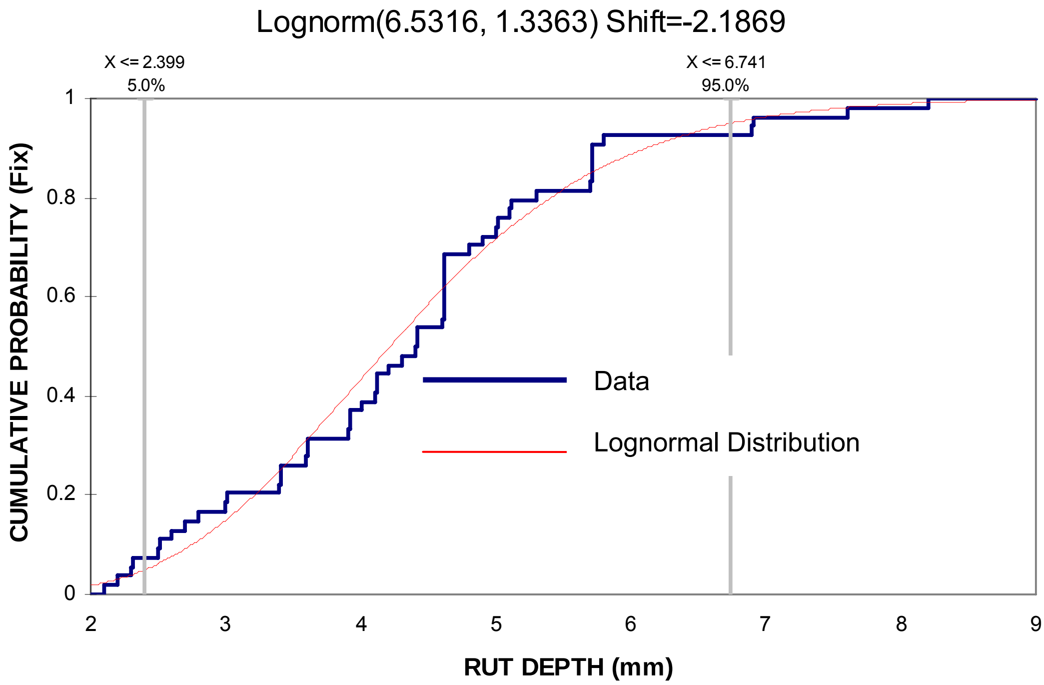

Figure B11-R11. Cumulative probability distributions of average rut depth for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT=5001-10000 (DNR-Fair-Bt-Flx-(5k-10k)

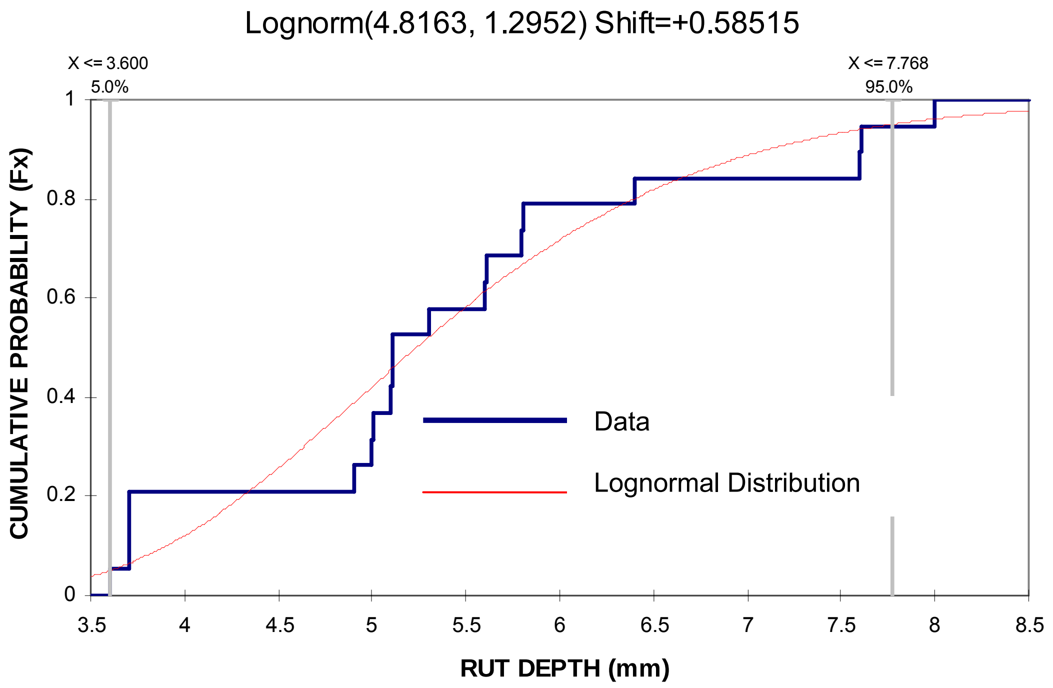

Figure B12-R12. Cumulative probability distributions of average rut depth for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT=10001-25000 (DNR-Fair-Bt-Flx-(10k-25k)

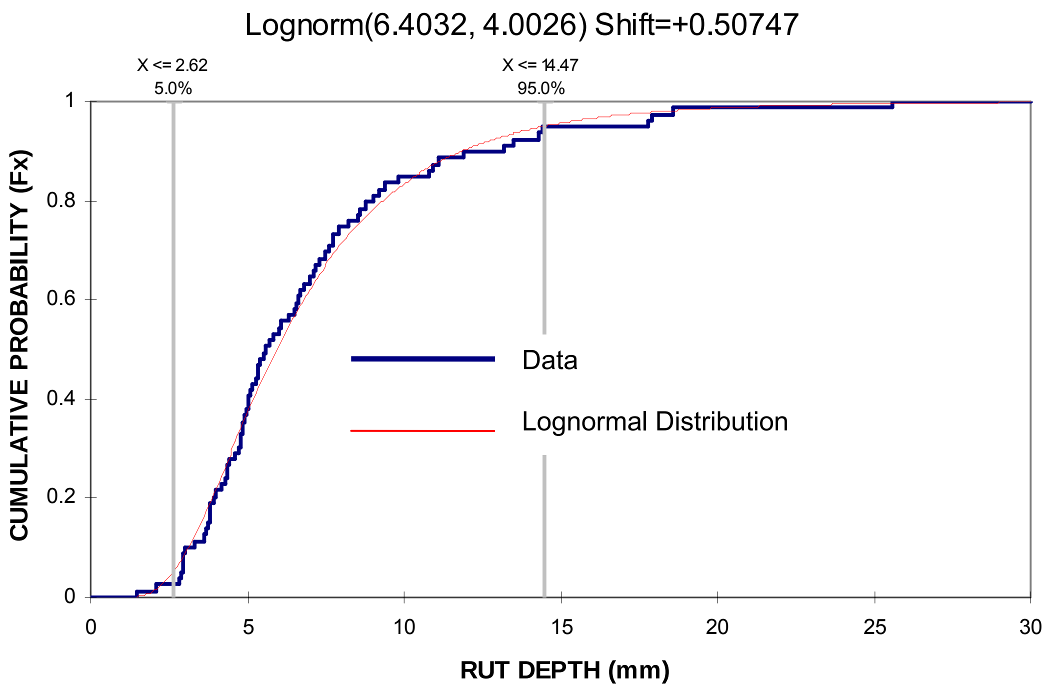

Figure B13-R13. Cumulative probability distributions of average rut depth for dry non reactive soil, bitumen surfacing, flexible pavement, IRI >4.2, AADT<501 (DNR-Poor-Bt-Flx-(<0.5k)

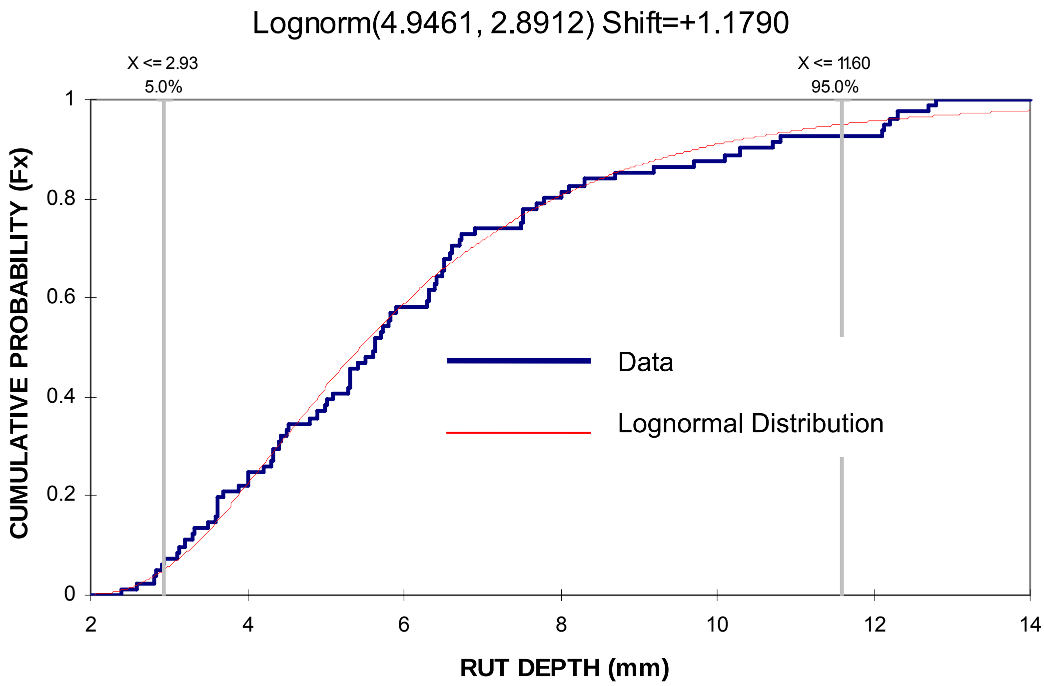

Figure B14-R14. Cumulative probability distributions of average rut depth for dry non reactive soil, bitumen surfacing, flexible pavement, IRI >4.2, AADT=501-1500 (DNR-Poor-Bt-Flx-(0.5k-1.5k)

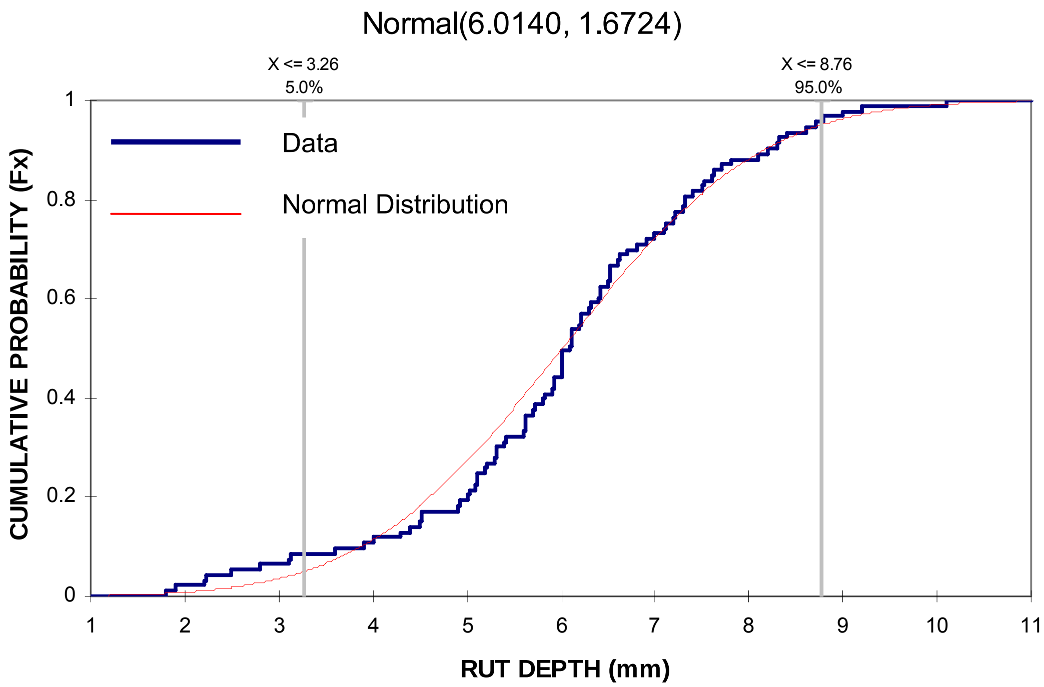

Figure B15-R15. Cumulative probability distributions of average rut depth for dry non reactive soil, asphalt concrete surfacing, flexible pavement, IRI <2.31, AADT=501-1500 (DNR-Good-AC-Flx-(0.5k-1.5k)

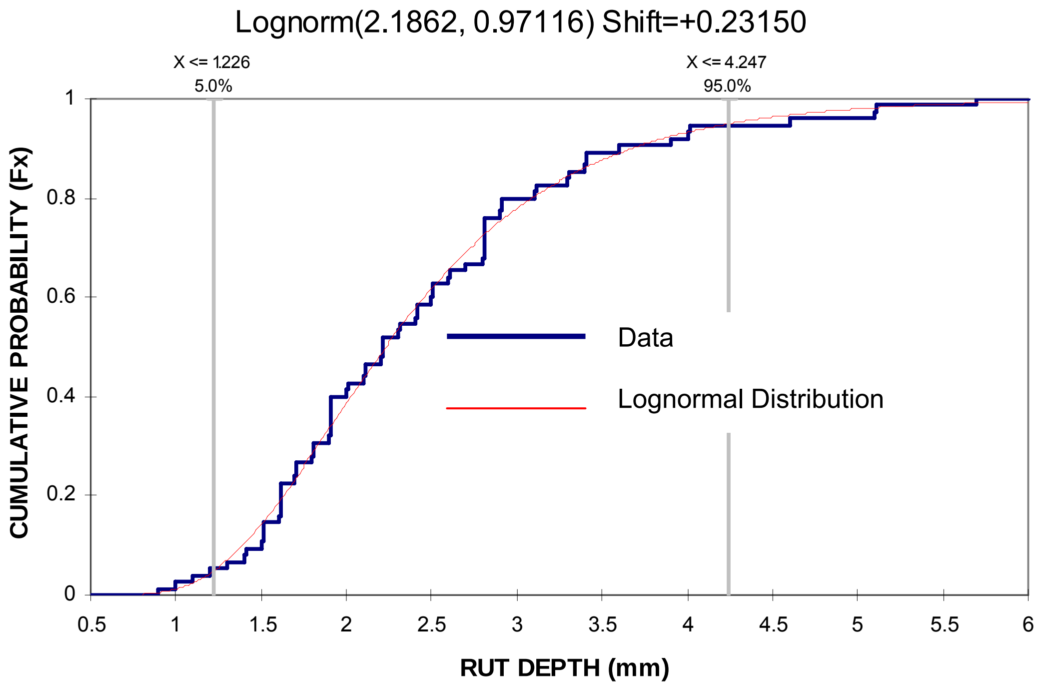

Figure B16-R16. Cumulative probability distributions of average rut depth for dry non reactive soil, asphalt concrete surfacing, flexible pavement, IRI <2.31, AADT=1501-3000 (DNR-Good-AC-Flx-(1.5k-3k)

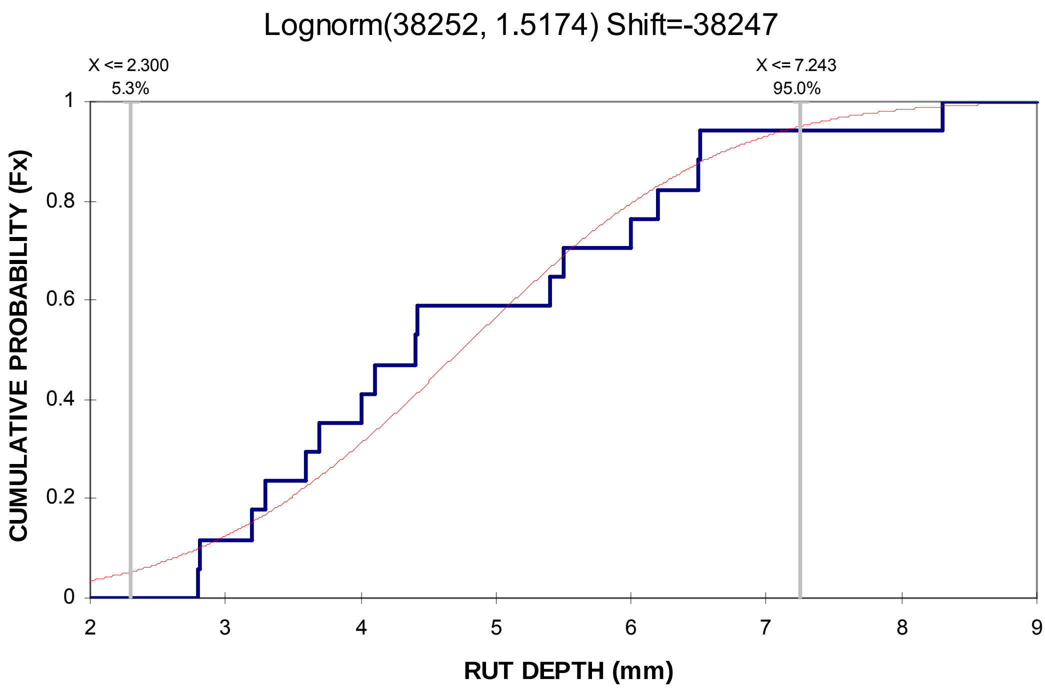

Figure B17-R17. Cumulative probability distributions of average rut depth for dry non reactive soil, asphalt concrete surfacing, flexible pavement, 2.31< IRI <4.2, AADT=501-1500 (DNR-Fair-AC-Flx-(0.5k-1.5k)

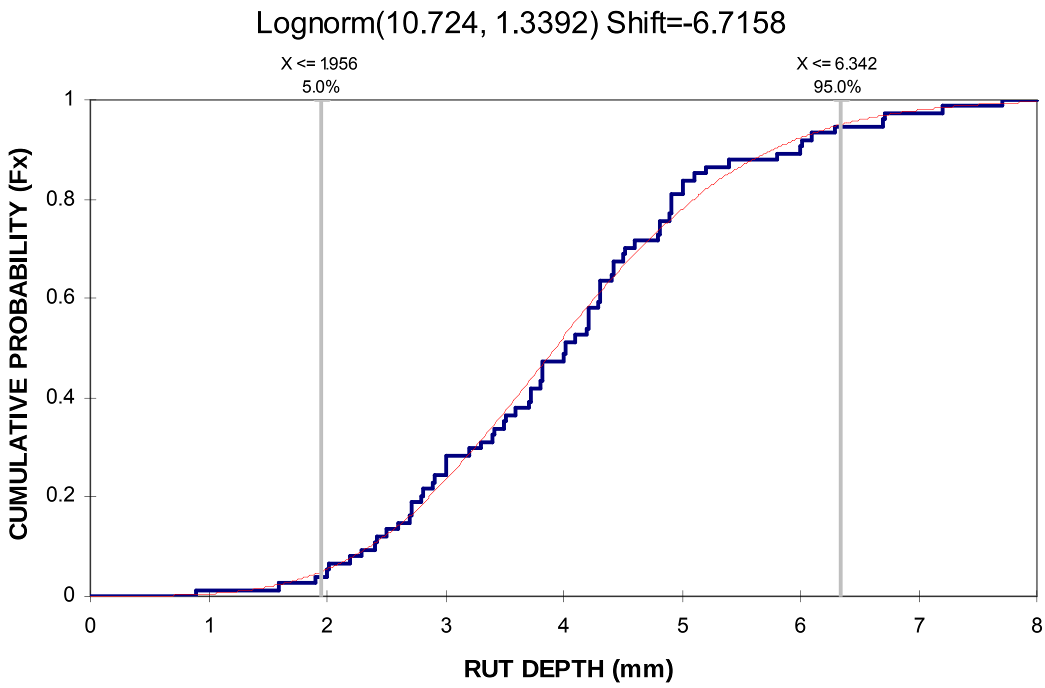

Figure B18-R18. Cumulative probability distributions of average rut depth for dry non reactive soil, asphalt concrete surfacing, semi rigid pavement, IRI <2.31, AADT=501-1500 (DNR-Good-AC-SR-(0.5k-1.5k)

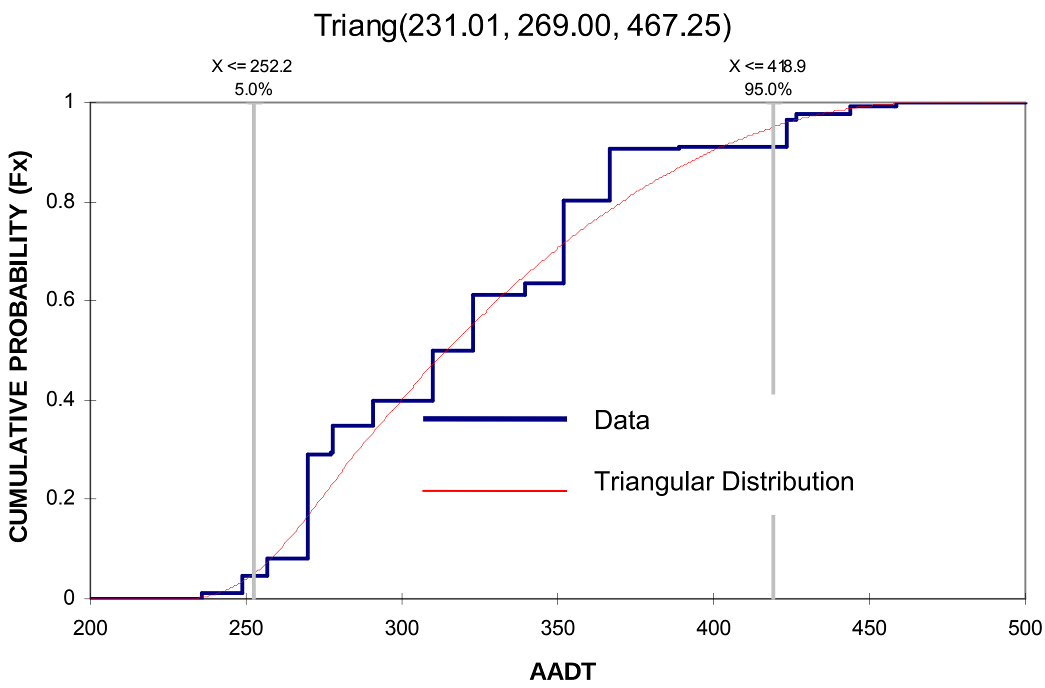

Figure C1-R1. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT<500 (DNR-Good-Bt-Flx-(<0.5k)

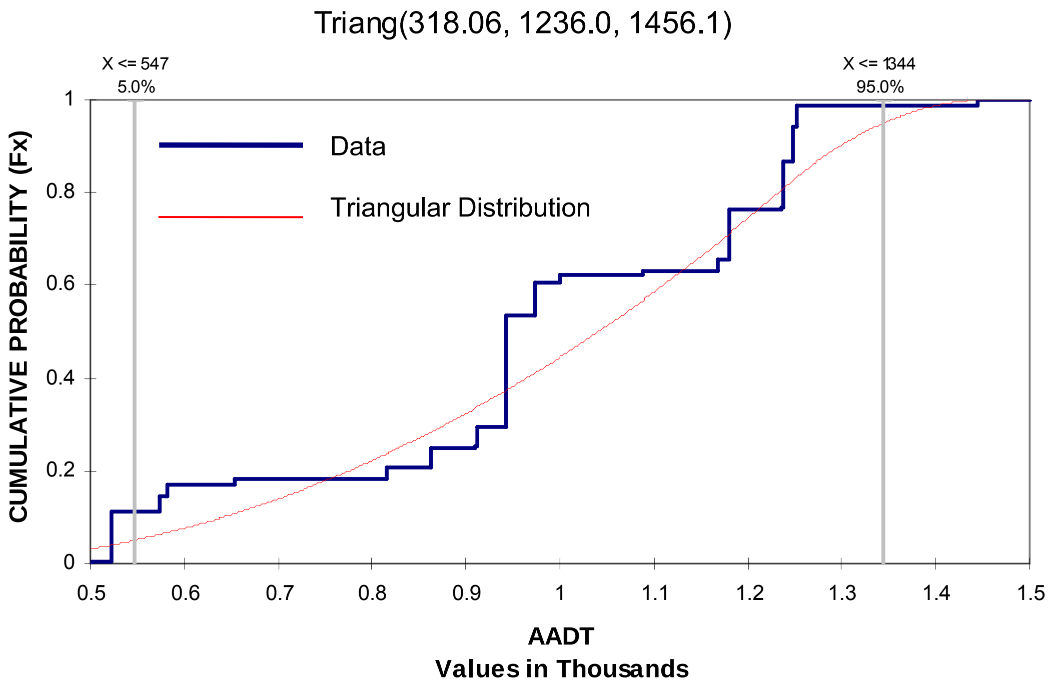

Figure C2-R2. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT=501-1500 (DNR-Good-Bt-Flx-(0.5k-1.5k)

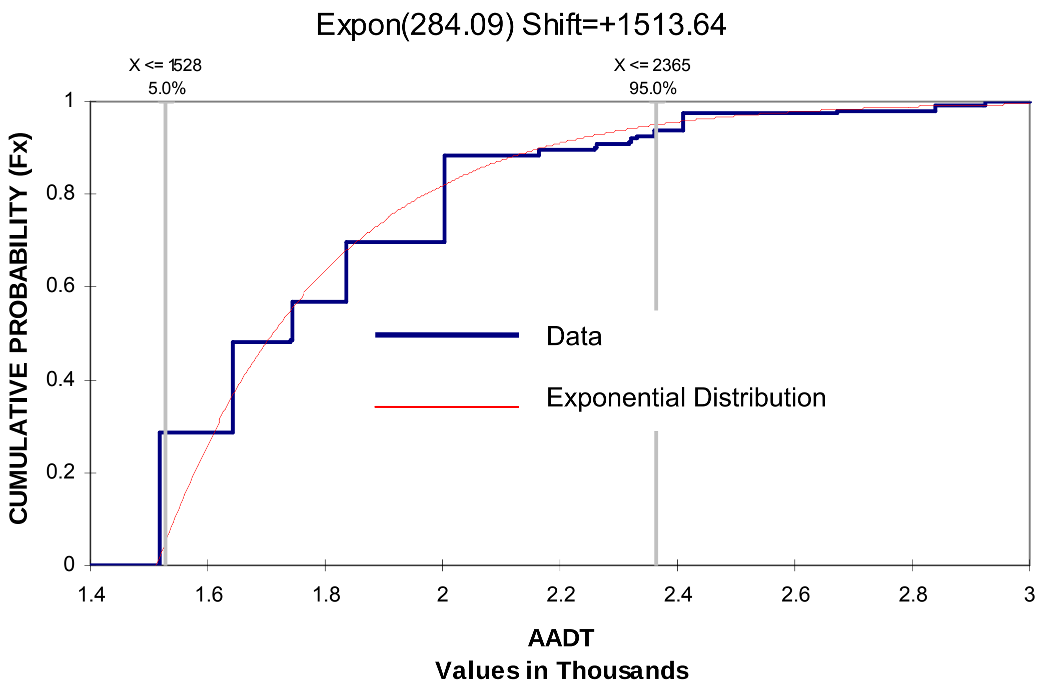

Figure C3-R3. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT=1501-3000 (DNR-Good-Bt-Flx-(1.5k-3k)

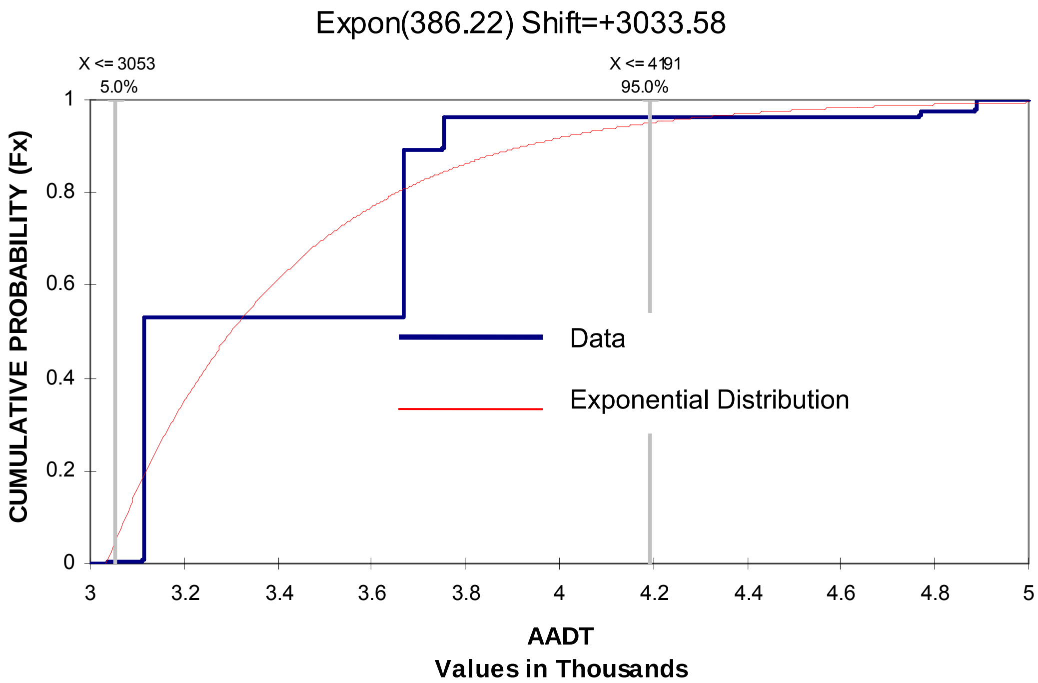

Figure C4-R4. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT=3001-5000 (DNR-Good-Bt-Flx-(3k-5k)

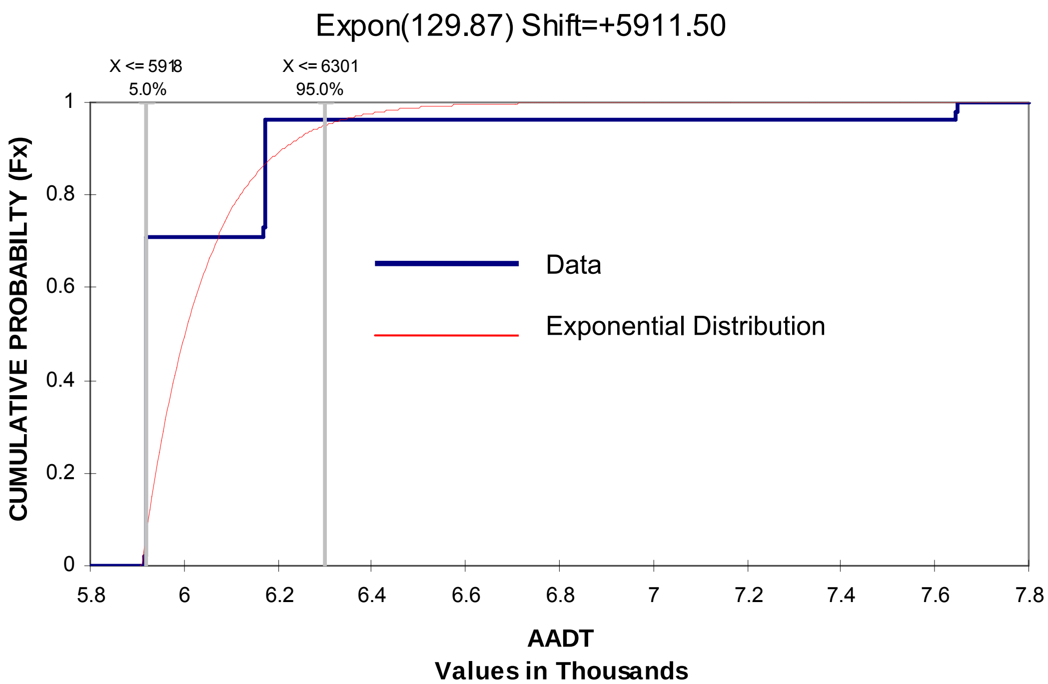

Figure C5-R5. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, bitumen surfacing, flexible pavement, IRI <2.31, AADT=5001-10000 (DNR-Good-Bt-Flx-(5k-10k)

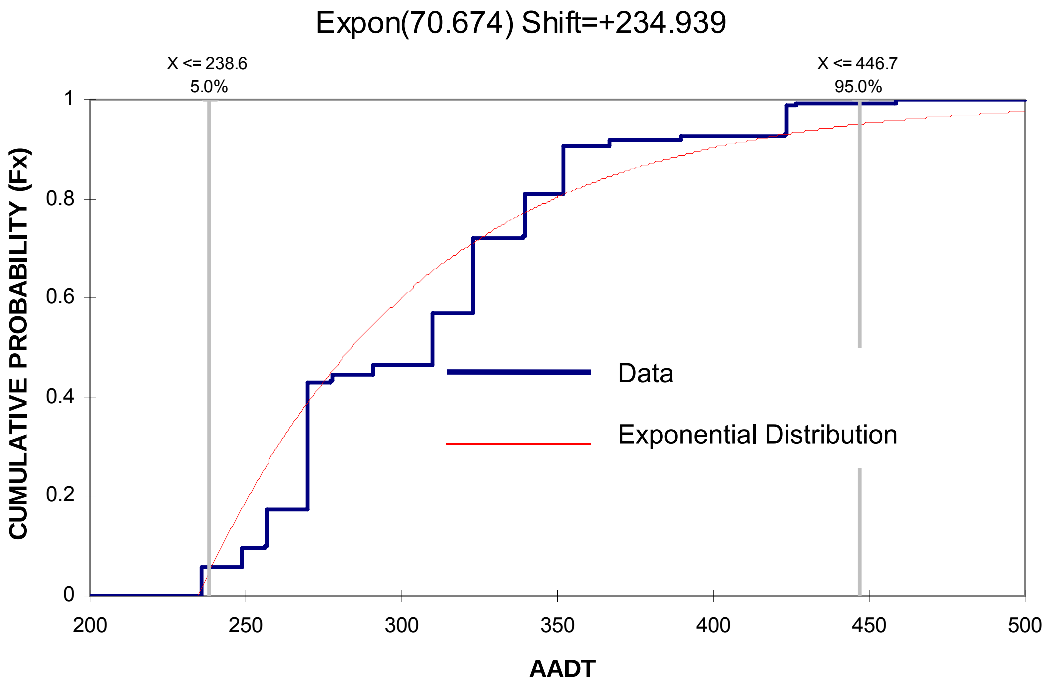

Figure C6-R7. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT<500 (DNR-Fair-Bt-Flx-(>0.5k)

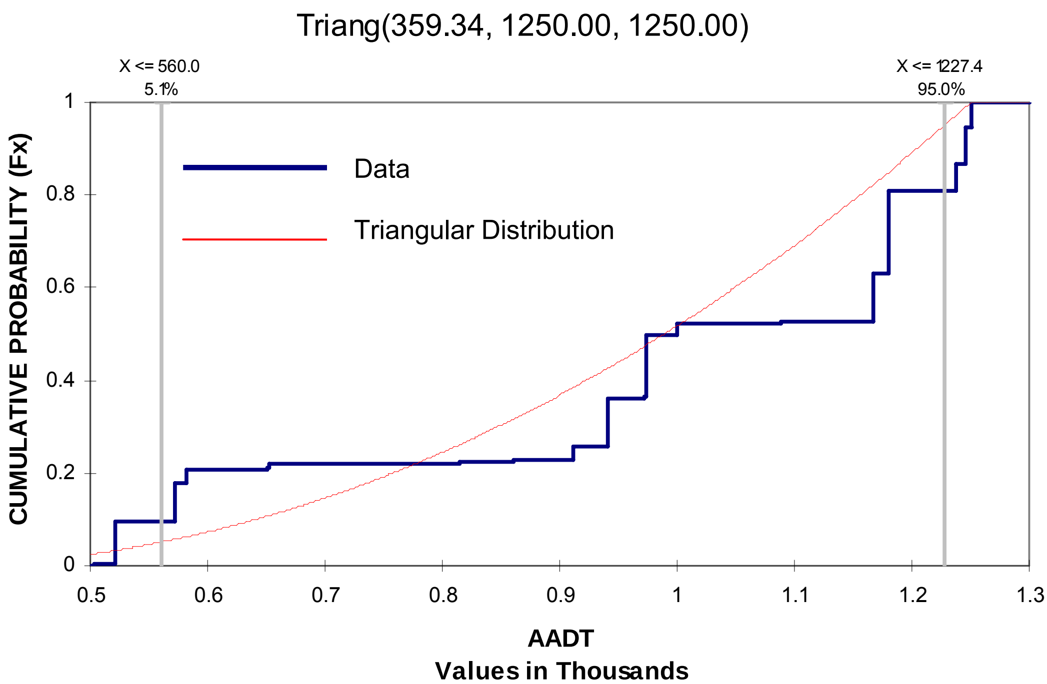

Figure C7-R8. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT=501-1500 (DNR-Fair-Bt-Flx-(0.5k-1.5k)

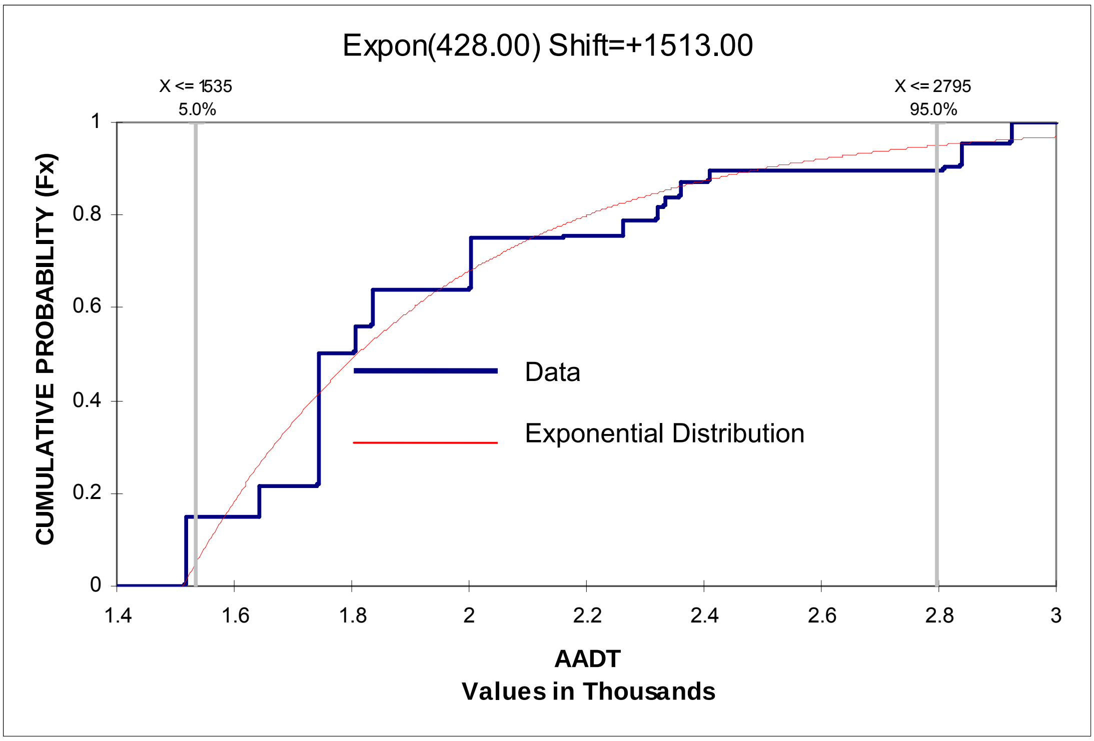

Figure C8-R9. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT=1501-3000 (DNR-Fair-Bt-Flx-(1.5k-3k)

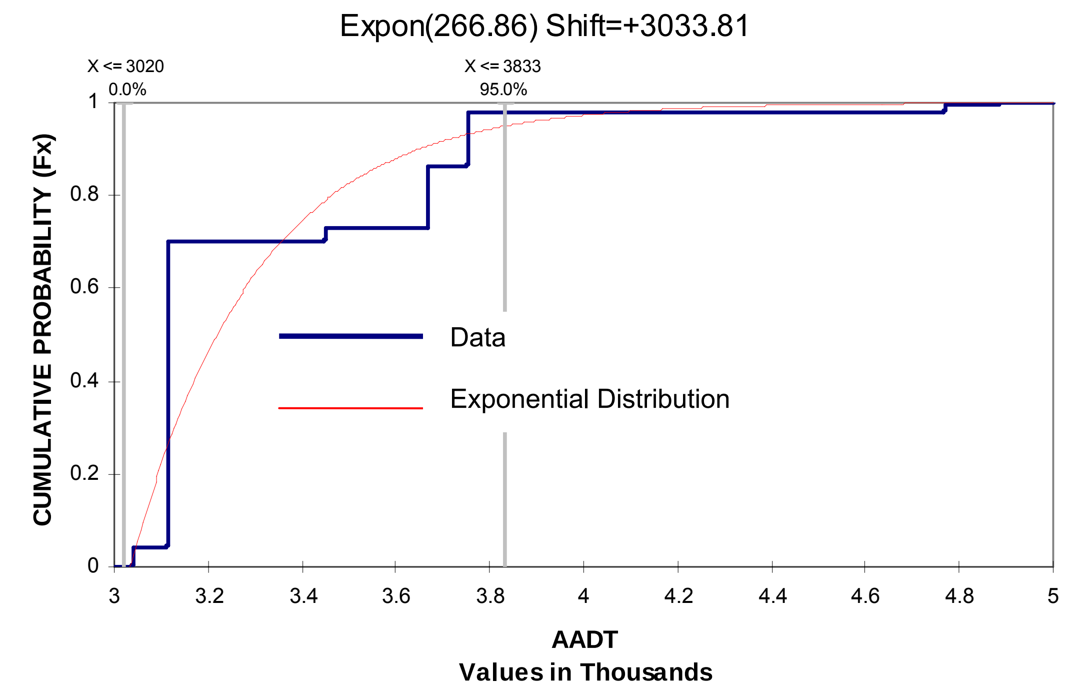

Figure C9-R10. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT=3001-5000 (DNR-Fair-Bt-Flx-(3k-5k)

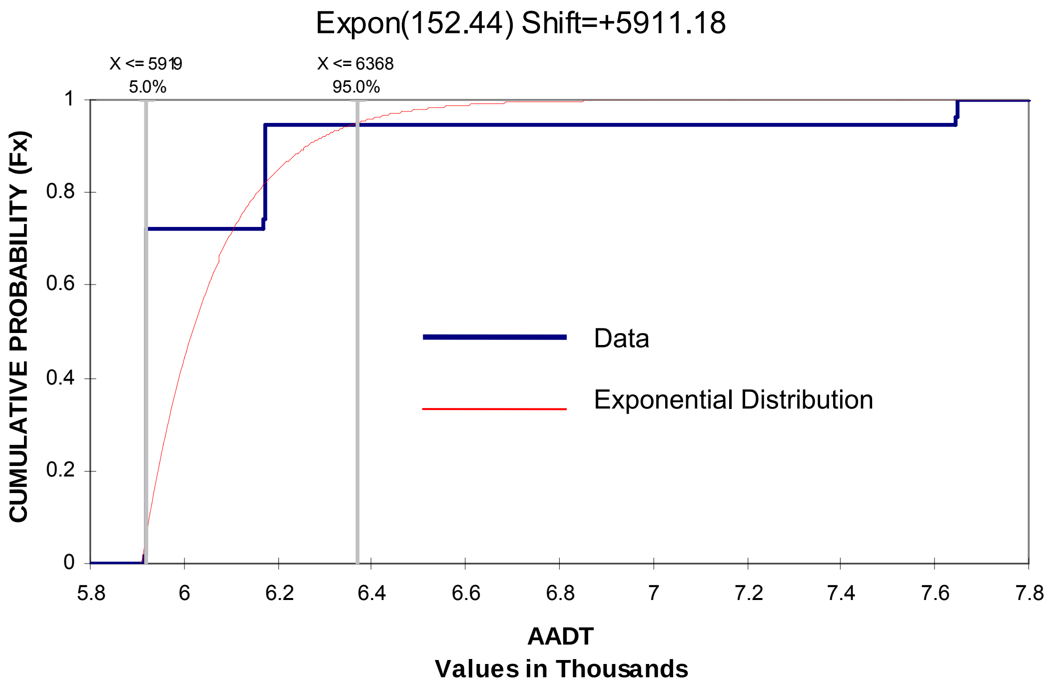

Figure C10-R11. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, bitumen surfacing, flexible pavement, 2.31< IRI <4.2, AADT=5001-10000 (DNR-Fair-Bt-Flx-(5k-10k)

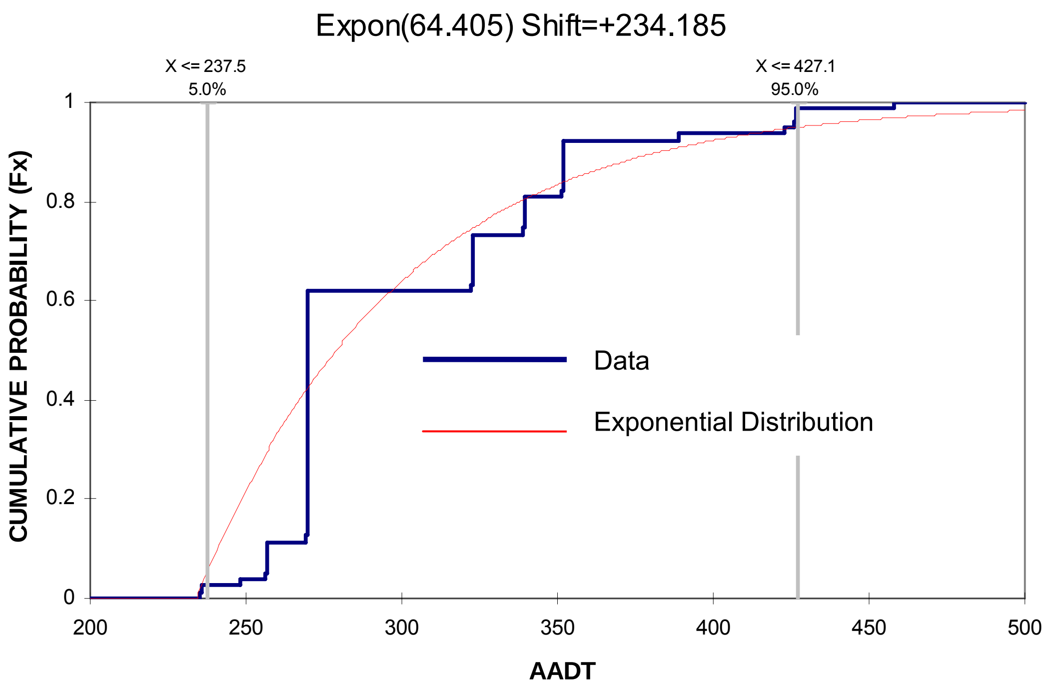

Figure C11-R13. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, bitumen surfacing, flexible pavement, IRI >4.2, AADT<501 (DNR-Poor-Bt-Flx-(<0.5k)

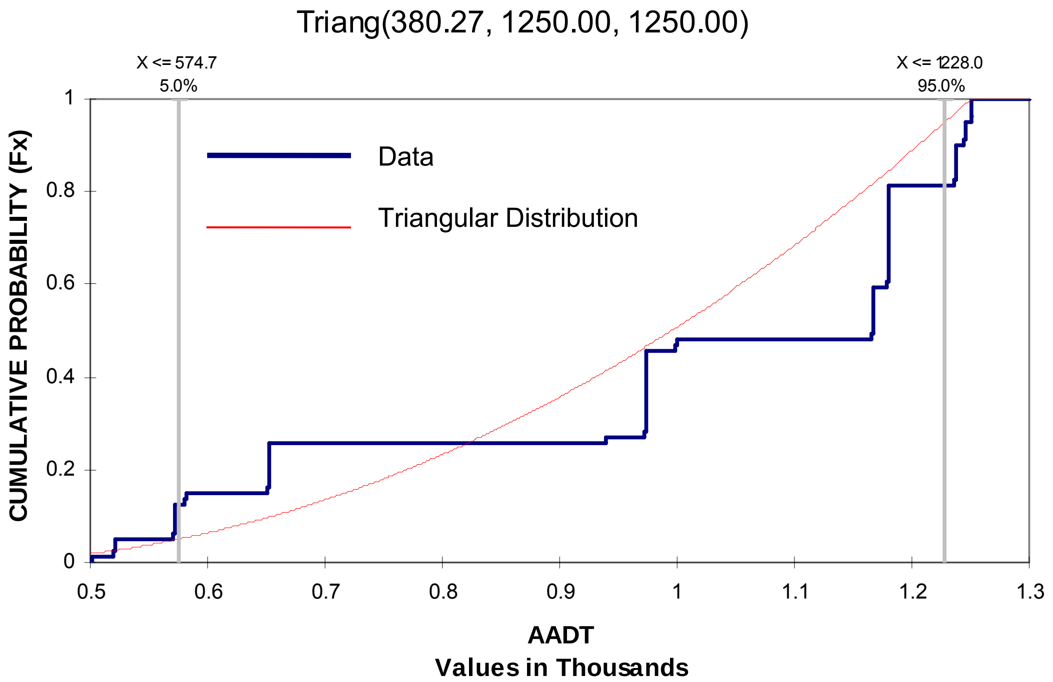

Figure C12-R14. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, bitumen surfacing, flexible pavement, IRI >4.2, AADT=501-1500 (DNR-Poor-Bt-Flx-(0.5k-1.5k)

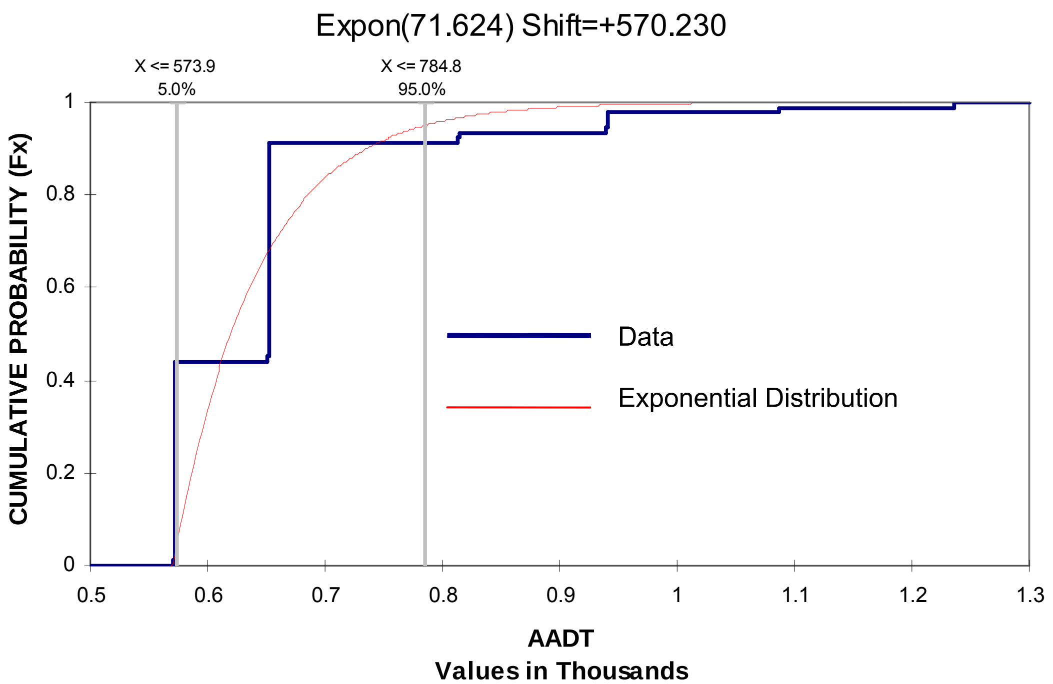

Figure C13-R15. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, asphalt concrete surfacing, flexible pavement, IRI <2.31, AADT=501-1500 (DNR-Good-AC-Flx-(0.5k-1.5k)

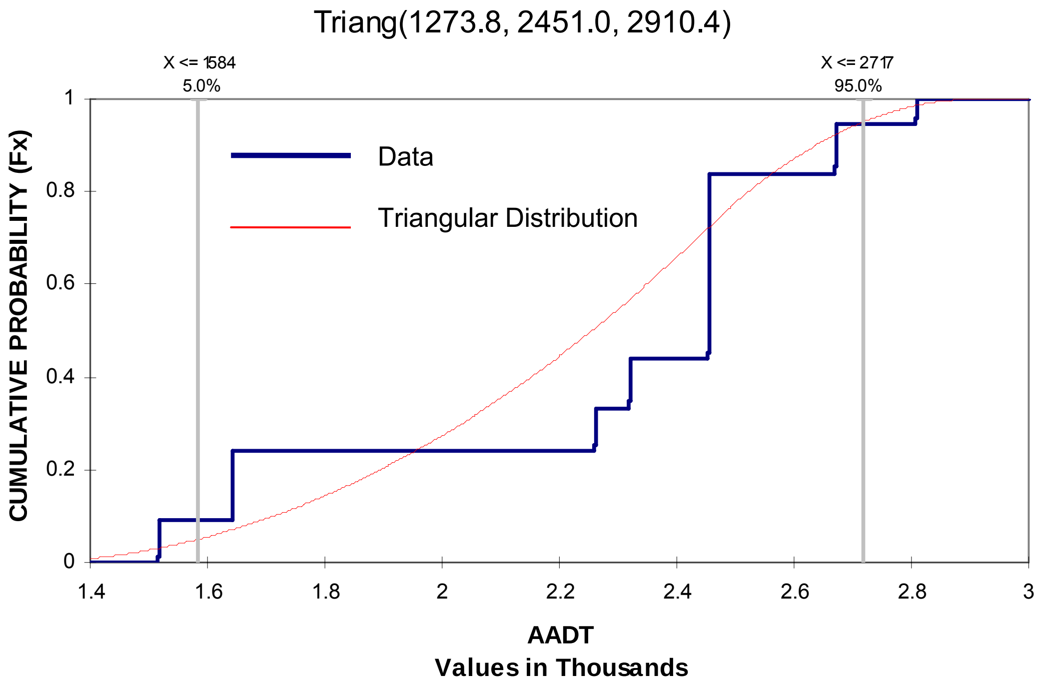

Figure C14-R16. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, asphalt concrete surfacing, flexible pavement, IRI <2.31, AADT=1501-3000 (DNR-Good-AC-Flx-(1.5k-3k)

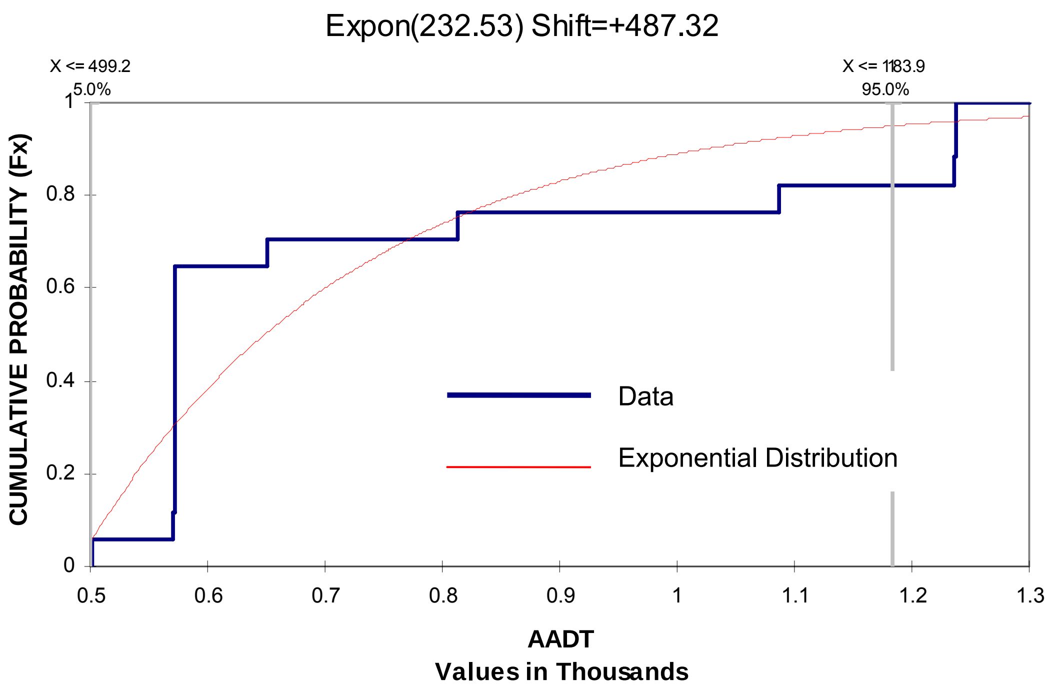

Figure C15-R17. Cumulative probability distributions of annual average daily traffic (AADT) for dry non reactive soil, asphalt concrete surfacing, flexible pavement, 2.31< IRI <4.2, AADT=501-1500 (DNR-Fair-AC-Flx-(0.5k-1.5k)

References

N.Piyatrapoomi, A. Kumar, N. Robertson, J Weligamage (2005). "Identification of Critical Input Variables for Risk-Based Cost Estimates for Road Maintenance and Rehabiliation" 4th International Conference on Maintenance and Rehabilitation of Pavements and Technological Control,18-20th August 2005, the University of Ulster, Northern Ireland.

N.Piyatrapoomi, A. Kumar, N. Robertson, J Weligamage (2005). "Probability Method for Assessing Variability in Budget Estimates for Highway Asset Management" 5th International Conference on Road and Airfield Pavement Technology (ICPT5), 10-12 May 2005, Seoul, South Korea.

Author Biography

Noppadol Piyatrapoomi obtained his Ph.D. degree from the University of Melbourne in 1996. He has practiced as a civil and structural engineer for ten years before he joined the CRC research project on Investment Decision-Making Framework for Infrastructure Asset Management. His research interests include the application of risk and reliability in decision-making for infrastructure asset management; assessment of public risk perception on engineering investments; risk and reliability assessment of structures; seismic risk and reliability assessment of structures; the application of an evolutionary method for data analysis. He developed an evolutionary method of data analysis during his Ph. D. study. This method can be used to refine existing functions and develop new formulas by using probability, statistical and risk assessment theories in the analysis. The method provides a more fine-grained analysis and yields more accurate results and better fitness of data than commonly used methods, such as regression or correlation analyses.

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Established and supported under the Australian Government's Cooperative Research Centres Program