SPI PowerNet Pty Ltd

Electricity Transmission Revenue Proposal 2014/15 – 2016/17

Appendix 6A:
PB STIPS Report

Fitting probability distributions for SP AusNet reliability data for STPIS Submission (Parsons Brinkerhoff)

Submitted: 28 February 2013

SP AusNet
A member of Singapore Power Group

SP AusNet

Fitting probability distributions for SP AusNet reliability data for STPIS Submission

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PARSONS BRINCKERHOFF

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1. Introduction

Parsons Brinckerhoff has been engaged by SP AusNet to assist with the determination of suitable targets and other attributes for the parameters of its service target performance incentive scheme (STIPS).

The service component of SP AusNet's STIPS will measure performance against the following parameters:

- Average outage duration (1 sub-parameter)
- Loss of supply event frequency (2 sub-parameters)
- Average circuit outage rates (6 sub-parameters).

Parsons Brinckerhoff determined a curve of best fit to SP AusNet's reliability data from the past five years 2008-2012 for each of the sub-parameters and calculated the standard deviation on which proposed caps and collars for this scheme are based.

1.1 Approach

Parsons Brinckerhoff used the @RISK product, a risk analysis and simulation add-in tool for Microsoft Excel, to determine the types of probability distribution that best fit the reliability data.

Recognising the need to present the best fit distribution curve based on the nature of the reliability data, the following distribution parameters were chosen for this exercise.

- Average outage duration data are fitted using continuous probability distributions bounded at a lower limit of zero
- Loss of supply event frequency are fitted with discrete probability distributions
- Availability rates are fitted with continuous probability distributions bounded at a lower limit of zero.

Three key fit statistics were used to measure how well the probability distribution functions fit the input data. For discrete probability distributions, the Chi Squared (ChiSq) fit statistic was used. For non-discrete distributions, the Kolmogorov-Smirnov (K-S) and the Anderson-Darling (A-D) fit statistics were used.

The K-S fit statistic focuses on the differences between the middle of the fitted distribution and the input data. The A-D fit statistic focuses on the difference between the tails of fitted distribution and input data. Where the input data was concentrated around the middle of a distribution curve the K-S fit statistic was used and where the data was near the tails the A-D fit statistic was used. The results from both were compared in each case. Where the input data was both in the middle and the tails of a distribution, the result from the A-D fit statistic was favoured, because the best fit of the data and the distribution curve at the tails improves the calculation of the scheme measures (caps and collars at one or two standard deviations).

Once the probability distribution function of best fit was determined for each sub-parameter the standard deviation of the probability distribution functions were calculated.

Because a probability distribution is being fitted to a dataset of five values only for each sub-parameter, the fit statistics are typically low in value and the curve of best fit is sensitive to small changes in any of the five values. The curve of second best fit was examined to test for any large variations in the calculated standard deviation that might indicate that the curve of best fit should not be used.

2. Results of distribution fitting

2.1 Average outage duration

The average outage duration is a measure of the response time to outages. The optimal performance limit is close to zero, which represents an immediate response; as such a lower limit of zero is set for fitting curves to the data.

The best fit using the A-D fit statistic is the Exponential distribution curve (figure 1), where the duration data is spread across the middle and tails of the distribution. Table 1 shows the statistical results using other distributions to fit the duration data using the A-D fit statistic, where it can be seen the Erlang distribution curve exhibits the second best fit.

Figure 1 Average outage duration – continuous distribution fit comparison using A-D

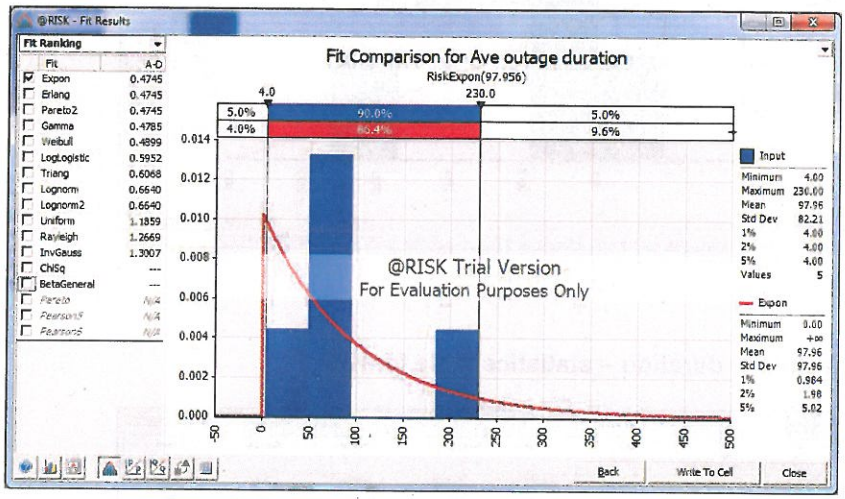
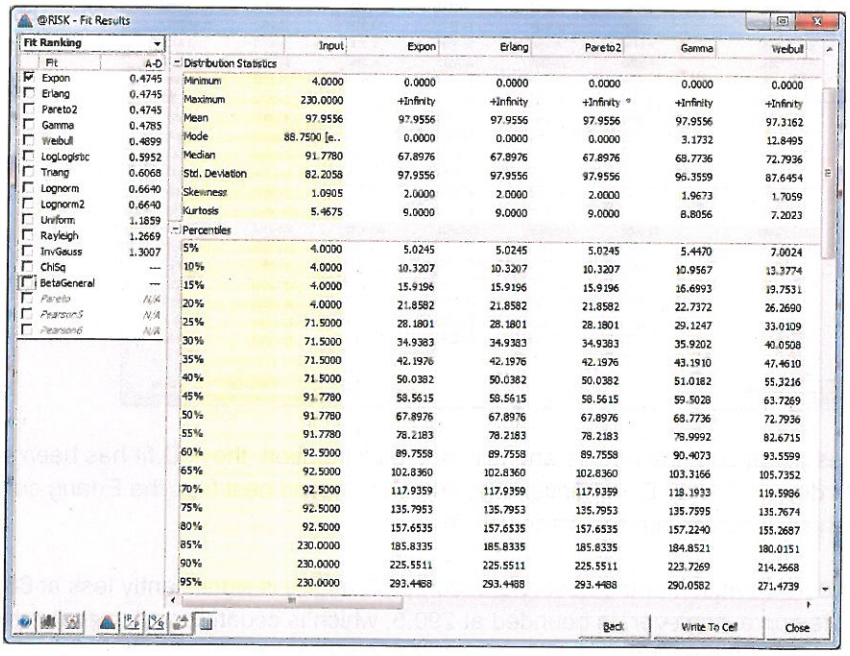


Table 1 Average outage duration – statistics table for A-D



Distribution Statistics	Input	Expon	Erlang	Pareto2	Gamma	Weibull
Minimum	4.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Maximum	230.0000	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity
Mean	97.9556	97.9556	97.9556	97.9556	97.9556	97.3162
Mode	88.7500 [e..	0.0000	0.0000	0.0000	3.1732	12.8495
Median	91.7780	67.8976	67.8976	67.8976	68.7736	72.7936
Std. Deviation	82.2058	97.9556	97.9556	97.9556	96.3559	87.6454
Skewness	1.0905	2.0000	2.0000	2.0000	1.9673	1.7059
Kurtosis	5.4675	9.0000	9.0000	9.0000	8.8056	7.2023
Percentiles						
5%	4.0000	5.0245	5.0245	5.0245	5.4470	7.0024
10%	4.0000	10.3207	10.3207	10.3207	10.9567	13.3774
15%	4.0000	15.9196	15.9196	15.9196	16.6993	19.7531
20%	4.0000	21.8582	21.8582	21.8582	22.7372	26.2690
25%	71.5000	28.1801	28.1801	28.1801	29.1247	33.0109
30%	71.5000	34.9383	34.9383	34.9383	35.9202	40.0508
35%	71.5000	42.1976	42.1976	42.1976	43.1910	47.4610
40%	71.5000	50.0382	50.0382	50.0382	51.0182	55.3216
45%	91.7780	58.5615	58.5615	58.5615	59.5028	63.7269
50%	91.7780	67.8976	67.8976	67.8976	68.7736	72.7936
55%	91.7780	78.2183	78.2183	78.2183	78.9992	82.6715
60%	92.5000	89.7558	89.7558	89.7558	90.4073	93.5599
65%	92.5000	102.8360	102.8360	102.8360	103.3166	105.7352
70%	92.5000	117.9359	117.9359	117.9359	118.1933	119.5986
75%	92.5000	135.7953	135.7953	135.7953	135.7595	135.7674
80%	92.5000	157.6535	157.6535	157.6535	157.2240	155.2687
85%	230.0000	185.8335	185.8335	185.8335	184.8521	180.0151
90%	230.0000	225.5511	225.5511	225.5511	223.7269	214.2668
95%	230.0000	293.4488	293.4488	293.4488	290.0582	271.4739

The best fit using the K-S fit statistic is the Triangle distribution curve (figure 2). Table 2 illustrates other distribution curves fitting the outage duration data using the K-S statistics, the LogLogistic distribution curve exhibits the second best fit for the outage duration data.

Figure 2 Average outage duration – continuous distribution fit comparison using K-S

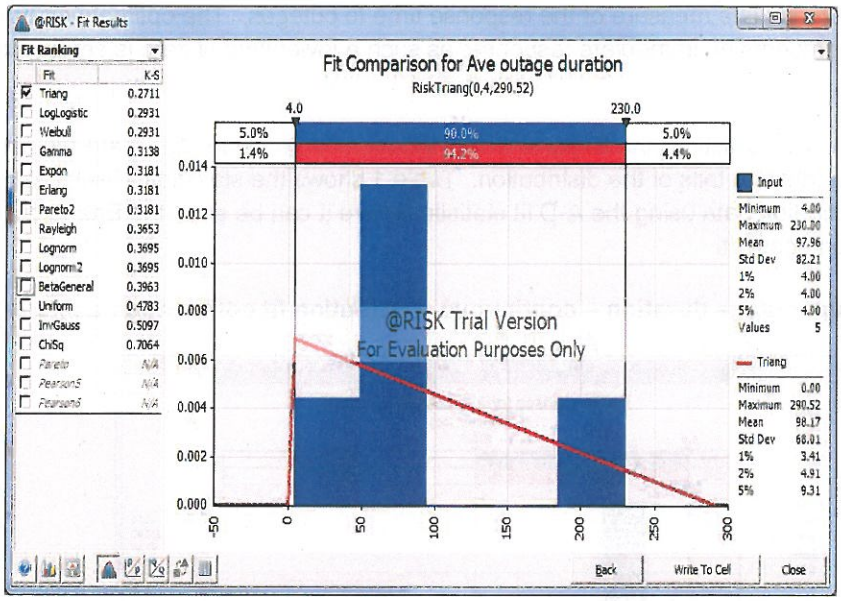
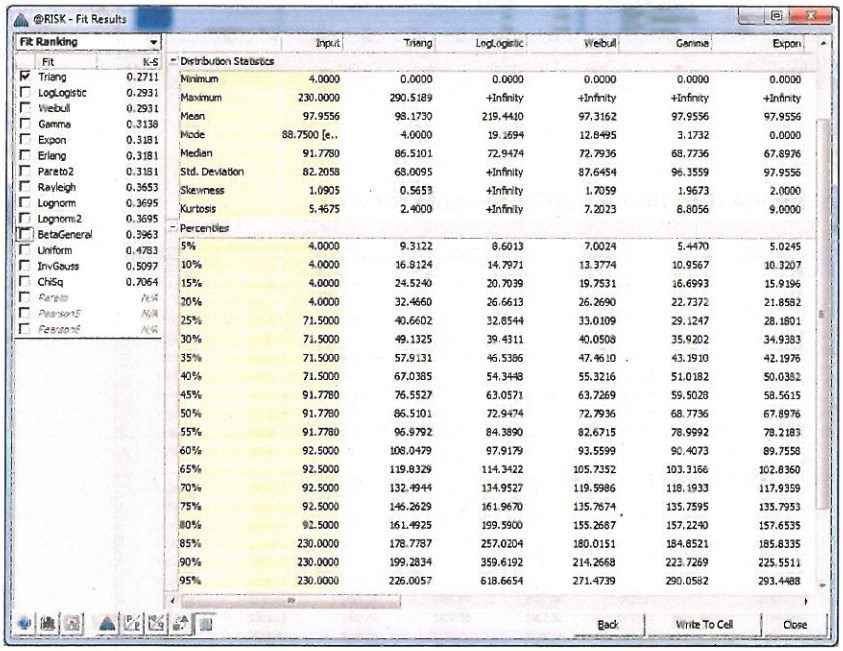


Table 2 Average outage duration – statistics table for K-S



Fit	K-S
Triang	0.2711
LogLogistic	0.2931
Weibull	0.2931
Gamma	0.3138
Expon	0.3181
Erlang	0.3181
Pareto2	0.3181
Rayleigh	0.3653
Lognorm	0.3695
Lognorm2	0.3695
BetaGeneral	0.3963
Uniform	0.4783
InvGauss	0.5097
ChiSq	0.7064
Pareto	N/A
Pearson5	N/A
Pearson6	N/A

Distribution Statistics	Input	Triang	LogLogistic	Weibull	Gamma	Expon
Minimum	4.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Maximum	230.0000	290.5189	+Infinity	+Infinity	+Infinity	+Infinity
Mean	97.9556	98.1730	219.4410	97.3162	97.9556	97.9556
Mode	88.7500 [e..	4.0000	19.1694	12.8495	3.1732	0.0000
Median	91.7780	86.5101	72.9474	72.7936	68.7736	67.8976
Std. Deviation	82.2058	68.0095	+Infinity	87.6454	96.3559	97.9556
Skewness	1.0905	0.5653	+Infinity	1.7059	1.9673	2.0000
Kurtosis	5.4675	2.4000	+Infinity	7.2023	8.8056	9.0000
Percentiles						
5%	4.0000	9.3122	8.6013	7.0024	5.4470	5.0245
10%	4.0000	16.8124	14.7971	13.3774	10.9567	10.3207
15%	4.0000	24.5240	20.7039	19.7531	16.6993	15.9196
20%	4.0000	32.4660	26.6613	26.2690	22.7372	21.8582
25%	71.5000	40.6602	32.8544	33.0109	29.1247	28.1801
30%	71.5000	49.1325	39.4311	40.0508	35.9202	34.9383
35%	71.5000	57.9131	46.5386	47.4610	43.1910	42.1976
40%	71.5000	67.0385	54.3448	55.3216	51.0182	50.0382
45%	91.7780	76.5527	63.0571	63.7269	59.5028	58.5615
50%	91.7780	86.5101	72.9474	72.7936	68.7736	67.8976
55%	91.7780	96.9792	84.3890	82.6715	78.9992	78.2183
60%	92.5000	108.0479	97.9179	93.5599	90.4073	89.7558
65%	92.5000	119.8329	114.3422	105.7352	103.3166	102.8360
70%	92.5000	132.4944	134.9527	119.5986	118.1933	117.9359
75%	92.5000	146.2629	161.9670	135.7674	135.7595	135.7953
80%	92.5000	161.4925	199.5900	155.2687	157.2240	157.6535
85%	230.0000	178.7787	257.0204	180.0151	184.8521	185.8335
90%	230.0000	199.2834	359.6192	214.2668	223.7269	225.5511
95%	230.0000	226.0057	618.6654	271.4739	290.0582	293.4488

As the data concentrates about both the middle and tails of the distribution, the A-D fit has been selected and the curve of best fit determined as Exponential. The curve of second best fit is the Erlang curve. The standard deviations of the two curves are the same (97.96).

In comparison, the standard deviation of the best K-S fit curve (Triangle) is significantly less at 68.01. The upper limit of the Triangle curve, however, is bounded at 290.5, which is counter intuitive to the possible performance outcomes. Hence the adoption of this curve to represent the data is inappropriate.

2.2 Loss of supply event frequency

Losses of supply events represent discrete occurrences of failure. In order to best fit the loss of supply events data, discrete distribution curves are used with equal interval binning.

Number of events > 0.05 system minutes

Figure 3 shows the NegBin discrete distribution curve is the best fit for the loss of supply events greater than 0.05 systems. Table 3 is provided to show the variation in statistics for other discrete distribution curves.

Noting that the Chi Squared fit statistics are similar for the top three curves of best fit, and that the standard deviations vary widely, the curve of second best fit (Geometric) and the curve of third best fit (Poisson) were also examined. The standard deviations are 2.45, 2.00 and 1.41 respectively. The relatively high variation in standard deviations indicates some uncertainty in the curve fitting.

The average of the three values (2.45, 2.00, 1.41) is 1.95, close to the standard deviation for the curve of best fit. This indicates that the standard deviation of 2.000 for the curve of best fit (NegBin) is an appropriate value to use in setting caps and collars.

Figure 3 No. of events > 0.05 system minutes – best discrete distribution fit - NegBin

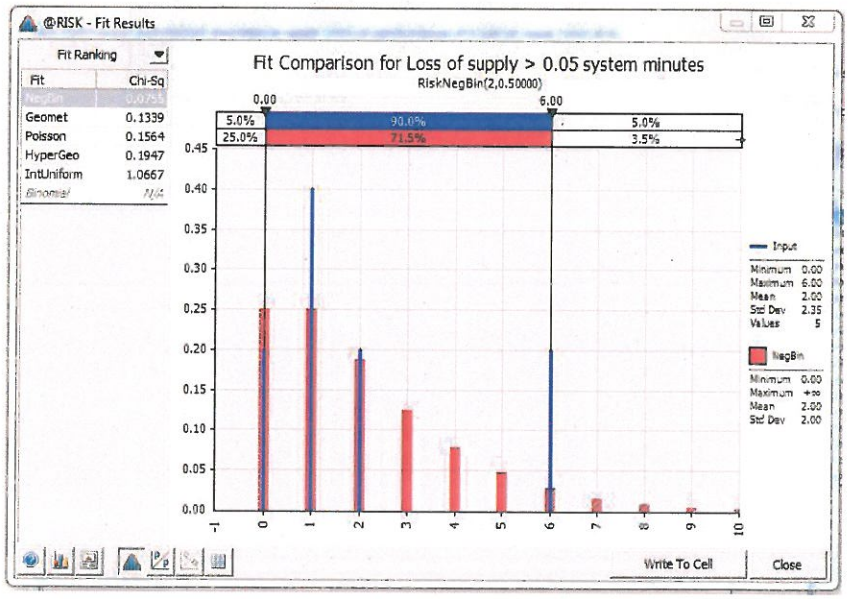
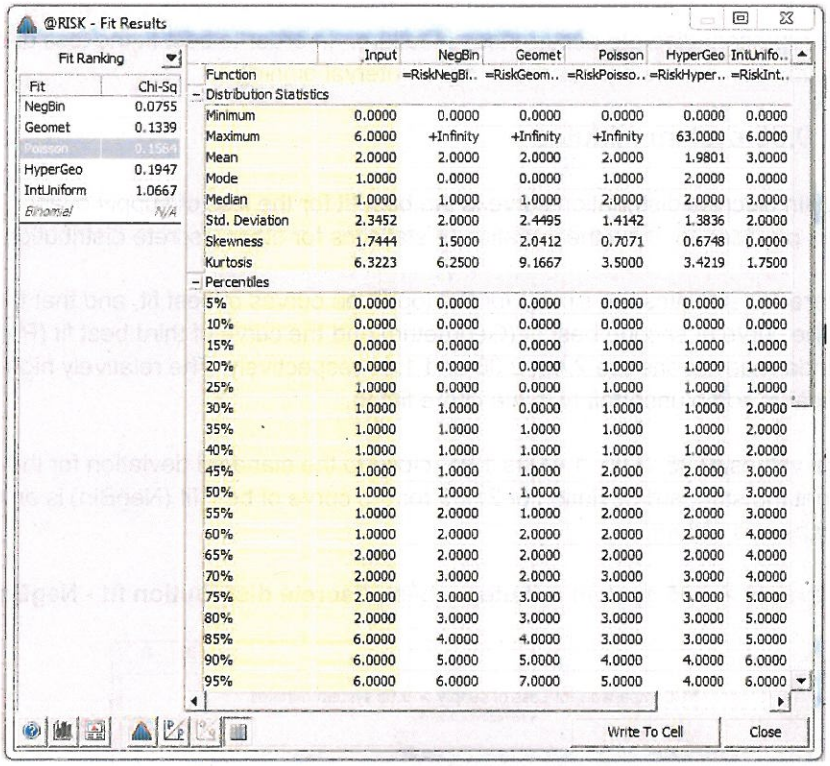


Table 3 No. of events > 0.05 system minutes – discrete distributions statistics table



@RISK - Fit Results

Fit Ranking

Fit	Chi-Sq
NegBin	0.0755
Geomet	0.1339
Poisson	0.1564
HyperGeo	0.1947
IntUniform	1.0667
Binomial	N/A

	Input	NegBin	Geomet	Poisson	HyperGeo	IntUnifo..
Function		=RiskNegBi..	=RiskGeom..	=RiskPoisso..	=RiskHyper..	=RiskInt..
Distribution Statistics						
Minimum	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Maximum	6.0000	+Infinity	+Infinity	+Infinity	63.0000	6.0000
Mean	2.0000	2.0000	2.0000	2.0000	1.9801	3.0000
Mode	1.0000	0.0000	0.0000	1.0000	2.0000	0.0000
Median	1.0000	1.0000	1.0000	2.0000	2.0000	3.0000
Std. Deviation	2.3452	2.0000	2.4495	1.4142	1.3836	2.0000
Skewness	1.7444	1.5000	2.0412	0.7071	0.6748	0.0000
Kurtosis	6.3223	6.2500	9.1667	3.5000	3.4219	1.7500
Percentiles						
5%	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10%	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15%	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000
20%	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000
25%	1.0000	0.0000	0.0000	1.0000	1.0000	1.0000
30%	1.0000	1.0000	0.0000	1.0000	1.0000	2.0000
35%	1.0000	1.0000	1.0000	1.0000	1.0000	2.0000
40%	1.0000	1.0000	1.0000	1.0000	1.0000	2.0000
45%	1.0000	1.0000	1.0000	2.0000	2.0000	3.0000
50%	1.0000	1.0000	1.0000	2.0000	2.0000	3.0000
55%	1.0000	2.0000	1.0000	2.0000	2.0000	3.0000
60%	1.0000	2.0000	2.0000	2.0000	2.0000	4.0000
65%	2.0000	2.0000	2.0000	2.0000	2.0000	4.0000
70%	2.0000	3.0000	2.0000	3.0000	3.0000	4.0000
75%	2.0000	3.0000	3.0000	3.0000	3.0000	5.0000
80%	2.0000	3.0000	3.0000	3.0000	3.0000	5.0000
85%	6.0000	4.0000	4.0000	3.0000	3.0000	5.0000
90%	6.0000	5.0000	5.0000	4.0000	4.0000	6.0000
95%	6.0000	6.0000	7.0000	5.0000	4.0000	6.0000

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Number of events > 0.30 system minutes

The discrete distribution of best fit for the loss of supply events greater than 0.30 system minutes is the IntUniform curve, giving a standard deviation of 0.816. Table 4 is provided to show the statistics for other discrete distribution curves.

The curve of second best fit (Bionomial) has a significantly worse fit statistic – 7.2 compared to 1.6 for the curve of best fit – hence it has not been considered.

Figure 4 No. of event > 0.30 system minutes – best discrete distribution fit – IntUniform

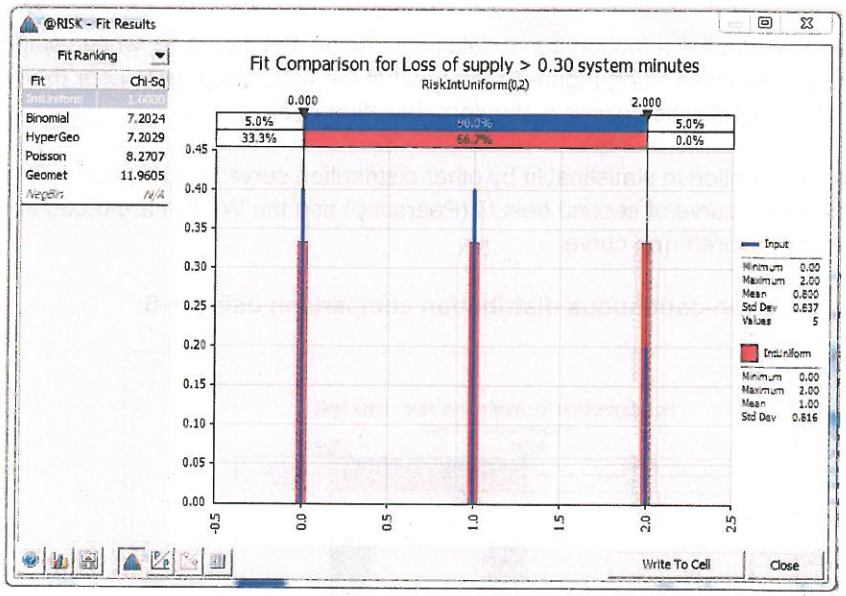
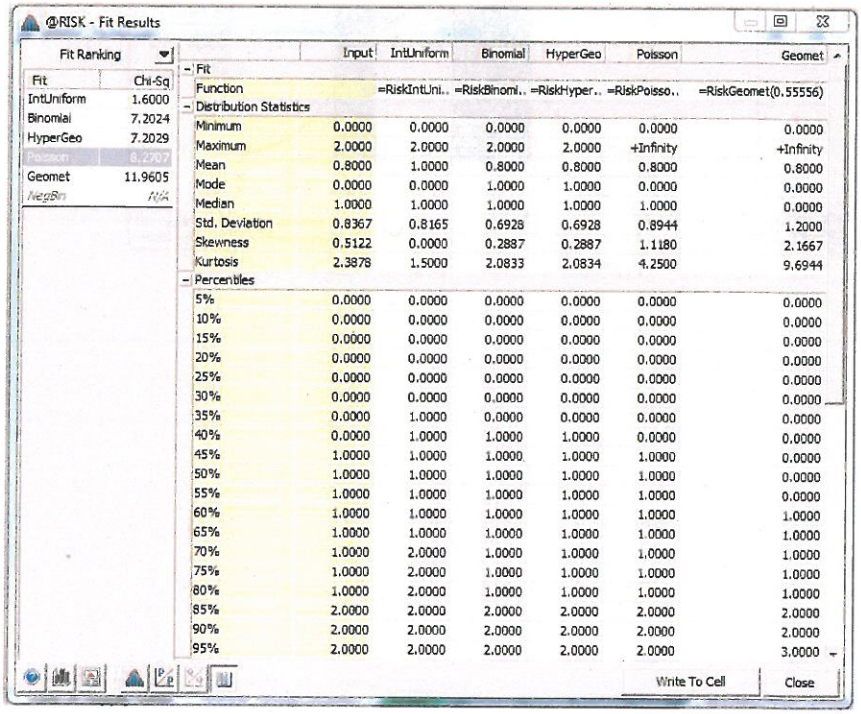


Table 4 No. of events > 0.30 system minutes – discrete distributions statistics table



	Input	IntUniform	Binomial	HyperGeo	Poisson	Geomet
Fit						
Function		=RiskIntUni..	=RiskBinomi..	=RiskHyper..	=RiskPoisso..	=RiskGeomet(0.55556)
Distribution Statistics						
Minimum	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Maximum	2.0000	2.0000	2.0000	2.0000	+Infinity	+Infinity
Mean	0.8000	1.0000	0.8000	0.8000	0.8000	0.8000
Mode	0.0000	0.0000	1.0000	1.0000	0.0000	0.0000
Median	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000
Std. Deviation	0.8367	0.8165	0.6928	0.6928	0.8944	1.2000
Skewness	0.5122	0.0000	0.2887	0.2887	1.1180	2.1667
Kurtosis	2.3878	1.5000	2.0833	2.0834	4.2500	9.6944
Percentiles						
5%	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10%	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15%	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20%	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25%	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30%	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35%	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
40%	0.0000	1.0000	1.0000	1.0000	0.0000	0.0000
45%	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000
50%	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000
55%	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000
60%	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
65%	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
70%	1.0000	2.0000	1.0000	1.0000	1.0000	1.0000
75%	1.0000	2.0000	1.0000	1.0000	1.0000	1.0000
80%	1.0000	2.0000	1.0000	1.0000	1.0000	1.0000
85%	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000
90%	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000
95%	2.0000	2.0000	2.0000	2.0000	2.0000	3.0000

2.3 Average circuit outage rate

Average circuit outage rates represent measures of availability for components of transmission circuits. The optimal performance limit is 0%, which represents total availability for the component for the year; as such a lower limit of zero is set for fitting non-continuous curves to the data.

The availability rate measures are presented based on the components and nature of availability in the following categories.

Lines outage rate – fault performance

The K-S fit statistic has the Weibull distribution curve delivering the best fit (figure 5), while using the A-D fit statistic, the LogLogistic curve is best fitting (figure 6). As most of the data congregate near the two tails, the A-D fit statistic is preferred (LogLogistic), giving a standard deviation of 0.090.

Tables 5 and 6 present the variation in statistical fit by other distribution curves for K-S and A-D respectively. The standard deviations for the curve of second best fit (Pearson5) and the Weibull are 0.080 and 0.072, being slightly lower than for the preferred curve.

Figure 5 Lines - fault non-continuous distribution comparison using K-S

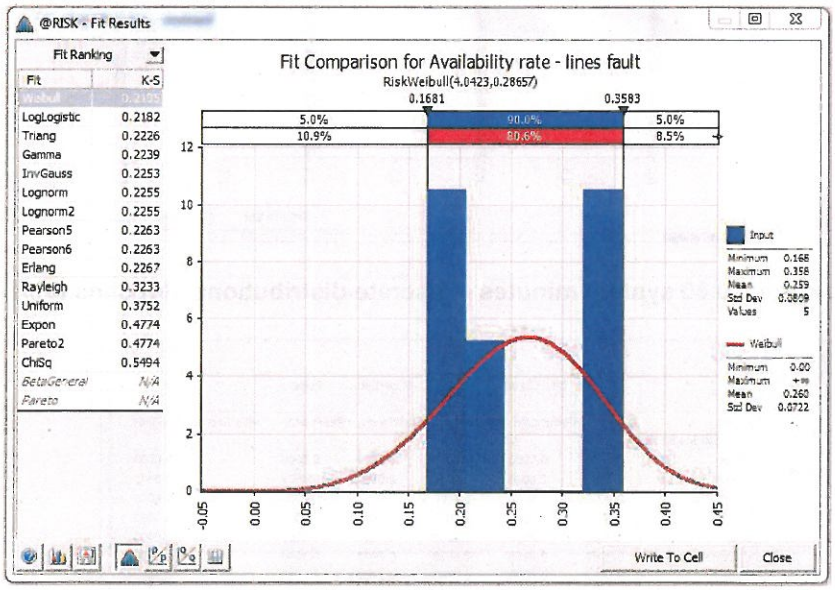


Table 5 Lines – fault non-continuous distribution statistics table for K-S

@RISK - Fit Results

Fit Ranking

Fit	K-S
Weibull	0.2195
LogLogistic	0.2182
Triang	0.2226
Gamma	0.2239
InvGauss	0.2253
Lognorm	0.2255
Lognorm2	0.2255
Pearson5	0.2263
Pearson6	0.2263
Erlang	0.2267
Rayleigh	0.3233
Uniform	0.3752
Expon	0.4774
Pareto2	0.4774
ChiSq	0.5494
BetaGeneral	N/A
Pareto	N/A

	Input	Weibull	LogLogistic	Triang	Gamma	InvGauss	Lognorm
Fit							
Function		=RiskWeibu..	=RiskLogLo..	=RiskTriang..	=RiskGamm..	=RiskInvGa..	=RiskLogno..
Distribution Statistics							
Minimum	0.1681	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Maximum	0.3583	+Infinity	+Infinity	0.3583	+Infinity	+Infinity	+Infinity
Mean	0.2590	0.2599	0.2622	0.2389	0.2590	0.2590	0.2592
Mode	0.1728 [est]	0.2671	0.2335	0.3583	0.2385	0.2285	0.2294
Median	0.2437	0.2617	0.2488	0.2534	0.2522	0.2487	0.2488
Std. Deviation	0.0809	0.0722	0.0902	0.0845	0.0729	0.0750	0.0754
Skewness	0.2398	-0.0957	2.0116	-0.5657	0.5629	0.8684	0.8977
Kurtosis	0.7325	2.7522	17.9225	2.4000	3.4752	4.2569	4.4663
Percentiles							
5%	0.1681	0.1374	0.1475	0.0801	0.1519	0.1561	0.1557
10%	0.1681	0.1642	0.1685	0.1133	0.1711	0.1727	0.1727
15%	0.1681	0.1828	0.1829	0.1388	0.1850	0.1851	0.1852
20%	0.1681	0.1977	0.1946	0.1603	0.1965	0.1956	0.1957
25%	0.2000	0.2106	0.2048	0.1792	0.2069	0.2051	0.2053
30%	0.2000	0.2221	0.2141	0.1963	0.2164	0.2140	0.2143
35%	0.2000	0.2327	0.2229	0.2120	0.2256	0.2227	0.2229
40%	0.2000	0.2427	0.2316	0.2266	0.2345	0.2313	0.2315
45%	0.2437	0.2523	0.2401	0.2404	0.2433	0.2399	0.2401
50%	0.2437	0.2617	0.2488	0.2534	0.2522	0.2487	0.2488
55%	0.2437	0.2711	0.2579	0.2657	0.2613	0.2578	0.2579
60%	0.3250	0.2804	0.2674	0.2776	0.2708	0.2674	0.2675
65%	0.3250	0.2900	0.2777	0.2889	0.2809	0.2777	0.2777
70%	0.3250	0.3000	0.2892	0.2998	0.2917	0.2890	0.2890
75%	0.3250	0.3107	0.3024	0.3103	0.3038	0.3017	0.3016
80%	0.3250	0.3224	0.3183	0.3205	0.3175	0.3164	0.3163
85%	0.3583	0.3358	0.3386	0.3304	0.3341	0.3345	0.3344
90%	0.3583	0.3522	0.3675	0.3399	0.3557	0.3586	0.3586
95%	0.3583	0.3759	0.4197	0.3493	0.3894	0.3973	0.3977

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Figure 6 Lines - fault non-continuous distribution comparison using A-D

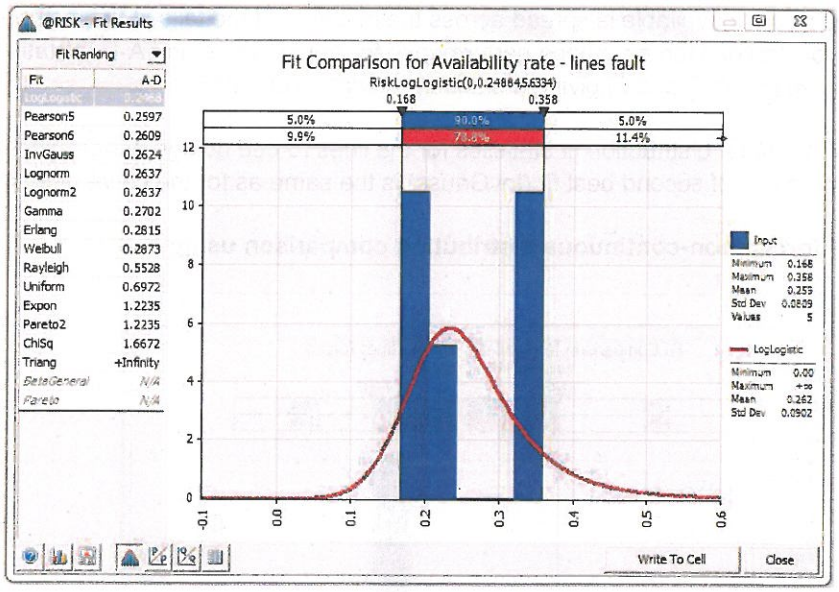
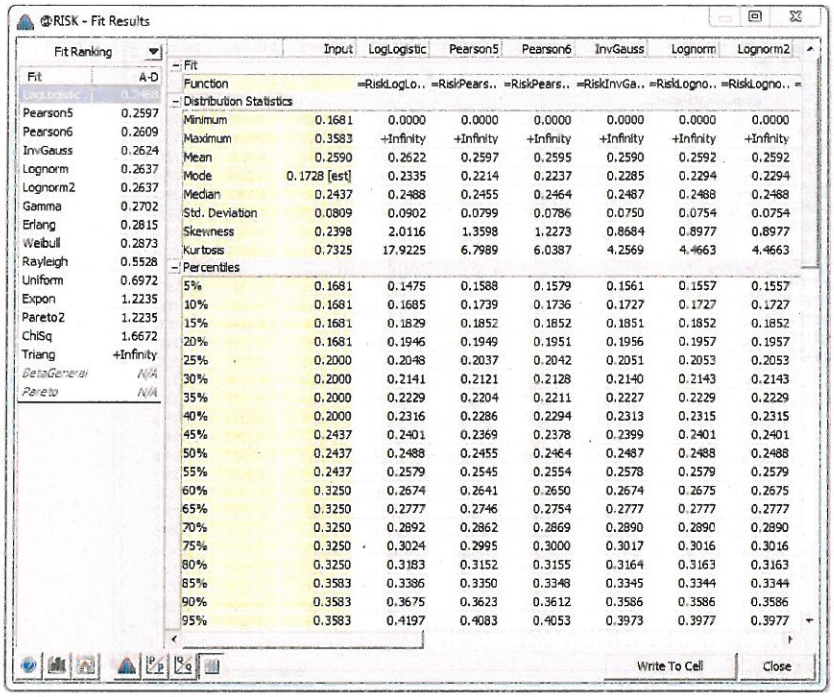


Table 6 Lines – fault non-continuous distribution statistics table for A-D



Lines outage rate – forced outage performance

The data for lines forced to be unavailable is spread across the middle and the tails of the distribution curve. The best fit distribution for the lines forced outage performance for both the K-S and A-D fit statistics is the Pearson5 distribution curve (figure 7 and 8) giving a standard deviation of 0.017.

Tables 7 and 8 illustrate the other distribution fit statistics for the lines forced outage performance. The standard deviation for the curve of second best fit (InvGauss) is the same as for the curve of best fit.

Figure 7 Lines - forced non-continuous distribution comparison using K-S

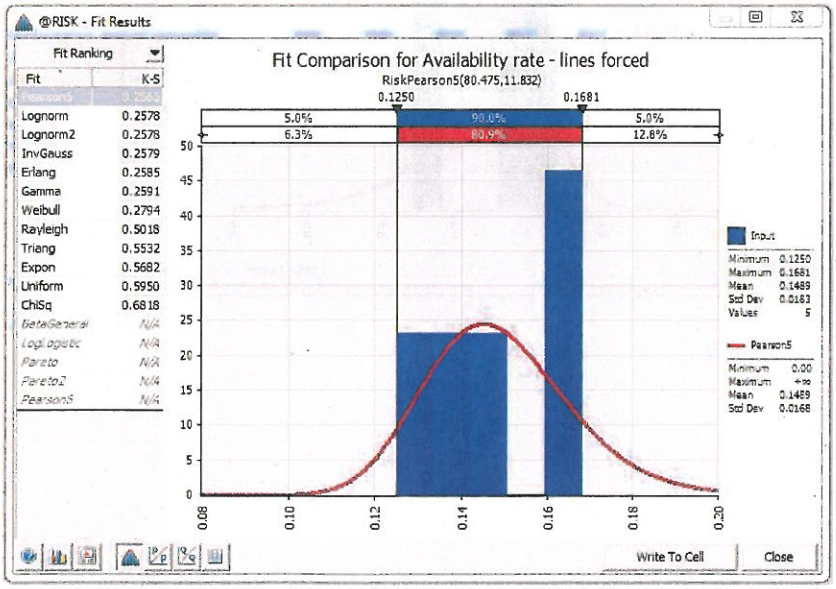


Table 7 Lines – forced non-continuous distribution statistics table for K-S

@RISK - Fit Results

Fit Ranking

Fit	K-S
Pearson5	0.2567
Lognorm	0.2578
Lognorm2	0.2578
InvGauss	0.2579
Erlang	0.2585
Gamma	0.2591
Weibull	0.2794
Rayleigh	0.5018
Triang	0.5532
Expon	0.5682
Uniform	0.5950
ChiSq	0.6818
BetaGeneral	N/A
LogLogistic	N/A
Pareto	N/A
Pareto2	N/A
Pearson6	N/A

	Input	Pearson5	Lognorm	Lognorm2	InvGauss	Erlang	Gamma
Fit							
Function		=RiskPears..	=RiskLogno..	=RiskLogno..	=RiskInvGa..	=RiskErlang..	=RiskGamm..
Distribution Statistics							
Minimum	0.1250	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Maximum	0.1681	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity
Mean	0.1489	0.1489	0.1489	0.1489	0.1489	0.1489	0.1489
Mode	0.1670 [est]	0.1452	0.1461	0.1461	0.1461	0.1470	0.1470
Median	0.1429	0.1476	0.1479	0.1479	0.1479	0.1482	0.1482
Std. Deviation	0.0183	0.0168	0.0166	0.0166	0.0166	0.0165	0.0165
Skewness	-0.0952	0.4574	0.3364	0.3364	0.3348	0.2222	0.2216
Kurtosis	1.2607	3.3963	3.2019	3.2019	3.1868	3.0741	3.0737
Percentiles							
5%	0.1250	0.1235	0.1232	0.1232	0.1232	0.1227	0.1228
10%	0.1250	0.1284	0.1283	0.1283	0.1283	0.1281	0.1281
15%	0.1250	0.1318	0.1318	0.1318	0.1318	0.1318	0.1318
20%	0.1250	0.1346	0.1347	0.1347	0.1347	0.1348	0.1348
25%	0.1417	0.1370	0.1372	0.1372	0.1372	0.1374	0.1374
30%	0.1417	0.1393	0.1395	0.1395	0.1395	0.1398	0.1398
35%	0.1417	0.1415	0.1417	0.1417	0.1417	0.1420	0.1420
40%	0.1417	0.1435	0.1438	0.1438	0.1438	0.1441	0.1441
45%	0.1429	0.1456	0.1459	0.1459	0.1459	0.1462	0.1462
50%	0.1429	0.1476	0.1479	0.1479	0.1479	0.1482	0.1482
55%	0.1429	0.1497	0.1500	0.1500	0.1500	0.1503	0.1503
60%	0.1667	0.1519	0.1522	0.1522	0.1522	0.1525	0.1525
65%	0.1667	0.1542	0.1544	0.1544	0.1544	0.1547	0.1547
70%	0.1667	0.1566	0.1568	0.1568	0.1568	0.1571	0.1570
75%	0.1667	0.1593	0.1595	0.1595	0.1595	0.1596	0.1596
80%	0.1667	0.1624	0.1625	0.1625	0.1625	0.1626	0.1625
85%	0.1681	0.1661	0.1660	0.1660	0.1660	0.1660	0.1660
90%	0.1681	0.1709	0.1706	0.1706	0.1706	0.1704	0.1703
95%	0.1681	0.1784	0.1777	0.1777	0.1776	0.1771	0.1770

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Figure 8 Lines - forced non-continuous distribution comparison using A-D

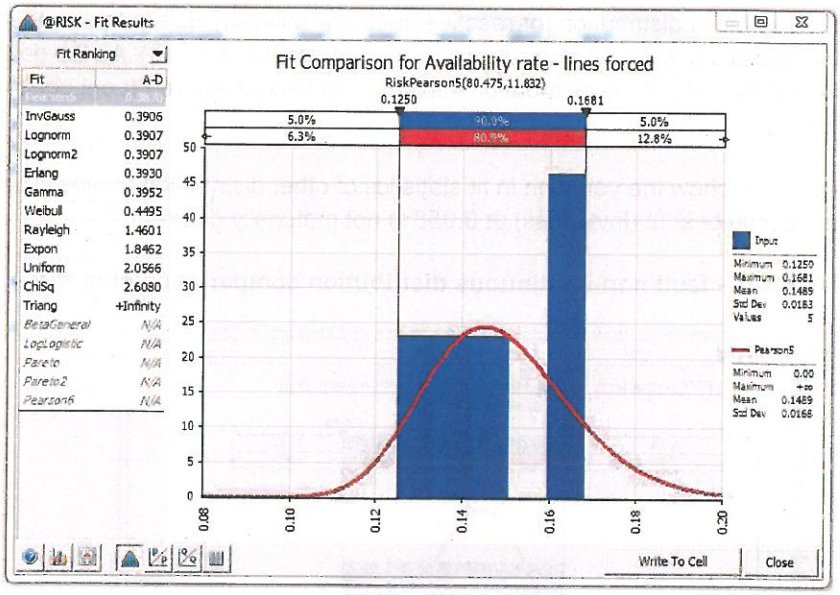

Table 8 Lines – forced non-continuous distribution statistics table for A-D

@RISK - Fit Results

Fit Ranking

Fit	A-D
Pearson5	0.3870
InvGauss	0.3906
Lognorm	0.3907
Lognorm2	0.3907
Erlang	0.3930
Gamma	0.3952
Weibull	0.4495
Rayleigh	1.4601
Expon	1.8462
Uniform	2.0566
ChiSq	2.6080
Triang	+Infinity
BetaGeneral	N/A
LogLogistic	N/A
Pareto	N/A
Pareto2	N/A
Pearson5	N/A

	Input	Pearson5	InvGauss	Lognorm	Lognorm2	Erlang	Gamma
Fit							
Function		=RiskPears..	=RiskInvGa..	=RiskLogno..	=RiskLogno..	=RiskErlang..	=RiskGamm..
Distribution Statistics							
Minimum	0.1250	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Maximum	0.1681	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity
Mean	0.1489	0.1489	0.1489	0.1489	0.1489	0.1489	0.1489
Mode	0.1670 [est]	0.1452	0.1461	0.1461	0.1461	0.1470	0.1470
Median	0.1429	0.1476	0.1479	0.1479	0.1479	0.1482	0.1482
Std. Deviation	0.0183	0.0168	0.0166	0.0166	0.0166	0.0165	0.0165
Skewness	-0.0952	0.4574	0.3348	0.3364	0.3364	0.2222	0.2216
Kurtosis	1.2607	3.3963	3.1868	3.2019	3.2019	3.0741	3.0737
Percentiles							
5%	0.1250	0.1235	0.1232	0.1232	0.1232	0.1227	0.1228
10%	0.1250	0.1284	0.1283	0.1283	0.1283	0.1281	0.1281
15%	0.1250	0.1318	0.1318	0.1318	0.1318	0.1318	0.1318
20%	0.1250	0.1346	0.1347	0.1347	0.1347	0.1348	0.1348
25%	0.1417	0.1370	0.1372	0.1372	0.1372	0.1374	0.1374
30%	0.1417	0.1393	0.1395	0.1395	0.1395	0.1398	0.1398
35%	0.1417	0.1415	0.1417	0.1417	0.1417	0.1420	0.1420
40%	0.1417	0.1435	0.1438	0.1438	0.1438	0.1441	0.1441
45%	0.1429	0.1456	0.1459	0.1459	0.1459	0.1462	0.1462
50%	0.1429	0.1476	0.1479	0.1479	0.1479	0.1482	0.1482
55%	0.1429	0.1497	0.1500	0.1500	0.1500	0.1503	0.1503
60%	0.1667	0.1519	0.1522	0.1522	0.1522	0.1525	0.1525
65%	0.1667	0.1542	0.1544	0.1544	0.1544	0.1547	0.1547
70%	0.1667	0.1566	0.1568	0.1568	0.1568	0.1571	0.1570
75%	0.1667	0.1593	0.1595	0.1595	0.1595	0.1596	0.1596
80%	0.1667	0.1624	0.1625	0.1625	0.1625	0.1626	0.1625
85%	0.1681	0.1661	0.1660	0.1660	0.1660	0.1660	0.1660
90%	0.1681	0.1709	0.1706	0.1706	0.1706	0.1704	0.1703
95%	0.1681	0.1784	0.1776	0.1777	0.1777	0.1771	0.1770

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Reactive plant outage rate – fault performance

Using the K-S fit statistic, the best fit distribution for reactive plant unavailability due to fault is the InvGauss (figure 9), while the A-D fit statistic has the Loglogistic curve as the best fit (figure 10). As the data is spread evenly across the middle and the tails of the distribution curve the A-D fit is preferred (LogLogistic), giving a standard deviation of 0.064.

Tables 9 and 10 are provided to show the variation in fit statistics of other distribution curves. The standard deviation for the curve of second best fit (InvGauss) at 0.058 is not materially different.

Figure 9 Reactive plant – fault non-continuous distribution comparison using K-S

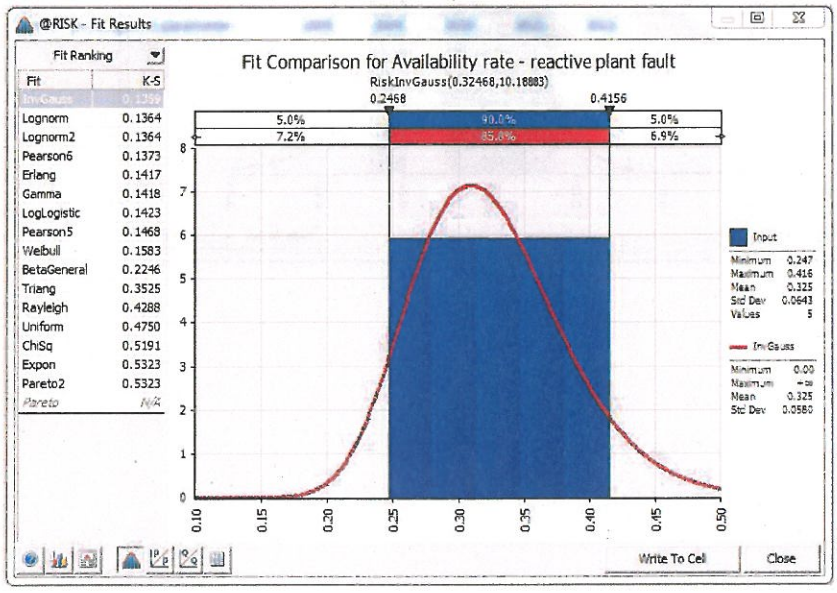

Table 9 Reactive plant – fault non-continuous distribution statistics table for K-S

@RISK - Fit Results

Fit Ranking

Fit	K-S
InvGauss	0.1352
Lognorm	0.1364
Lognorm2	0.1364
Pearson6	0.1373
Erlang	0.1417
Gamma	0.1418
LogLogistic	0.1423
Pearson5	0.1468
Weibull	0.1583
BetaGeneral	0.2246
Triang	0.3525
Rayleigh	0.4288
Uniform	0.4750
ChiSq	0.5191
Expon	0.5323
Pareto2	0.5323
Pareto	N/A

	Input	InvGauss	Lognorm	Lognorm2	Pearson6	Erlang	Gamma
Fit							
Function		=RiskInvGa..	=RiskLogno..	=RiskLogno..	=RiskPears..	=RiskErlang..	=RiskGamm..
Distribution Statistics							
Minimum	0.2468	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Maximum	0.4156	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity
Mean	0.3247	0.3247	0.3247	0.3247	0.3247	0.3247	0.3247
Mode	0.2510 [est]	0.3095	0.3097	0.3097	0.3090	0.3145	0.3145
Median	0.3247	0.3196	0.3196	0.3196	0.3193	0.3213	0.3213
Std. Deviation	0.0643	0.0580	0.0580	0.0580	0.0583	0.0574	0.0574
Skewness	0.3711	0.5355	0.5420	0.5420	0.5822	0.3536	0.3534
Kurtosis	2.9009	3.4780	3.5268	3.5268	3.6374	3.1875	3.1873
Percentiles							
5%	0.2468	0.2389	0.2387	0.2387	0.2391	0.2364	0.2364
10%	0.2468	0.2546	0.2546	0.2546	0.2548	0.2536	0.2537
15%	0.2468	0.2659	0.2660	0.2660	0.2660	0.2657	0.2658
20%	0.2468	0.2752	0.2753	0.2753	0.2753	0.2757	0.2757
25%	0.2857	0.2835	0.2836	0.2836	0.2835	0.2843	0.2844
30%	0.2857	0.2912	0.2912	0.2912	0.2911	0.2923	0.2923
35%	0.2857	0.2984	0.2985	0.2985	0.2983	0.2998	0.2998
40%	0.2857	0.3055	0.3056	0.3056	0.3053	0.3071	0.3071
45%	0.3247	0.3125	0.3126	0.3126	0.3123	0.3142	0.3142
50%	0.3247	0.3196	0.3196	0.3196	0.3193	0.3213	0.3213
55%	0.3247	0.3268	0.3268	0.3268	0.3265	0.3285	0.3285
60%	0.3506	0.3343	0.3343	0.3343	0.3340	0.3360	0.3360
65%	0.3506	0.3423	0.3422	0.3422	0.3419	0.3438	0.3438
70%	0.3506	0.3508	0.3508	0.3508	0.3505	0.3522	0.3521
75%	0.3506	0.3603	0.3602	0.3602	0.3600	0.3613	0.3613
80%	0.3506	0.3712	0.3711	0.3711	0.3709	0.3717	0.3717
85%	0.4156	0.3842	0.3841	0.3841	0.3841	0.3841	0.3841
90%	0.4156	0.4012	0.4012	0.4012	0.4014	0.4001	0.4000
95%	0.4156	0.4278	0.4279	0.4279	0.4286	0.4245	0.4244

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Figure 10 Reactive plant – fault non-continuous distribution comparison using A-D

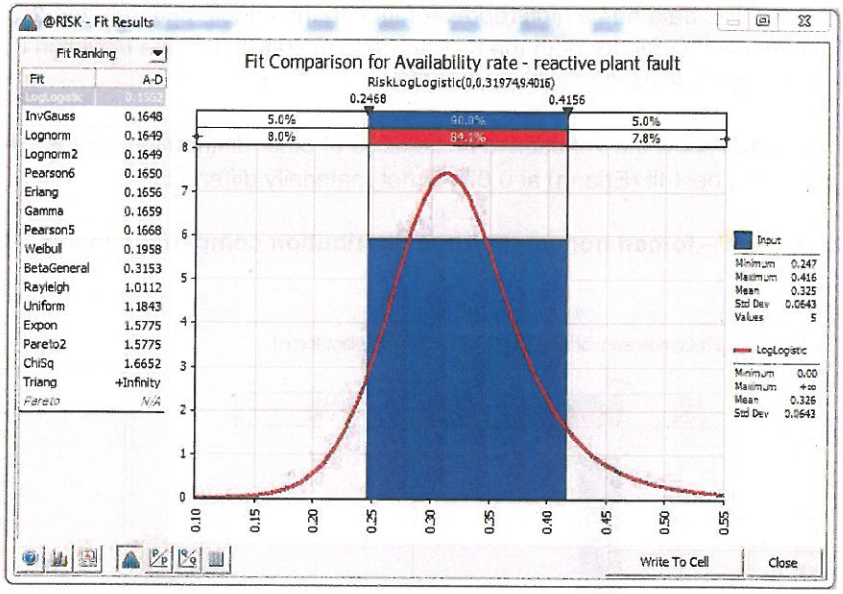

Table 10 Reactive plant – fault non-continuous distribution statistics table for A-D

@RISK - Fit Results

Fit Ranking

Fit	A-D
InvGauss	0.1648
Lognorm	0.1649
Lognorm2	0.1649
Pearson6	0.1650
Erlang	0.1656
Gamma	0.1659
Pearson5	0.1668
Weibull	0.1958
BetaGeneral	0.3153
Rayleigh	1.0112
Uniform	1.1843
Expon	1.5775
Pareto2	1.5775
ChiSq	1.6652
Triang	+Infinity
Pareto	*N/A*

	Input	LogLogistic	InvGauss	Lognorm	Lognorm2	Pearson6	Erlang
Fit							
Function		=RiskLogLo..	=RiskInvGa..	=RiskLogno..	=RiskLogno..	=RiskPears..	=RiskErlang..
Distribution Statistics							
Minimum	0.2468	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Maximum	0.4156	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity
Mean	0.3247	0.3258	0.3247	0.3247	0.3247	0.3247	0.3247
Mode	0.2510 [est]	0.3126	0.3095	0.3097	0.3097	0.3090	0.3145
Median	0.3247	0.3197	0.3196	0.3196	0.3196	0.3193	0.3213
Std. Deviation	0.0643	0.0643	0.0580	0.0580	0.0580	0.0583	0.0574
Skewness	0.3711	1.0065	0.5355	0.5420	0.5420	0.5822	0.3536
Kurtosis	2.9009	6.8954	3.4780	3.5268	3.5268	3.6374	3.1875
Percentiles							
5%	0.2468	0.2338	0.2389	0.2387	0.2387	0.2391	0.2364
10%	0.2468	0.2531	0.2546	0.2546	0.2546	0.2548	0.2536
15%	0.2468	0.2659	0.2659	0.2660	0.2660	0.2660	0.2657
20%	0.2468	0.2759	0.2752	0.2753	0.2753	0.2753	0.2757
25%	0.2857	0.2845	0.2835	0.2836	0.2836	0.2835	0.2843
30%	0.2857	0.2922	0.2912	0.2912	0.2912	0.2911	0.2923
35%	0.2857	0.2994	0.2984	0.2985	0.2985	0.2983	0.2998
40%	0.2857	0.3062	0.3055	0.3056	0.3056	0.3053	0.3071
45%	0.3247	0.3130	0.3125	0.3126	0.3126	0.3123	0.3142
50%	0.3247	0.3197	0.3196	0.3196	0.3196	0.3193	0.3213
55%	0.3247	0.3266	0.3268	0.3268	0.3268	0.3265	0.3285
60%	0.3506	0.3338	0.3343	0.3343	0.3343	0.3340	0.3360
65%	0.3506	0.3415	0.3423	0.3422	0.3422	0.3419	0.3438
70%	0.3506	0.3499	0.3508	0.3508	0.3508	0.3505	0.3522
75%	0.3506	0.3594	0.3603	0.3602	0.3602	0.3600	0.3613
80%	0.3506	0.3705	0.3712	0.3711	0.3711	0.3709	0.3717
85%	0.4156	0.3845	0.3842	0.3841	0.3841	0.3841	0.3841
90%	0.4156	0.4039	0.4012	0.4012	0.4012	0.4014	0.4001
95%	0.4156	0.4373	0.4278	0.4279	0.4279	0.4286	0.4245

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Reactive plant outage rate – forced outage performance

Reactive plant forced unavailability data has a high representation in the middle and right tail of the distribution. The best fit distribution curve for both the K-S and A-D fit statistics is the Rayleigh distribution curve (figures 11 and 12), giving a standard deviation of 0.076.

Tables 11 and 12 are provided to show the variation in fit statistics of other distribution curves. The standard deviation for the curve of second best fit (Erlang) at 0.074 is not materially different.

Figure 11 Reactive plant – forced non-continuous distribution comparison using K-S

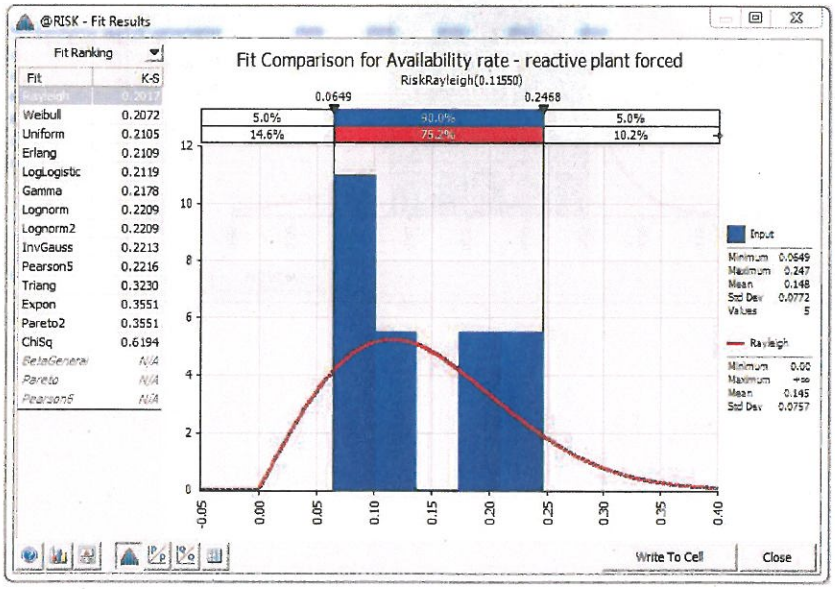


Table 11 Reactive plant – forced non-continuous distribution statistics table for K-S

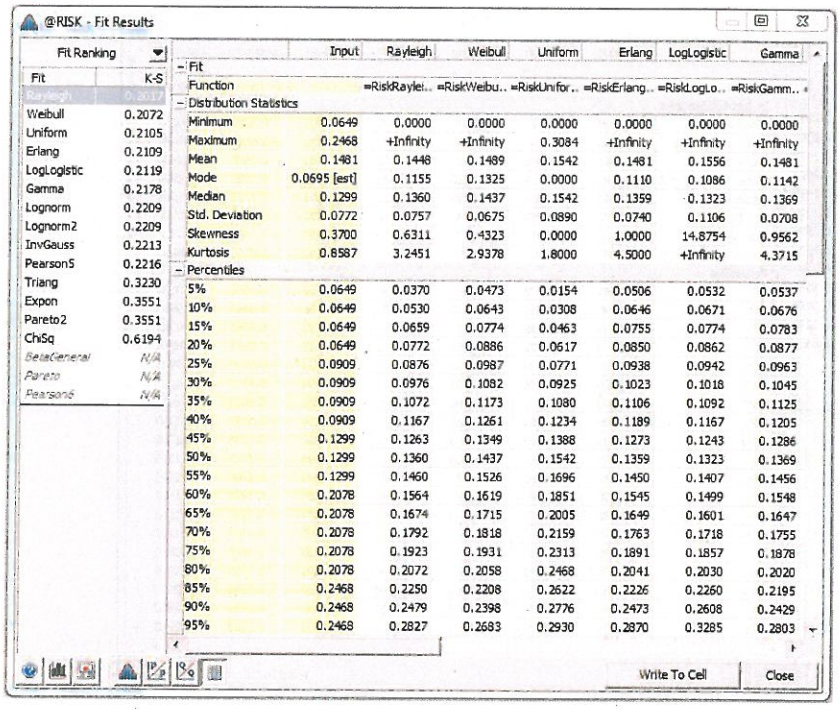


Figure 12 Reactive plant – forced non-continuous distribution comparison using A-D

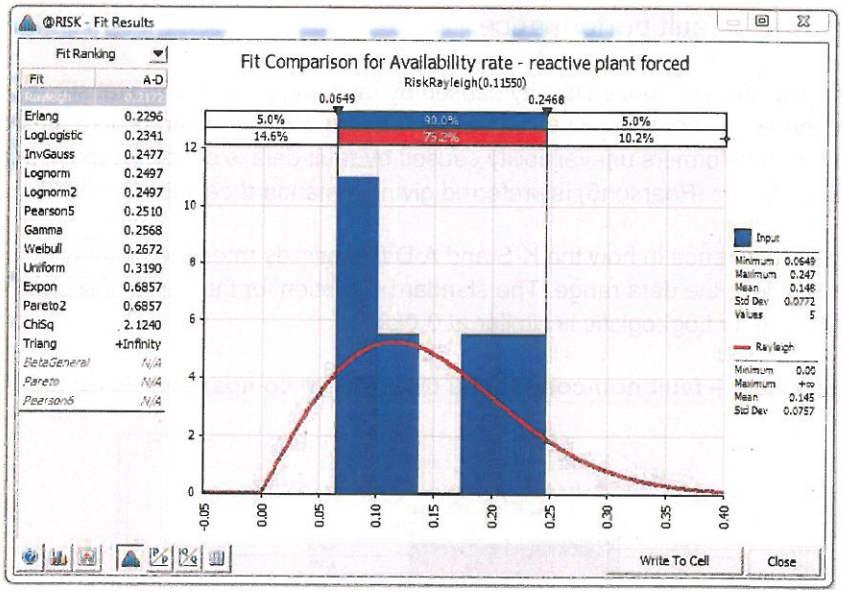
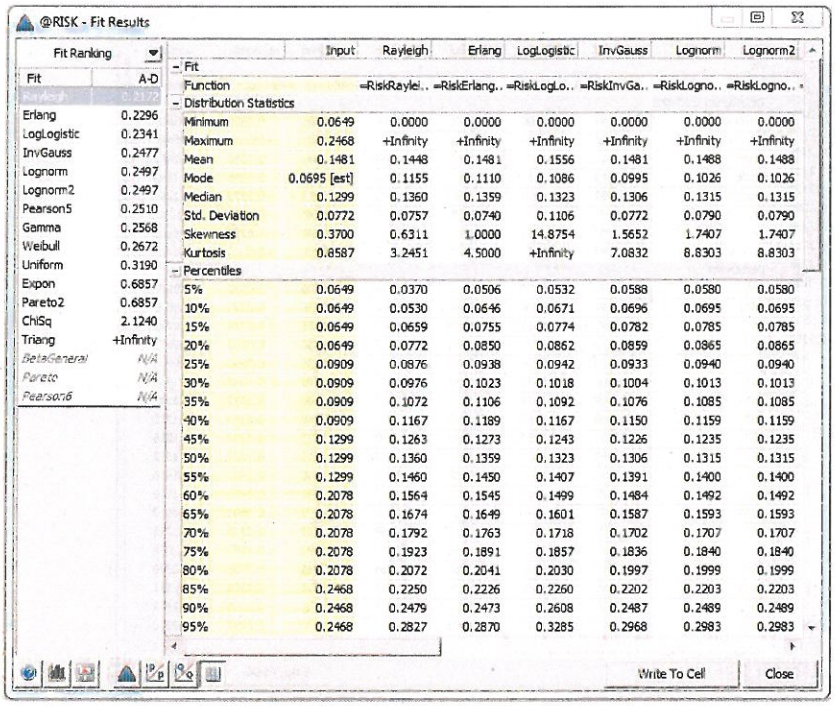


Table 12 Reactive plant – forced non-continuous distribution statistics table for A-D



Transformers outage rate – fault performance

The best fitting curve for Transformers unavailability caused by fault using the K-S fit statistic is the Pearson5 distribution (figure 13) curve while the A-D fit statistic has the LogLogistic distribution curve as the best fit (figure 14). As the data for Transformers unavailability caused by fault data is concentrated in the middle of the distribution, the K-S fit statistic (Pearson5) is preferred giving a standard deviation of 0.085.

Tables 13 and 14 show the difference in how the K-S and A-D fit statistics rated the distribution curves according their goodness of fit to the data range. The standard deviation for the curve of second best fit (Triang) is lower at 0.069, and for LogLogistic is similar at 0.089.

Figure 13 Transformers – fault non-continuous distribution comparison using K-S

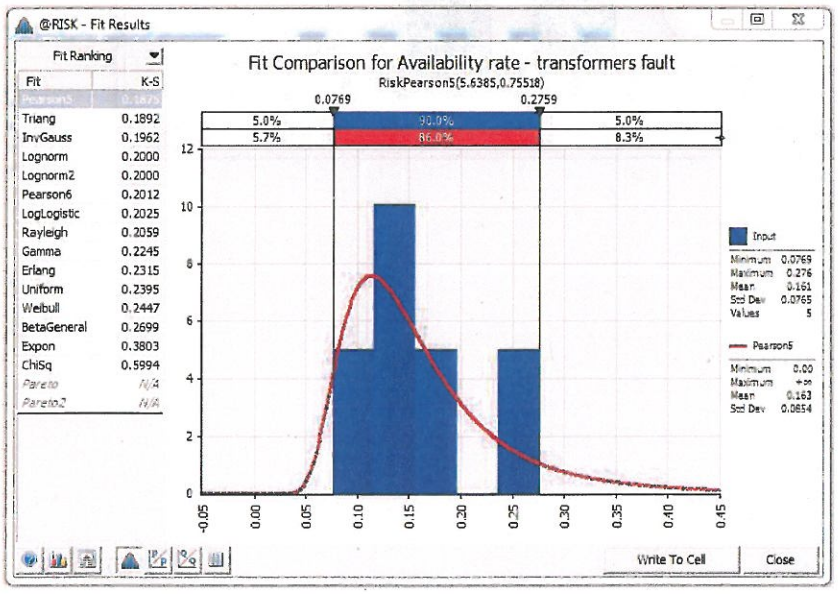


Table 13 Transformers – fault non-continuous distribution statistics table for K-S

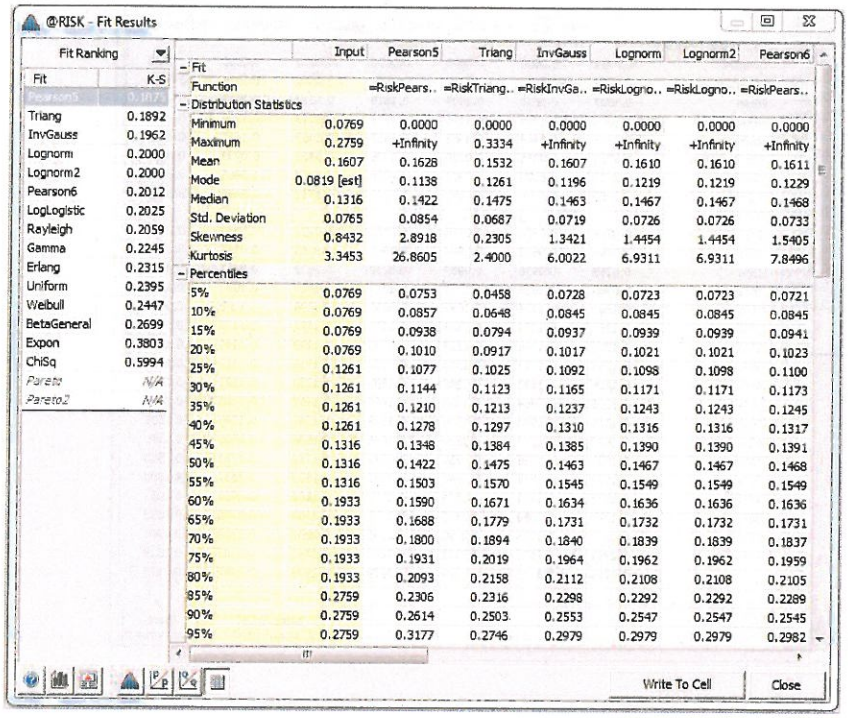


Figure 14 Transformers – fault non-continuous distribution comparison using A-D

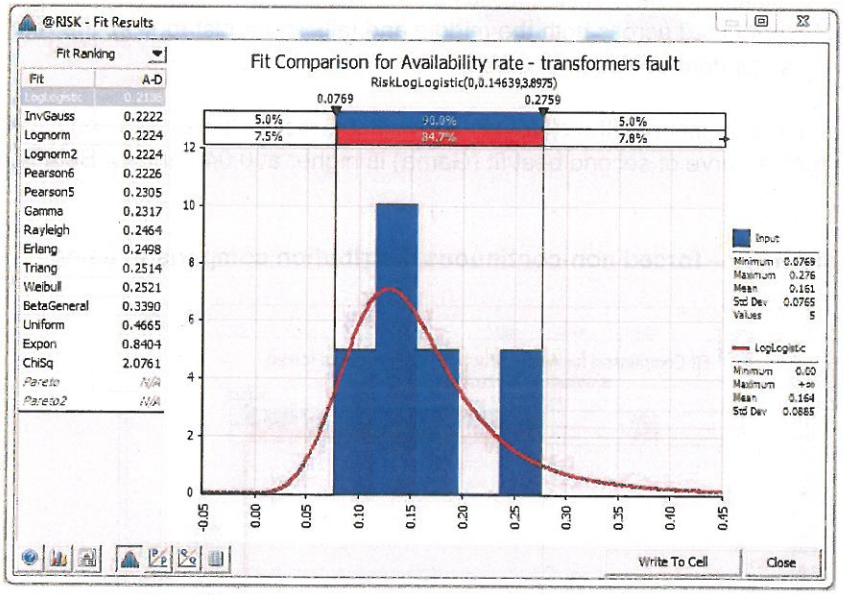


Table 14 Transformers – fault non-continuous distribution statistics table for A-D

@RISK - Fit Results

Fit Ranking

Fit	A-D
InvGauss	0.2222
Lognorm	0.2224
Lognorm2	0.2224
Pearson6	0.2226
Pearson5	0.2305
Gamma	0.2317
Rayleigh	0.2464
Erlang	0.2498
Triang	0.2514
Weibull	0.2521
BetaGeneral	0.3390
Uniform	0.4665
Expon	0.8404
ChiSq	2.0761
Pareto	*N/A*
Pareto2	*N/A*

	Input	LogLogistic	InvGauss	Lognorm	Lognorm2	Pearson6	Pearson5
Fit							
Function		=RiskLogLo..	=RiskInvGa..	=RiskLogno..	=RiskLogno..	=RiskPears..	=RiskPears..
Distribution Statistics							
Minimum	0.0769	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Maximum	0.2759	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity
Mean	0.1607	0.1635	0.1607	0.1610	0.1610	0.1611	0.1628
Mode	0.0819 [est]	0.1279	0.1196	0.1219	0.1219	0.1229	0.1138
Median	0.1316	0.1464	0.1463	0.1467	0.1467	0.1468	0.1422
Std. Deviation	0.0765	0.0885	0.0719	0.0726	0.0726	0.0733	0.0854
Skewness	0.8432	4.6772	1.3421	1.4454	1.4454	1.5405	2.8918
Kurtosis	3.3453	+Infinity	6.0022	6.9311	6.9311	7.8496	26.8605
Percentiles							
5%	0.0769	0.0688	0.0728	0.0723	0.0723	0.0721	0.0753
10%	0.0769	0.0833	0.0845	0.0845	0.0845	0.0845	0.0857
15%	0.0769	0.0938	0.0937	0.0939	0.0939	0.0941	0.0938
20%	0.0769	0.1026	0.1017	0.1021	0.1021	0.1023	0.1010
25%	0.1261	0.1104	0.1092	0.1098	0.1098	0.1100	0.1077
30%	0.1261	0.1178	0.1165	0.1171	0.1171	0.1173	0.1144
35%	0.1261	0.1249	0.1237	0.1243	0.1243	0.1245	0.1210
40%	0.1261	0.1319	0.1310	0.1316	0.1316	0.1317	0.1278
45%	0.1316	0.1390	0.1385	0.1390	0.1390	0.1391	0.1348
50%	0.1316	0.1464	0.1463	0.1467	0.1467	0.1468	0.1422
55%	0.1316	0.1541	0.1545	0.1549	0.1549	0.1549	0.1503
60%	0.1933	0.1624	0.1634	0.1636	0.1636	0.1636	0.1590
65%	0.1933	0.1716	0.1731	0.1732	0.1732	0.1731	0.1688
70%	0.1933	0.1819	0.1840	0.1839	0.1839	0.1837	0.1800
75%	0.1933	0.1941	0.1964	0.1962	0.1962	0.1959	0.1931
80%	0.1933	0.2089	0.2112	0.2108	0.2108	0.2105	0.2093
85%	0.2759	0.2285	0.2298	0.2292	0.2292	0.2289	0.2306
90%	0.2759	0.2573	0.2553	0.2547	0.2547	0.2545	0.2614
95%	0.2759	0.3116	0.2979	0.2979	0.2979	0.2982	0.3177

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Transformers outage rate – forced outage performance

The data for forced unavailability of transformers is best fitted with a BetaGeneral distribution curve (figure 15) according to the K-S fit statistic. The A-D fit statistic has the Weibull distribution curve as the best fit (figure 16). As the data is distributed across both the middle and tails of the distribution, the A-D fit statistic is preferred (Weibull), giving a standard deviation of 0.034.

Tables 15 and 16 presents the variation in the distribution curve statistics between K-S and A-D fit statistics. The standard deviation for the curve of second best fit (Gama) is higher at 0.045 and for BetaGeneral is similar at 0.038.

Figure 15 Transformers – forced non-continuous distribution comparison using K-S

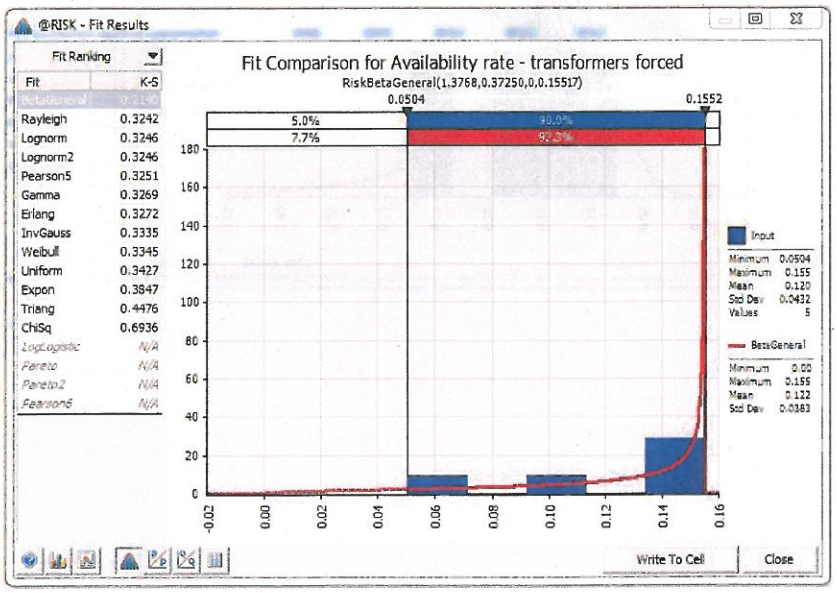


Table 15 Transformers – forced non-continuous distribution statistics table for K-S

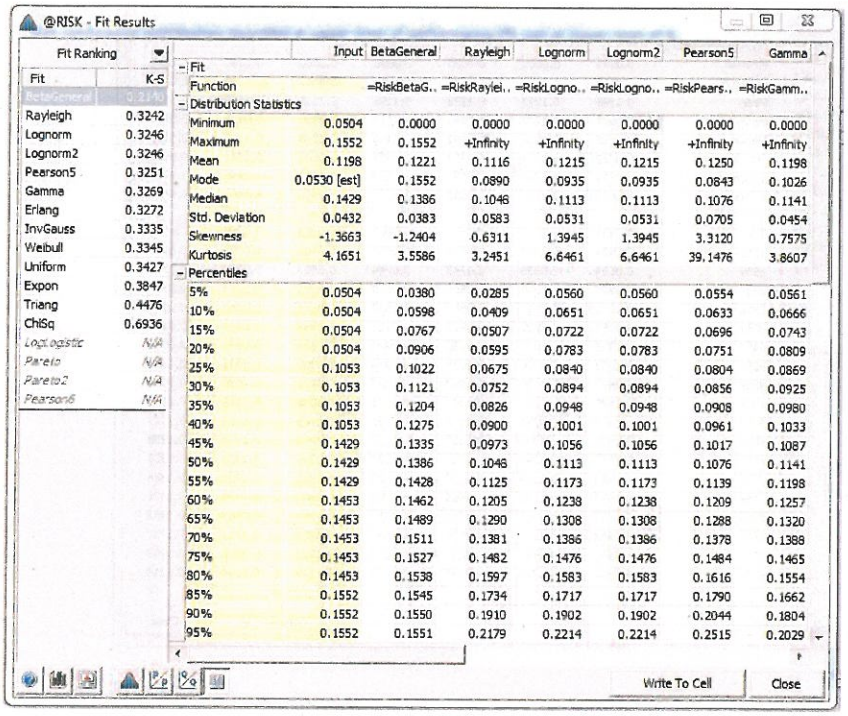


Figure 16 Transformers – forced non-continuous distribution comparison using A-D

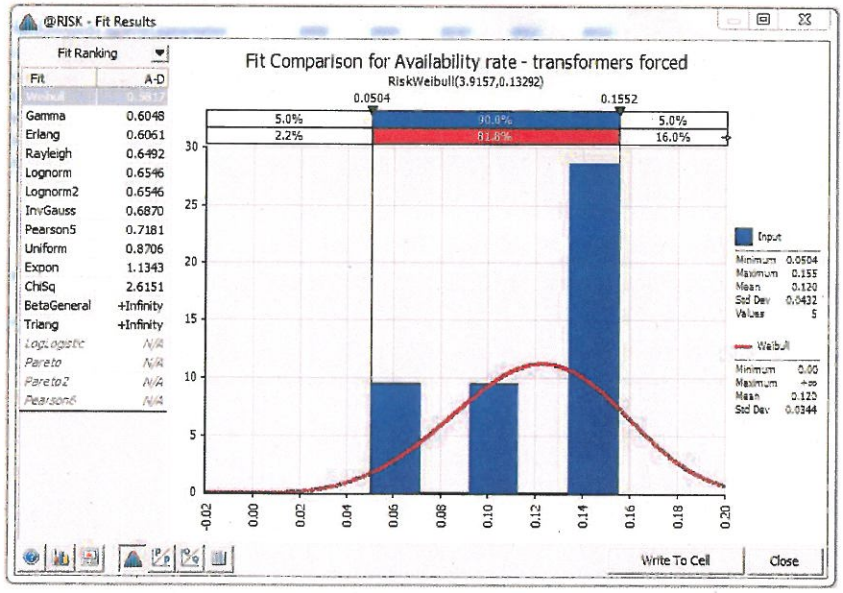
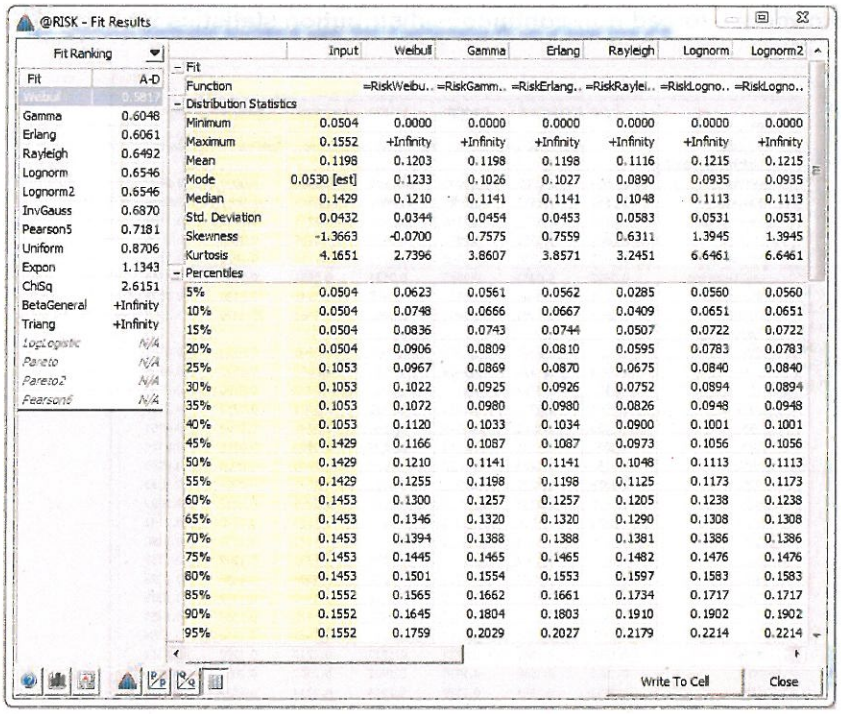


Table 16 Transformers – forced non-continuous distribution statistics table for A-D



@RISK - Fit Results

Fit Ranking

Fit	A-D
Weibull	0.5817
Gamma	0.6048
Erlang	0.6061
Rayleigh	0.6492
Lognorm	0.6546
Lognorm2	0.6546
InvGauss	0.6870
Pearson5	0.7181
Uniform	0.8706
Expon	1.1343
ChiSq	2.6151
BetaGeneral	+Infinity
Triang	+Infinity
Log Logistic	N/A
Pareto	N/A
Pareto2	N/A
Pearson6	N/A

	Input	Weibull	Gamma	Erlang	Rayleigh	Lognorm	Lognorm2
Fit							
Function		=RiskWeibu..	=RiskGamm..	=RiskErlang..	=RiskRaylei..	=RiskLogno..	=RiskLogno..
Distribution Statistics							
Minimum	0.0504	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Maximum	0.1552	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity	+Infinity
Mean	0.1198	0.1203	0.1198	0.1198	0.1116	0.1215	0.1215
Mode	0.0530 [est]	0.1233	0.1026	0.1027	0.0890	0.0935	0.0935
Median	0.1429	0.1210	0.1141	0.1141	0.1048	0.1113	0.1113
Std. Deviation	0.0432	0.0344	0.0454	0.0453	0.0583	0.0531	0.0531
Skewness	-1.3663	-0.0700	0.7575	0.7559	0.6311	1.3945	1.3945
Kurtosis	4.1651	2.7396	3.8607	3.8571	3.2451	6.6461	6.6461
Percentiles							
5%	0.0504	0.0623	0.0561	0.0562	0.0285	0.0560	0.0560
10%	0.0504	0.0748	0.0666	0.0667	0.0409	0.0651	0.0651
15%	0.0504	0.0836	0.0743	0.0744	0.0507	0.0722	0.0722
20%	0.0504	0.0906	0.0809	0.0810	0.0595	0.0783	0.0783
25%	0.1053	0.0967	0.0869	0.0870	0.0675	0.0840	0.0840
30%	0.1053	0.1022	0.0925	0.0926	0.0752	0.0894	0.0894
35%	0.1053	0.1072	0.0980	0.0980	0.0826	0.0948	0.0948
40%	0.1053	0.1120	0.1033	0.1034	0.0900	0.1001	0.1001
45%	0.1429	0.1166	0.1087	0.1087	0.0973	0.1056	0.1056
50%	0.1429	0.1210	0.1141	0.1141	0.1048	0.1113	0.1113
55%	0.1429	0.1255	0.1198	0.1198	0.1125	0.1173	0.1173
60%	0.1453	0.1300	0.1257	0.1257	0.1205	0.1238	0.1238
65%	0.1453	0.1346	0.1320	0.1320	0.1290	0.1308	0.1308
70%	0.1453	0.1394	0.1388	0.1388	0.1381	0.1386	0.1386
75%	0.1453	0.1445	0.1465	0.1465	0.1482	0.1476	0.1476
80%	0.1453	0.1501	0.1554	0.1553	0.1597	0.1583	0.1583
85%	0.1552	0.1565	0.1662	0.1661	0.1734	0.1717	0.1717
90%	0.1552	0.1645	0.1804	0.1803	0.1910	0.1902	0.1902
95%	0.1552	0.1759	0.2029	0.2027	0.2179	0.2214	0.2214

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3. Summary of findings

Table 17 summarises the probability distribution functions that have been chosen to best fit the parameter data (table 18). In Parsons Brinckerhoff's view this approach is robust and does not seem to be sensitive to the choice of distribution function, because the results were close for the next best fit distributions. The approach is also consistent with the Australian Energy Regulator's previous regulatory decisions to use a curve of best fit approach.

Table 17 Summary of best fit distributions

Parameter	Best fit distribution	Standard Deviation
Average outage duration	Exponential	97.96
No. of events >0.05 system minutes	NegBin	2.000
No. of events >0.30 system minutes	IntUniform	0.816
Lines outage rate - fault	LogLogistic	0.090
Lines outage rate - forced outage	Pearson5	0.017
Reactive plant outage rate - fault	LogLogistic	0.064
Reactive plant outage rate - forced outage	Rayleigh	0.076
Transformers outage rate - fault	Pearson5	0.085
Transformers outage rate - forced outage	Weibull	0.034

Table 18 Reliability Data 2008-2012

Parameter	2008	2009	2010	2011	2012
Average outage duration	71.5	91.8	92.5	4.0	230.0
No. of events >0.05 system minutes	1	6	1	0	2
No. of events >0.30 system minutes	1	2	0	0	1
Lines outage rate - fault	20.0%	35.8%	16.8%	24.4%	32.5%
Lines outage rate - forced outage	16.7%	12.5%	14.3%	16.8%	14.2%
Reactive plant outage rate - fault	28.6%	35.1%	24.7%	32.5%	41.6%
Reactive plant outage rate - forced outage	6.5%	9.1%	13.0%	24.7%	20.8%
Transformers outage rate - fault	13.2%	27.6%	7.7%	12.6%	19.3%
Transformers outage rate - forced outage	10.5%	15.5%	14.5%	5.0%	14.3%