TransGrid

TransGrid Revenue Proposal 2018/19 – 2022/23

Appendix X

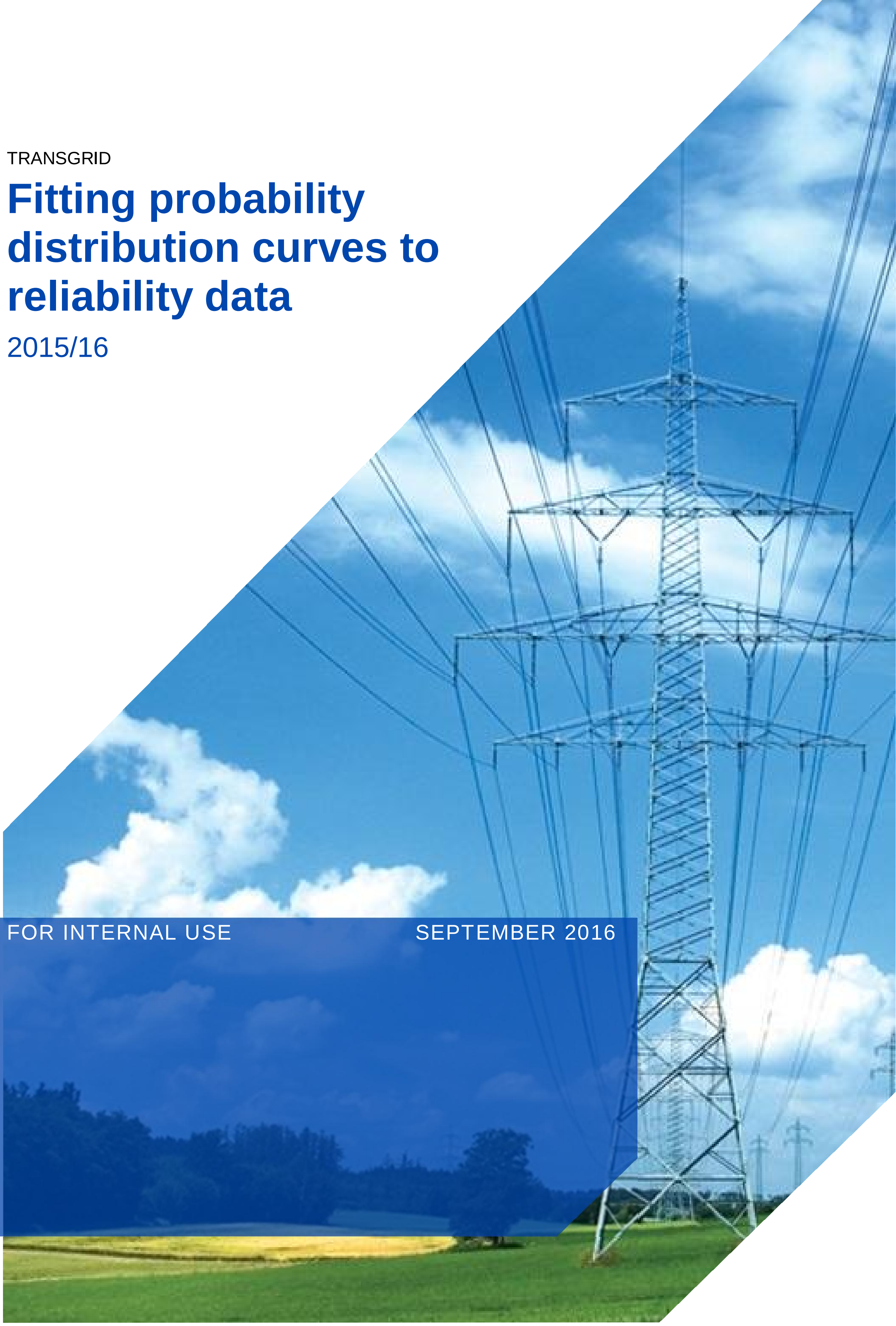
WSP Parsons Brinckerhoff:

STPIS: Fitting probability curves to reliability data

TRANSGRID

Fitting probability distribution curves to reliability data

2015/16



FOR INTERNAL USE

SEPTEMBER 2016

Fitting probability distribution curves to reliability data

2015/16

TransGrid

For internal use

REV	DATE	DETAILS
A	26/08/2016	Draft for review
B	7/09/2016	Final

AUTHOR, REVIEWER AND APPROVER DETAILS

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1 INTRODUCTION

WSP | Parsons Brinckerhoff was engaged by TransGrid to assist with the determination of suitable attributes for the parameters of its service target performance incentive scheme (STPIS). The parameters and sub-parameters of the service component of TransGrid's STPIS included in the review are:

- Average circuit outage rate
  - lines outage rate - fault
  - transformer outage rate - fault
  - reactive plant outage rate - fault
  - lines outage rate - forced outage
  - transformer outage rate - forced outage
  - reactive plant outage rate - forced outage
- loss of supply event frequency
- average outage duration
- proper operation of equipment
  - failure of protection system
  - material failure of Supervisory Control and Data Acquisition (SCADA) system
  - incorrect operational isolation of primary or secondary equipment

We note that the Proper Operation of Equipment parameter has an incentive weighting of zero and hence has no financial impact.

WSP | Parsons Brinckerhoff determined a curve of best fit to TransGrid's reliability data from the past five years 2012-2016 (2016 data is currently forecast) for each of the parameters and calculated the 5th and 95th percentile values on which proposed caps and collars for this scheme are based. Recommended values for the parameter targets, caps and collars are proposed.

1.1 Approach

WSP | 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 circuit outage rates are fitted with continuous probability distributions bounded at a lower limit of zero.
- Loss of supply event frequency are fitted with discrete probability distributions.
- Average outage duration data are fitted using 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 Akaike Information Criterion (AIC) was used. For non-discrete distributions, the Kolmogorov-Smirnov (K-S) and the Anderson-Darling (A-D) fit statistics were used, based on the following rationale:

- Discrete data:

- For discrete probability distributions, tests relied on are the chi-square, the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC).
- For the chi-square approximation to be valid the expected frequency in each interval bin should be at least 5. As this is not possible with only 5 values in the dataset (one value for each year 2011 to 2015), some uncertainty in the fitted distribution will occur.
- AIC is a measure of the relative quality of a statistical model for a given set of data. AIC deals with the trade-off between the goodness of fit of the model and the complexity of the model. It is founded on information entropy: it offers a relative estimate of the information lost when a given model is used to represent the process that generates the data. As such, AIC provides a means for model selection.
- BIC is closely related to the AIC, with a greater penalty for the number of parameters in the model. It is only valid for sample sizes much larger than the number of parameters in the model and is therefore likely to be inaccurate for small sample sizes.
- AIC is considered to provide a more appropriate methodology for determining the curve of best fit to small datasets than the chi-square or BIC.

→ Continuous data:

- For non-discrete distributions, tests relied on are the chi-square, the Kolmogorov-Smirnov (K-S), the Anderson-Darling (A-D), and the AIC and BIC.
- The chi-square test, as discussed above, will have some uncertainty in the fitted distribution for small sample sizes.
- 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. Hence, where the input data is concentrated around the middle of a distribution curve the K-S fit statistic is preferred and where the data is near the tails the A-D fit statistic is preferred. 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.
- The AIC test, as discussed above, is a valid test and is preferred over the BIC for small sample sizes.
- Given that the A-D test focusses on the goodness of fit in the tails of the distribution, the A-D test is preferred when the performance data has data in the tails as this is the part of the distribution of most interest in setting collars. Otherwise the K-S or AIC tests are appropriate.

Where the A-D and K-S tests identify different probability distribution functions of best fit, the shape of the distribution of the data is examined. Where it is distributed across both the middle and tails of the distribution, the A-D fit statistic is preferred, where it is distributed across only the middle of the distribution the K-S statistic is preferred.

Once the probability distribution function of best fit for the preferred fit statistic was verified for each parameter the standard deviation was examined against the standard deviation of the curve of second best fit. Because a probability distribution is being fitted to a dataset of five values only for each 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 standard deviation is a reasonable indicator about the similarity of the curves.

The curve of second best fit is examined to test for any large variations in the calculated values that might indicate that the curve of best fit should not have be used. Where standard deviation suggest that the curve of best fit should not have been used a number of other parameters may be examined:

→ the 5th and 95th percentile values of the probability distribution functions- As these values were used to set the caps and collars, where the 5th and 95th percentile values of the curve of best fit and the curve of second best fit align, the curve of best fit is likely to be appropriate to use.

→ the underlying data - A distribution may be chosen that best reflects the shape and spread of the underlying data,

→ other fit statistics – The results of other fit statistics may indicate the use of another curve.

→ longer run data to assist in improving the fit statistic.

Figure 1.1 shows where the information about the fit statistic and distribution is located on the charts that are produced by @RISK.

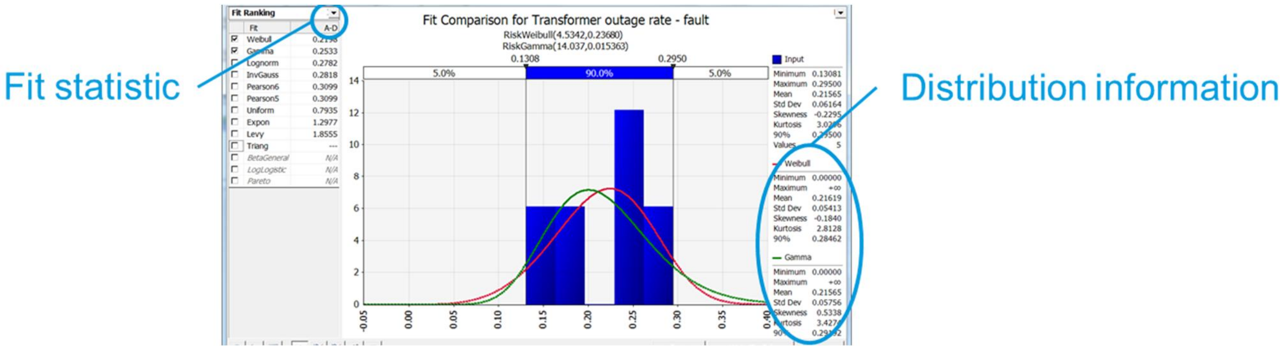

Figure 1.1 @Risk information locations

1.2 Parameter data

Table 1.1 shows the data used to calculate the parameter values.

The 2016 data has been estimated based on the 'year to date' values prorated until the end of the year.

Table 1.1 Reliability Data 2012-2016

PARAMETER	EST. 2016	2015	2014	2013	2012
LINES OUTAGE RATE – FAULT	13.27%	11.41%	10.23%	18.36%	16.65%
TRANSFORMERS OUTAGE RATE – FAULT	19.76%	13.06%	10.84%	18.14%	16.38%
REACTIVE PLANT OUTAGE RATE – FAULT	11.00%	9.47%	15.65%	9.90%	15.71%
LINES OUTAGE RATE - FORCED OUTAGE	7.58%	22.82%	17.05%	21.34%	8.07%
TRANSFORMERS OUTAGE RATE - FORCED OUTAGE	18.66%	31.02%	39.02%	23.64%	20.33%
REACTIVE PLANT OUTAGE RATE - FORCED OUTAGE	26.41%	26.96%	22.36%	24.38%	13.47%
NO. OF EVENTS >0.05 SYSTEM MINUTES	2	4	3	5	3
NO. OF EVENTS >0.25 SYSTEM MINUTES	0	3	0	0	1
AVERAGE OUTAGE DURATION	262.64	63.55	71.14	178.69	94.23
FAILURE OF PROTECTION SYSTEM	23	21	24	11	20
MATERIAL FAILURE OF SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA) SYSTEM	5	3	6	3	21
INCORRECT OPERATIONAL ISOLATION OF PRIMARY OR SECONDARY EQUIPMENT	3	9	6	10	7

2 RESULTS OF DISTRIBUTION FITTING

This section contains an explanation of the fitting for each parameter, followed by a summary of the distribution fittings.

2.1 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 curves to the data.

2.1.1 Lines outage rate – fault performance

The data for Lines outage rate is best fitted with a Weibull distribution according to the K-S fit statistic (Figure 2.1) and best fitted with LogLogistic distribution according to the A-D fit statistic (Figure 2.2).

As the data is distributed across both the middle and tails of the distribution, the A-D fit statistic is preferred (LogLogistic), giving a standard deviation of 0.03642. The standard deviation for the curve of second best fit for the A-D fit statistic (Pearson 5) is 0.03216, being only slightly lower than for the preferred curve, indicating that LogLogistic is appropriate.

LogLogistic is also the curve of third best fit for the K-S fit statistic.

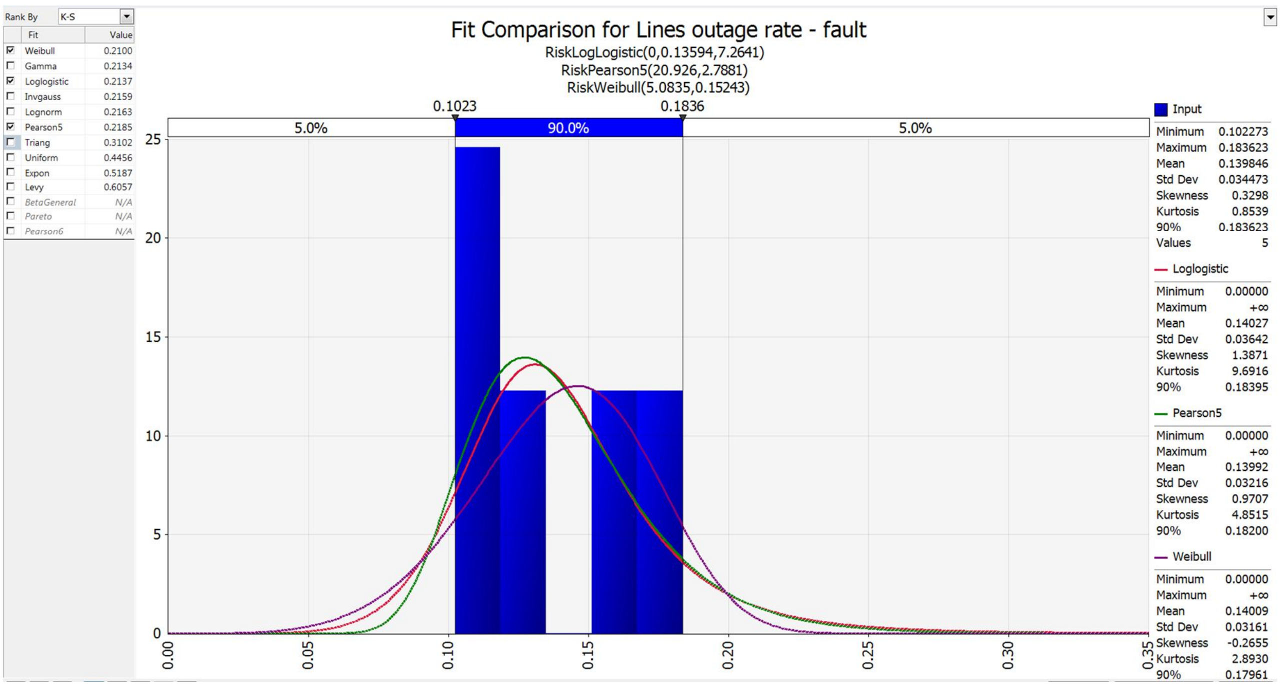

Figure 2.1 Lines – fault, comparison using K-S

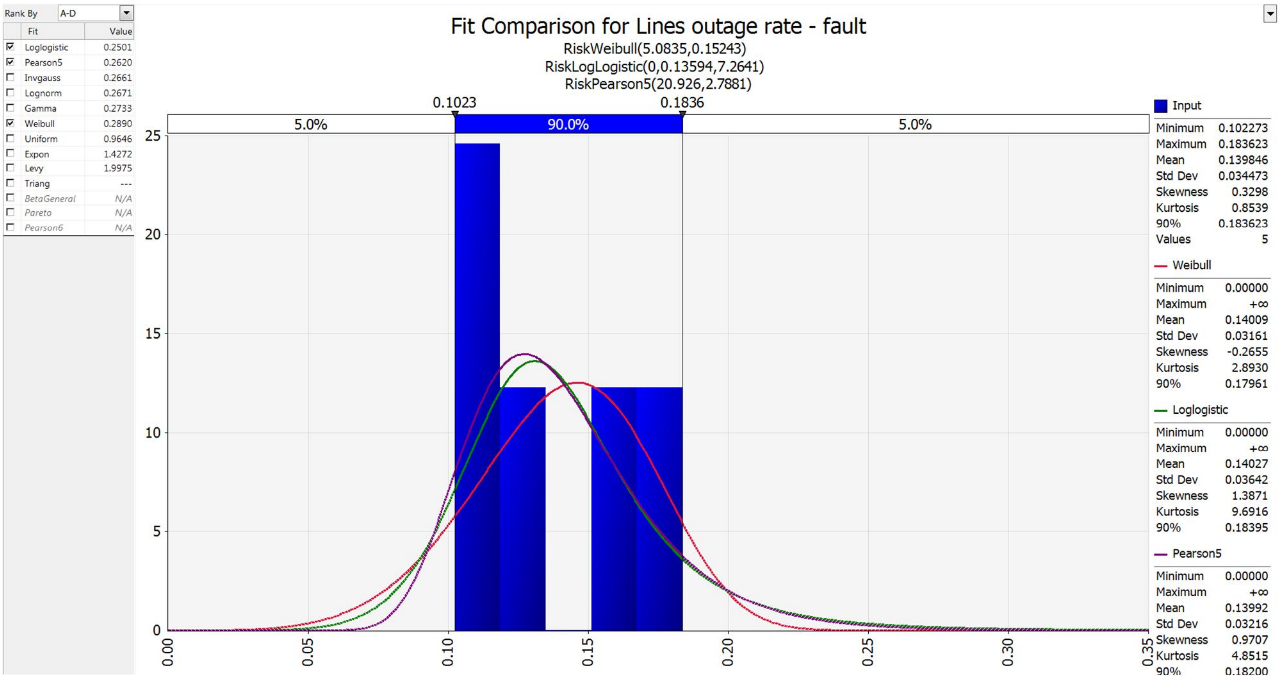

Figure 2.2 Lines – fault, comparison using A-D

As shown in Figure 2.3, the 5th and 95th percentile parameters for the preferred curve are 9.1% and 20.4% respectively.

@RISK - Fit Results

Rank By: A-D

Fit	Value
Loglogistic	0.2501
Pearson5	0.2620
Invgauss	0.2661
Lognorm	0.2671
Gamma	0.2733
Weibull	0.2890
Uniform	0.9646
Expon	1.4272
Levy	1.9975
Triang	---
BetaGeneral	N/A
Pareto	N/A
Pearson6	N/A

Percentiles	Input	Loglogistic	Pearson5	Invgauss	Lognorm	Gamma	Weibull	Uniform	Expon	Levy	Triang
5%	0.1023	0.0906	0.0962	0.0950	0.0949	0.09340	0.0850	0.0115	0.00717	0.0347	0.0411
10%	0.1023	0.1005	0.1034	0.1029	0.1028	0.10218	0.0979	0.0230	0.0147	0.0492	0.0581
15%	0.1023	0.1071	0.1087	0.1086	0.1086	0.10840	0.1066	0.0344	0.0227	0.0643	0.0711
20%	0.1023	0.1123	0.1131	0.1133	0.1133	0.11354	0.1135	0.0459	0.0312	0.0811	0.0821
25%	0.1141	0.1169	0.1171	0.1176	0.1176	0.11807	0.1193	0.0574	0.0402	0.1007	0.0918
30%	0.1141	0.1210	0.1209	0.1215	0.1216	0.12224	0.1244	0.0689	0.0499	0.1240	0.1006
35%	0.1141	0.1248	0.1245	0.1253	0.1253	0.12620	0.1292	0.0803	0.0602	0.1525	0.1086
40%	0.1141	0.1286	0.1281	0.1290	0.1291	0.13003	0.1336	0.0918	0.0714	0.1881	0.1161
45%	0.1327	0.1322	0.1317	0.1327	0.1327	0.13381	0.1378	0.1033	0.0836	0.2335	0.1232
50%	0.1327	0.1359	0.1354	0.1365	0.1365	0.13760	0.1418	0.1148	0.0969	0.2929	0.1298
55%	0.1327	0.1397	0.1392	0.1403	0.1403	0.14146	0.1458	0.1262	0.1117	0.3729	0.1362
60%	0.1665	0.1437	0.1432	0.1443	0.1443	0.14546	0.1498	0.1377	0.1281	0.4845	0.1422
65%	0.1665	0.1480	0.1475	0.1486	0.1486	0.14967	0.1539	0.1492	0.1468	0.6471	0.1480
70%	0.1665	0.1528	0.1523	0.1533	0.1532	0.15419	0.1581	0.1607	0.1684	0.8974	0.1536
75%	0.1665	0.1581	0.1576	0.1584	0.1584	0.15918	0.1625	0.1721	0.1939	1.3122	0.1590
80%	0.1665	0.1645	0.1639	0.1644	0.1643	0.16485	0.1674	0.1836	0.2251	2.0758	0.1642
85%	0.1836	0.1726	0.1716	0.1716	0.1716	0.17162	0.1729	0.1951	0.2653	3.7251	0.1693
90%	0.1836	0.1840	0.1820	0.1811	0.1811	0.18041	0.1796	0.2066	0.3220	8.4374	0.1742
95%	0.1836	0.2039	0.1990	0.1961	0.1962	0.19396	0.1891	0.2181	0.4189	33.8830	0.1790

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Figure 2.3 Lines – fault, distribution percentiles

2.1.2 Transformers outage rate – fault performance

The data for Transformer outage rate is best fitted with a Weibull distribution according to both the K-S fit statistic (Figure 2.4) and the A-D fit statistic (Figure 2.5).

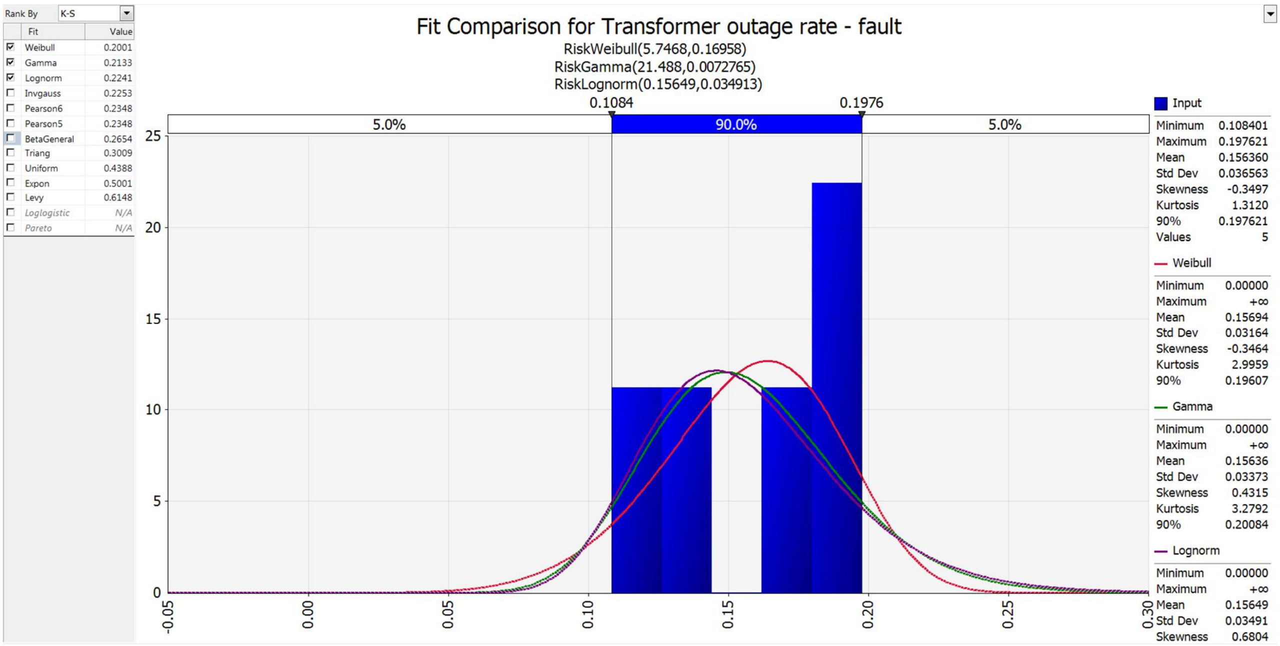

Figure 2.4 Transformers – fault, comparison using K-S

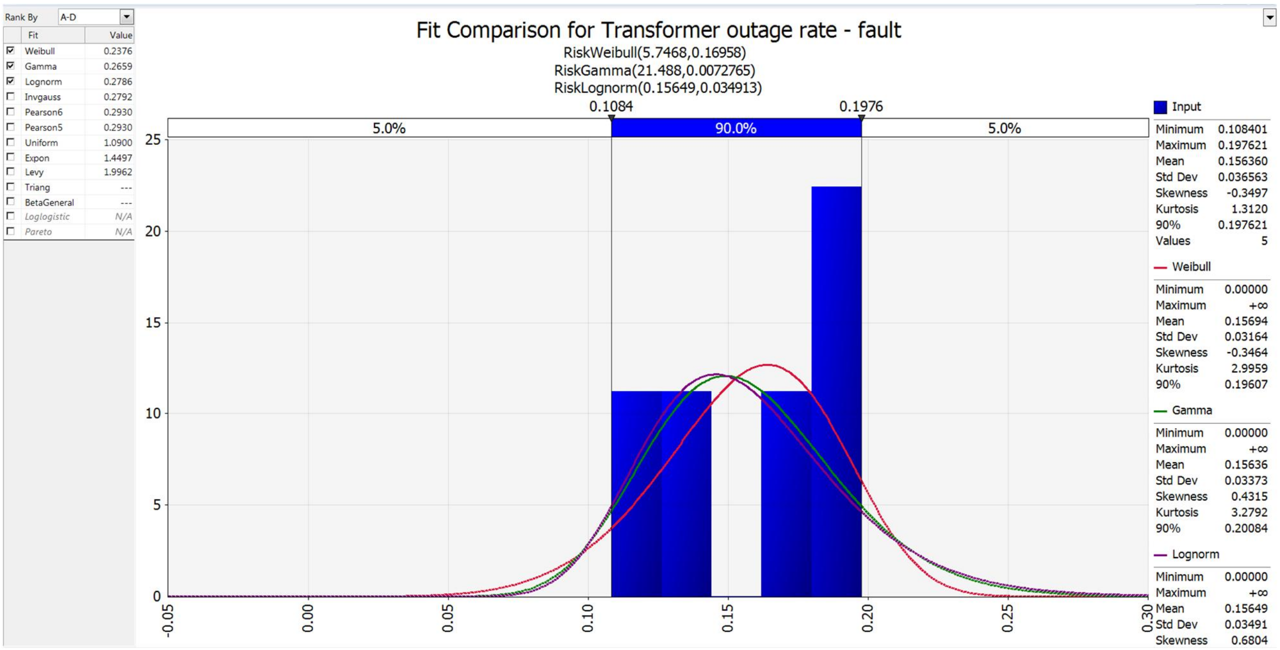

Figure 2.5 Transformers – fault, comparison using A-D

As shown in Figure 2.6, the 5th and 95th percentile parameters for the preferred curve are 10.1% and 20.5% respectively.

@RISK - Fit Results

Rank By: K-S

Fit	Value
Weibull	0.2001
Gamma	0.2133
Lognorm	0.2241
Invgauss	0.2253
Pearson6	0.2348
Pearson5	0.2348
BetaGeneral	0.2654
Triang	0.3009
Uniform	0.4388
Expon	0.5001
Levy	0.6148
Loglogistic	*N/A*
Pareto	*N/A*

Percentiles	Input	Weibull	Gamma	Lognorm	Invgauss	Pearson6	Pearson5	BetaGeneral	Triang	Uniform	Expon	Levy
5%	0.1084	0.1011	0.10531	0.1063	0.1063	0.10709529	0.1071	0.0699	0.0442	0.0124	0.00802	0.0388
10%	0.1084	0.1146	0.11499	0.1152	0.1151	0.11521611	0.1152	0.0963	0.0625	0.0247	0.0165	0.0551
15%	0.1084	0.1236	0.12185	0.1215	0.1214	0.12117004	0.1212	0.1150	0.0765	0.0371	0.0254	0.0719
20%	0.1084	0.1306	0.12750	0.1269	0.1267	0.12620068	0.1262	0.1296	0.0884	0.0494	0.0349	0.0907
25%	0.1306	0.1365	0.13249	0.1316	0.1315	0.13074246	0.1307	0.1415	0.0988	0.0618	0.0450	0.1126
30%	0.1306	0.1417	0.13707	0.1361	0.1359	0.13500979	0.1350	0.1515	0.1082	0.0741	0.0558	0.1387
35%	0.1306	0.1465	0.14142	0.1403	0.1401	0.13913218	0.1391	0.1598	0.1169	0.0865	0.0674	0.1706
40%	0.1306	0.1509	0.14563	0.1444	0.1443	0.14320103	0.1432	0.1670	0.1250	0.0988	0.0799	0.2103
45%	0.1638	0.1551	0.14978	0.1486	0.1484	0.14729036	0.1473	0.1731	0.1326	0.1112	0.0935	0.2611
50%	0.1638	0.1591	0.15394	0.1527	0.1526	0.15146836	0.1515	0.1783	0.1397	0.1235	0.1084	0.3275
55%	0.1638	0.1631	0.15818	0.1570	0.1569	0.15580576	0.1558	0.1827	0.1466	0.1359	0.1249	0.4170
60%	0.1814	0.1670	0.16257	0.1615	0.1614	0.16038399	0.1604	0.1864	0.1531	0.1482	0.1433	0.5418
65%	0.1814	0.1710	0.16718	0.1663	0.1662	0.16530580	0.1653	0.1894	0.1593	0.1606	0.1642	0.7236
70%	0.1814	0.1751	0.17214	0.1714	0.1714	0.17071201	0.1707	0.1919	0.1653	0.1729	0.1883	1.0035
75%	0.1814	0.1795	0.17760	0.1772	0.1771	0.17681231	0.1768	0.1939	0.1711	0.1853	0.2168	1.4674
80%	0.1814	0.1842	0.18381	0.1839	0.1838	0.18394954	0.1839	0.1954	0.1768	0.1976	0.2517	2.3212
85%	0.1976	0.1896	0.19123	0.1919	0.1918	0.19275740	0.1928	0.1965	0.1822	0.2100	0.2966	4.1656
90%	0.1976	0.1961	0.20084	0.2026	0.2025	0.20464740	0.2046	0.1972	0.1875	0.2223	0.3600	9.4350
95%	0.1976	0.2053	0.21566	0.2195	0.2192	0.22410886	0.2241	0.1975	0.1926	0.2347	0.4684	37.8891

Information Criteria

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Figure 2.6 Transformers – fault, distribution percentiles

2.1.3 Reactive plant outage rate – fault performance

The data for Reactive plant unavailability due to fault is best fitted with a LogLogistic distribution according to both the K-S fit statistic (Figure 2.7) and the A-D fit statistic (Figure 2.8).

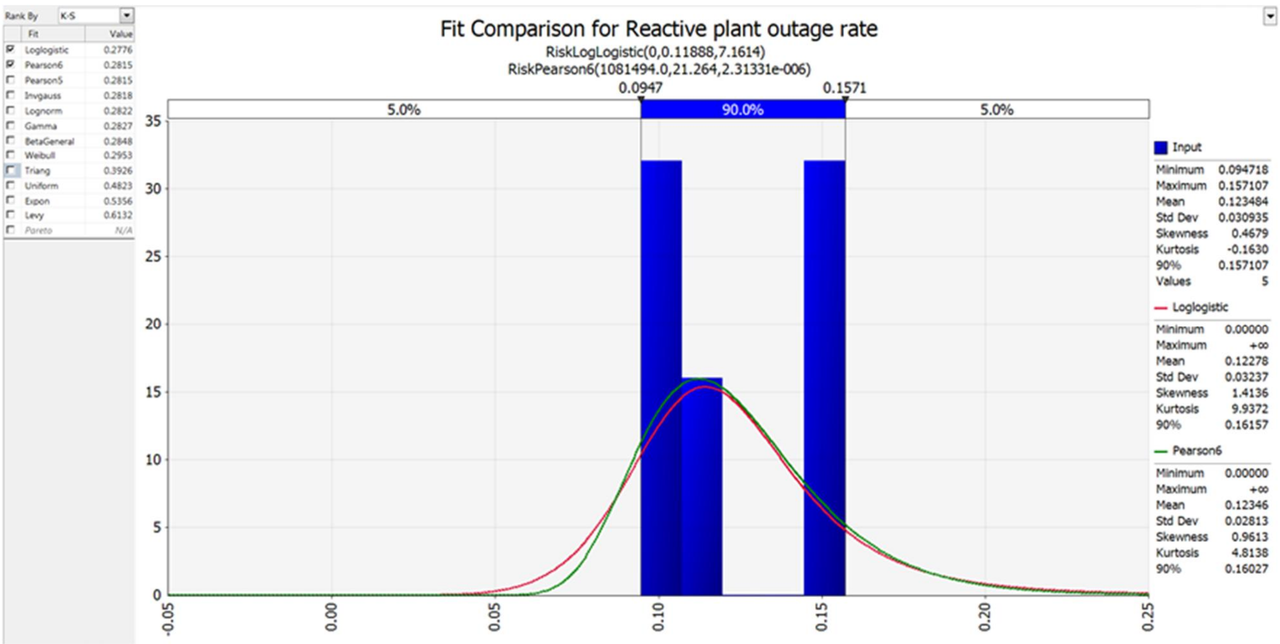


Figure 2.7 Reactive plant – fault, comparison using K-S

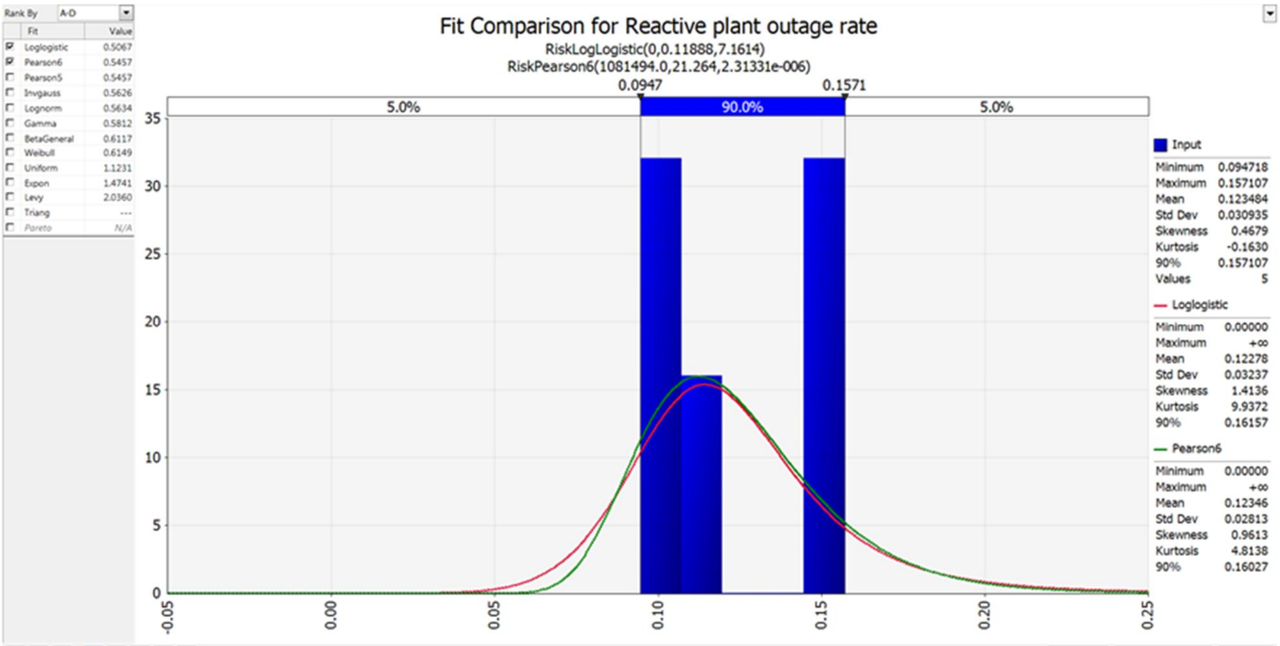
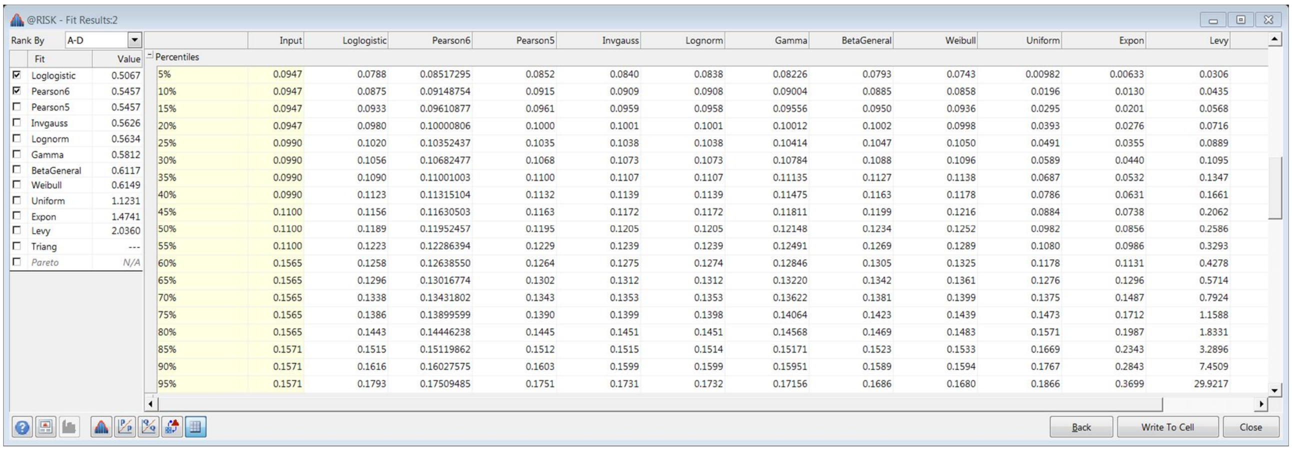


Figure 2.8 Reactive plant – fault, comparison using A-D

As shown in Figure 2.9, the 5th and 95th percentile parameters for the preferred curve are 7.9% and 17.9% respectively.



Fit	Value
Loglogistic	0.5067
Pearson6	0.5457
Pearson5	0.5457
Invgauss	0.5626
Lognorm	0.5634
Gamma	0.5812
BetaGeneral	0.6117
Weibull	0.6149
Uniform	1.1231
Expon	1.4741
Levy	2.0360
Triang	---
Pareto	N/A

Percentiles	Input	Loglogistic	Pearson6	Pearson5	Invgauss	Lognorm	Gamma	BetaGeneral	Weibull	Uniform	Expon	Levy
5%	0.0947	0.0788	0.08517295	0.0852	0.0840	0.0838	0.08226	0.0793	0.0743	0.00982	0.00633	0.0306
10%	0.0947	0.0875	0.09148754	0.0915	0.0909	0.0908	0.09004	0.0885	0.0858	0.0196	0.0130	0.0435
15%	0.0947	0.0933	0.09610877	0.0961	0.0959	0.0958	0.09556	0.0950	0.0936	0.0295	0.0201	0.0568
20%	0.0947	0.0980	0.10000806	0.1000	0.1001	0.1001	0.10012	0.1002	0.0998	0.0393	0.0276	0.0716
25%	0.0990	0.1020	0.10352437	0.1035	0.1038	0.1038	0.10414	0.1047	0.1050	0.0491	0.0355	0.0889
30%	0.0990	0.1056	0.10682477	0.1068	0.1073	0.1073	0.10784	0.1088	0.1096	0.0589	0.0440	0.1095
35%	0.0990	0.1090	0.11001003	0.1100	0.1107	0.1107	0.11135	0.1127	0.1138	0.0687	0.0532	0.1347
40%	0.0990	0.1123	0.11315104	0.1132	0.1139	0.1139	0.11475	0.1163	0.1178	0.0786	0.0631	0.1661
45%	0.1100	0.1156	0.11630503	0.1163	0.1172	0.1172	0.11811	0.1199	0.1216	0.0884	0.0738	0.2062
50%	0.1100	0.1189	0.11952457	0.1195	0.1205	0.1205	0.12148	0.1234	0.1252	0.0982	0.0856	0.2586
55%	0.1100	0.1223	0.12286394	0.1229	0.1239	0.1239	0.12491	0.1269	0.1289	0.1080	0.0986	0.3293
60%	0.1565	0.1258	0.12638550	0.1264	0.1275	0.1274	0.12846	0.1305	0.1325	0.1178	0.1131	0.4278
65%	0.1565	0.1296	0.13016774	0.1302	0.1312	0.1312	0.13220	0.1342	0.1361	0.1276	0.1296	0.5714
70%	0.1565	0.1338	0.13431802	0.1343	0.1353	0.1353	0.13622	0.1381	0.1399	0.1375	0.1487	0.7924
75%	0.1565	0.1386	0.13899599	0.1390	0.1399	0.1398	0.14064	0.1423	0.1439	0.1473	0.1712	1.1588
80%	0.1565	0.1443	0.14446238	0.1445	0.1451	0.1451	0.14568	0.1469	0.1483	0.1571	0.1987	1.8331
85%	0.1571	0.1515	0.15119862	0.1512	0.1515	0.1514	0.15171	0.1523	0.1533	0.1669	0.2343	3.2896
90%	0.1571	0.1616	0.16027575	0.1603	0.1599	0.1599	0.15951	0.1589	0.1594	0.1767	0.2843	7.4509
95%	0.1571	0.1793	0.17509485	0.1751	0.1731	0.1732	0.17156	0.1686	0.1680	0.1866	0.3699	29.9217

Figure 2.9 Reactive plant – fault, distribution percentiles

2.1.4 Lines outage rate – forced outage performance

The data for lines forced to be unavailable is best fitted with a Uniform distribution according to both the K-S fit statistic (Figure 2.10) and the A-D fit statistic (Figure 2.11).

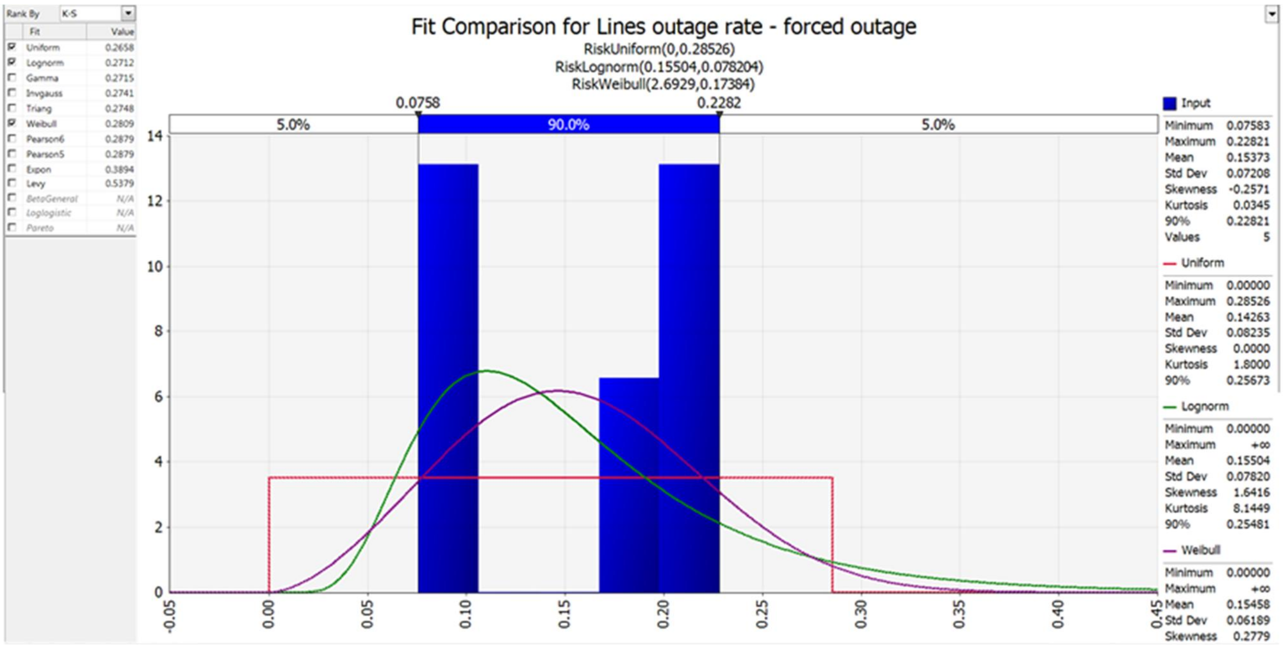


Figure 2.10 Lines – forced, comparison using K-S

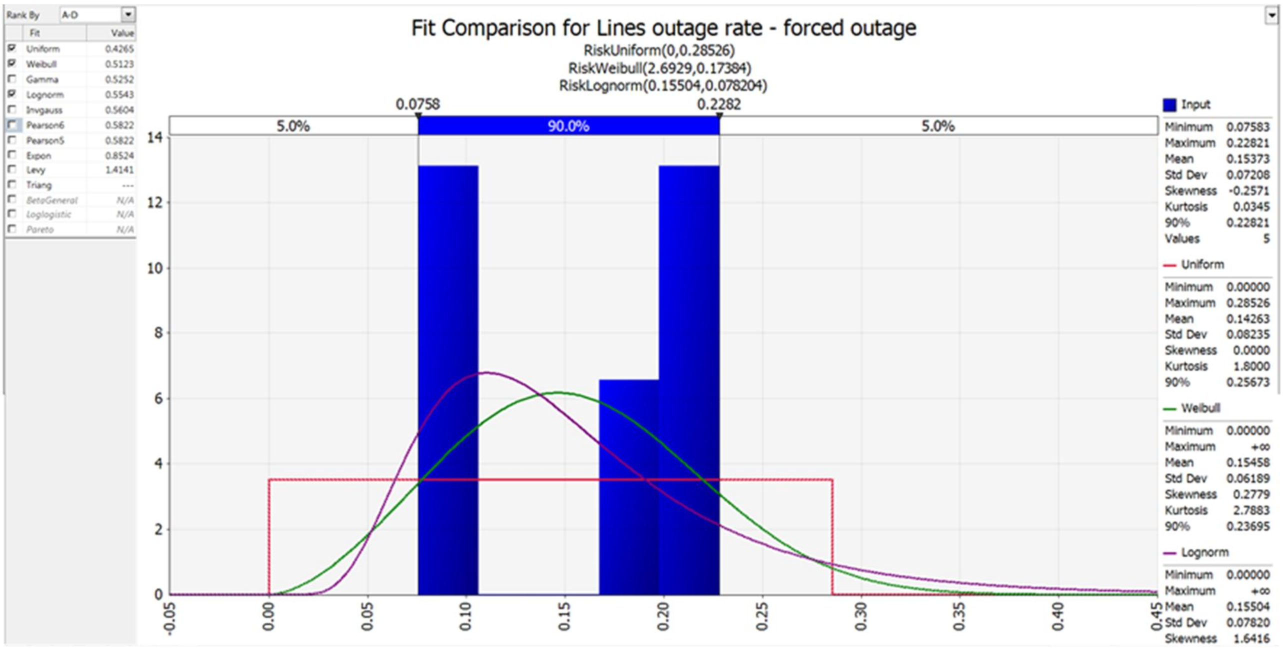


Figure 2.11 Lines – forced, comparison using A-D

As shown in Figure 2.12, the 5th and 95th percentile parameters for the preferred curve are 1.4% and 27.1% respectively.

@RISK - Fit Results:3

Rank By: K-S

Fit	Value
☑ Uniform	0.2658
☑ Lognorm	0.2712
☐ Gamma	0.2715
☐ Invgauss	0.2741
☐ Triang	0.2748
☑ Weibull	0.2809
☐ Pearson6	0.2879
☐ Pearson5	0.2879
☐ Expon	0.3894
☐ Levy	0.5379
☐ *BetaGeneral*	*N/A*
☐ *Loglogistic*	*N/A*
☐ *Pareto*	*N/A*

Percentiles	Input	Uniform	Lognorm	Gamma	Invgauss	Triang	Weibull	Pearson6	Pearson5	Expon	Levy
5%	0.0758	0.0143	0.0633	0.0601	0.0640	0.0510	0.0577	0.06574298	0.0657	0.00789	0.0321
10%	0.0758	0.0285	0.0752	0.0743	0.0752	0.0722	0.0754	0.07572880	0.0757	0.0162	0.0456
15%	0.0758	0.0428	0.0845	0.0852	0.0841	0.0884	0.0885	0.08366420	0.0837	0.0250	0.0596
20%	0.0758	0.0571	0.0927	0.0946	0.0920	0.1021	0.0996	0.09079514	0.0908	0.0343	0.0752
25%	0.0807	0.0713	0.1004	0.1032	0.0995	0.1141	0.1095	0.09758230	0.0976	0.0442	0.0933
30%	0.0807	0.0856	0.1078	0.1114	0.1068	0.1250	0.1185	0.10427230	0.1043	0.0548	0.1149
35%	0.0807	0.0998	0.1152	0.1194	0.1141	0.1350	0.1272	0.11103282	0.1110	0.0662	0.1413
40%	0.0807	0.1141	0.1227	0.1273	0.1215	0.1443	0.1355	0.11800166	0.1180	0.0785	0.1743
45%	0.1705	0.1284	0.1304	0.1353	0.1291	0.1531	0.1436	0.12531132	0.1253	0.0919	0.2163
50%	0.1705	0.1426	0.1384	0.1435	0.1372	0.1614	0.1517	0.13310597	0.1331	0.1066	0.2713
55%	0.1705	0.1569	0.1470	0.1520	0.1457	0.1692	0.1599	0.14155818	0.1416	0.1228	0.3454
60%	0.2134	0.1712	0.1562	0.1610	0.1550	0.1768	0.1683	0.15089071	0.1509	0.1409	0.4489
65%	0.2134	0.1854	0.1663	0.1706	0.1651	0.1840	0.1770	0.16141050	0.1614	0.1614	0.5995
70%	0.2134	0.1997	0.1777	0.1812	0.1766	0.1909	0.1862	0.17356824	0.1736	0.1851	0.8314
75%	0.2134	0.2139	0.1908	0.1931	0.1898	0.1976	0.1963	0.18807444	0.1881	0.2131	1.2157
80%	0.2134	0.2282	0.2067	0.2070	0.2056	0.2041	0.2074	0.20615372	0.2062	0.2474	1.9231
85%	0.2282	0.2425	0.2267	0.2239	0.2256	0.2104	0.2205	0.23019652	0.2302	0.2916	3.4512
90%	0.2282	0.2567	0.2548	0.2464	0.2533	0.2165	0.2370	0.26588389	0.2659	0.3540	7.8168
95%	0.2282	0.2710	0.3029	0.2824	0.3000	0.2224	0.2613	0.33304990	0.3331	0.4605	31.3910

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Figure 2.12 Lines – forced, distribution percentiles

2.1.5 Transformers outage rate – forced outage performance

The data for forced unavailability of transformers is best fitted with a LogLogistic distribution curve according to both the K-S fit statistic (Figure 2.13) and A-D fit statistic (Figure 2.14).

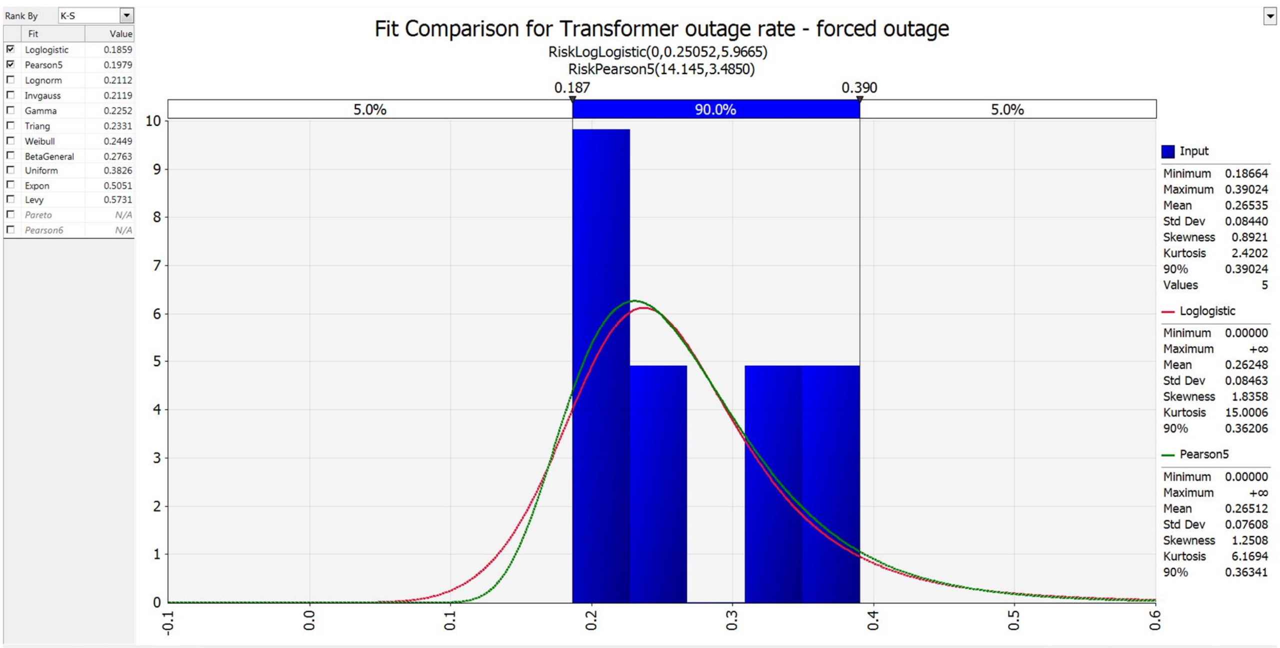

Figure 2.13 Transformers – forced, comparison using K-S

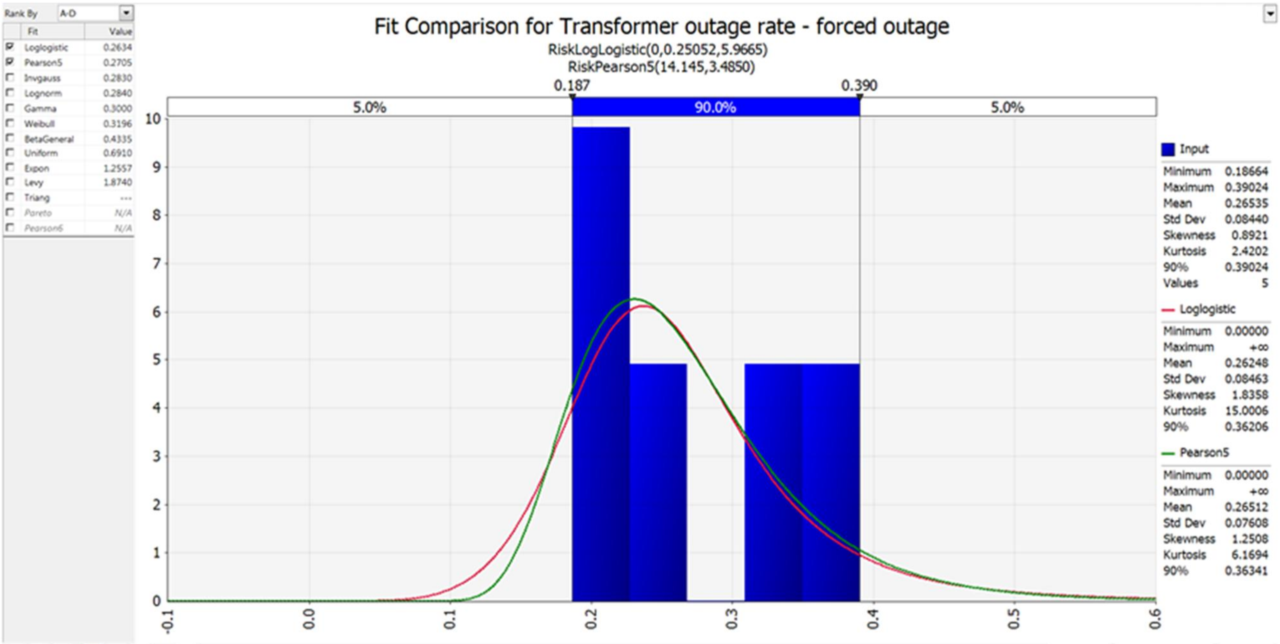

Figure 2.14 Transformers – forced, forced, comparison using A-D

As shown in Figure 2.15, the 5th and 95th percentile parameters for the preferred curve are 15.3% and 41.0% respectively.

@RISK - Fit Results:5

Rank By: A-D

Fit	Value
☑ Loglogistic	0.2634
☑ Pearson5	0.2705
☐ Invgauss	0.2830
☐ Lognorm	0.2840
☐ Gamma	0.3000
☐ Weibull	0.3196
☐ BetaGeneral	0.4335
☐ Uniform	0.6910
☐ Expon	1.2557
☐ Levy	1.8740
☐ Triang	---
☐ *Pareto*	*N/A*
☐ *Pearson6*	*N/A*

Percentiles	Input	Loglogistic	Pearson5	Invgauss	Lognorm	Gamma	Weibull	BetaGeneral	Uniform	Expon	Levy	Triang
5%	0.1866	0.1529	0.1672	0.1634	0.1628	0.1576	0.1338	0.1232	0.0244	0.0136	0.0641	0.0873
10%	0.1866	0.1733	0.1822	0.1802	0.1799	0.1771	0.1620	0.1557	0.0488	0.0280	0.0911	0.1234
15%	0.1866	0.1873	0.1934	0.1925	0.1923	0.1911	0.1817	0.1791	0.0732	0.0431	0.1189	0.1511
20%	0.1866	0.1986	0.2029	0.2030	0.2029	0.2027	0.1976	0.1982	0.0976	0.0592	0.1500	0.1745
25%	0.2033	0.2084	0.2116	0.2124	0.2123	0.2131	0.2114	0.2148	0.1220	0.0763	0.1862	0.1951
30%	0.2033	0.2174	0.2199	0.2213	0.2212	0.2227	0.2238	0.2297	0.1463	0.0946	0.2294	0.2137
35%	0.2033	0.2258	0.2279	0.2299	0.2298	0.2319	0.2352	0.2435	0.1707	0.1143	0.2821	0.2309
40%	0.2033	0.2341	0.2359	0.2384	0.2383	0.2409	0.2461	0.2563	0.1951	0.1355	0.3478	0.2468
45%	0.2364	0.2422	0.2440	0.2469	0.2467	0.2497	0.2566	0.2684	0.2195	0.1586	0.4318	0.2618
50%	0.2364	0.2505	0.2523	0.2556	0.2554	0.2587	0.2668	0.2801	0.2439	0.1839	0.5416	0.2759
55%	0.2364	0.2591	0.2610	0.2646	0.2643	0.2678	0.2770	0.2914	0.2683	0.2119	0.6895	0.2894
60%	0.3102	0.2681	0.2703	0.2740	0.2737	0.2773	0.2873	0.3024	0.2927	0.2431	0.8960	0.3023
65%	0.3102	0.2779	0.2803	0.2841	0.2837	0.2874	0.2979	0.3133	0.3171	0.2786	1.1966	0.3146
70%	0.3102	0.2887	0.2914	0.2952	0.2947	0.2983	0.3089	0.3242	0.3415	0.3195	1.6595	0.3265
75%	0.3102	0.3012	0.3041	0.3076	0.3071	0.3103	0.3206	0.3352	0.3659	0.3679	2.4267	0.3380
80%	0.3102	0.3160	0.3191	0.3220	0.3214	0.3241	0.3336	0.3465	0.3902	0.4271	3.8386	0.3490
85%	0.3902	0.3350	0.3378	0.3396	0.3390	0.3407	0.3484	0.3583	0.4146	0.5034	6.8888	0.3598
90%	0.3902	0.3621	0.3634	0.3631	0.3625	0.3623	0.3668	0.3711	0.4390	0.6110	15.6030	0.3702
95%	0.3902	0.4104	0.4063	0.4006	0.4004	0.3959	0.3933	0.3860	0.4634	0.7949	62.6587	0.3804

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Figure 2.15 Transformers - forced, distribution percentiles

2.1.6 Reactive plant outage rate – forced outage performance

The best fit distribution curve for Reactive plant forced outage performance data for the K-S fit statistic is the BetaGeneral distribution (Figure 2.16), while the A-D fit statistic indicates a Weibull distribution (Figure 2.17).

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 0.041. The standard deviation for the curve of second best fit using the A-D statistic (Gamma) is 0.054, 34% lower than the preferred curve.

As the comparison of the standard deviation of the curve of best fit and the curve of second best fit using the preferred fit statistics did not confirm the use of the curve of best fit, the 5th and 95th percentile parameters were examined. The 5th and 95th percentile parameters are 7% and 12% lower for the curve of second best fit, respectively. This suggests that the impact on the caps and collars for this parameter will not be significant if the Weibull distribution is chosen.

The Weibull distribution is also the curve of second best fit using the K-S statistic, confirming the use of the Weibull distribution.

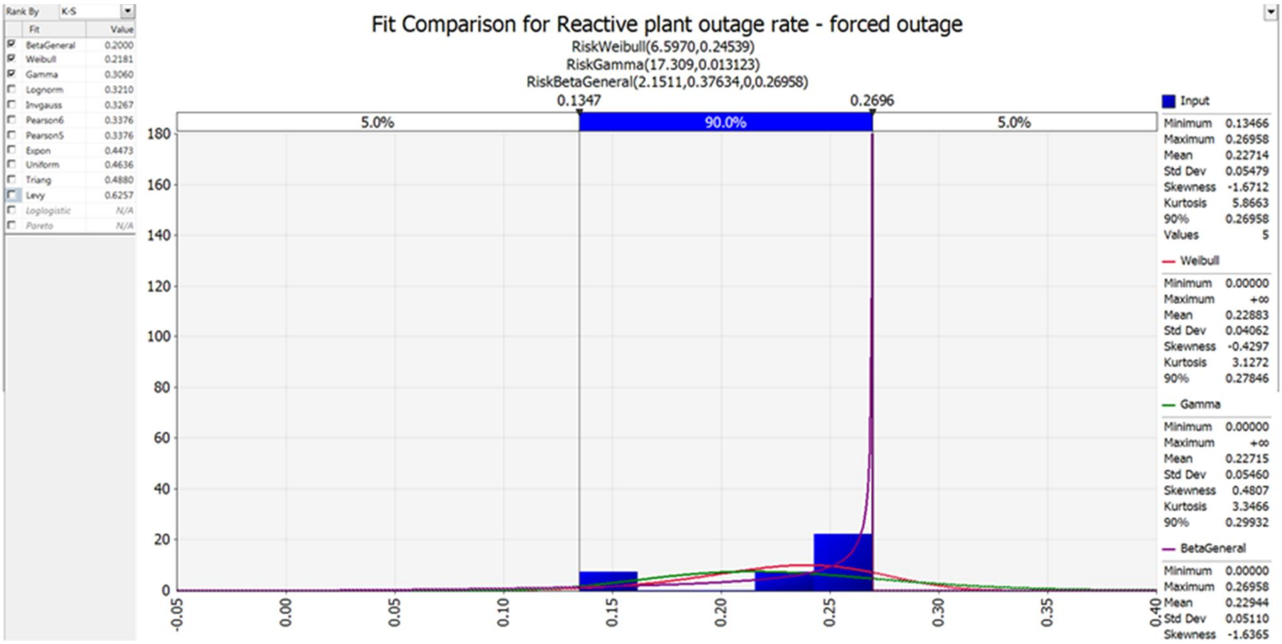

Figure 2.16 Reactive plant – forced, comparison using K-S

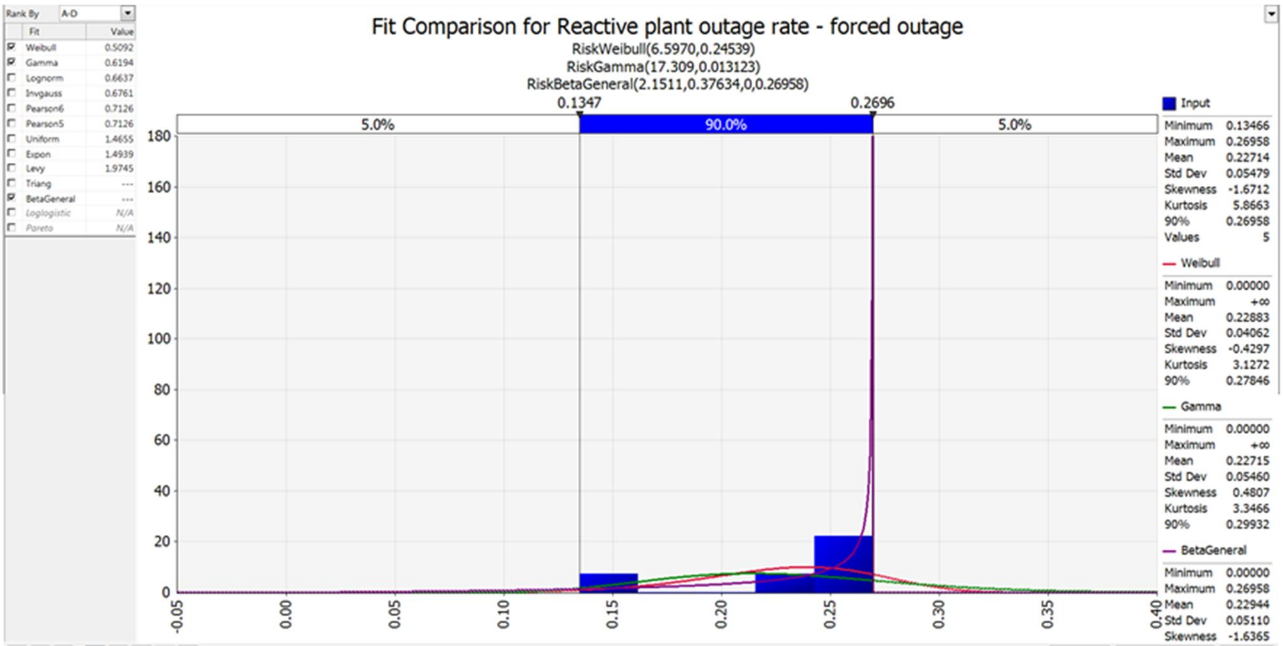

Figure 2.17 Reactive plant – forced, comparison using A-D

As shown in Figure 2.18, the 5th and 95th percentile parameters for the preferred curve are 15.6% and 29.0% respectively.

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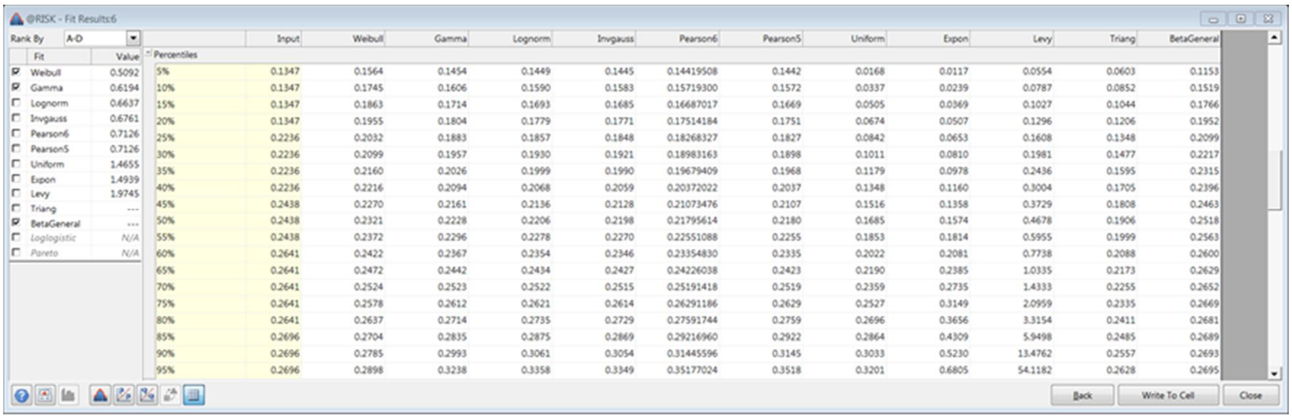

@RISK - Fit Results:6

Rank By: A-D

	Fit	Value
☑	Weibull	0.5092
☑	Gamma	0.6194
☐	Lognorm	0.6637
☐	Invgauss	0.6761
☐	Pearson6	0.7126
☐	Pearson5	0.7126
☐	Uniform	1.4655
☐	Expon	1.4939
☐	Levy	1.9745
☐	Triang	---
☑	BetaGeneral	---
☐	Loglogistic	N/A
☐	Pareto	N/A

Percentiles	Input	Weibull	Gamma	Lognorm	Invgauss	Pearson6	Pearson5	Uniform	Expon	Levy	Triang	BetaGeneral
5%	0.1347	0.1564	0.1454	0.1449	0.1445	0.14419508	0.1442	0.0168	0.0117	0.0554	0.0603	0.1153
10%	0.1347	0.1745	0.1606	0.1590	0.1583	0.15719300	0.1572	0.0337	0.0239	0.0787	0.0852	0.1519
15%	0.1347	0.1863	0.1714	0.1693	0.1685	0.16687017	0.1669	0.0505	0.0369	0.1027	0.1044	0.1766
20%	0.1347	0.1955	0.1804	0.1779	0.1771	0.17514184	0.1751	0.0674	0.0507	0.1296	0.1206	0.1952
25%	0.2236	0.2032	0.1883	0.1857	0.1848	0.18268327	0.1827	0.0842	0.0653	0.1608	0.1348	0.2099
30%	0.2236	0.2099	0.1957	0.1930	0.1921	0.18983163	0.1898	0.1011	0.0810	0.1981	0.1477	0.2217
35%	0.2236	0.2160	0.2026	0.1999	0.1990	0.19679409	0.1968	0.1179	0.0978	0.2436	0.1595	0.2315
40%	0.2236	0.2216	0.2094	0.2068	0.2059	0.20372022	0.2037	0.1348	0.1160	0.3004	0.1705	0.2396
45%	0.2438	0.2270	0.2161	0.2136	0.2128	0.21073476	0.2107	0.1516	0.1358	0.3729	0.1808	0.2463
50%	0.2438	0.2321	0.2228	0.2206	0.2198	0.21795614	0.2180	0.1685	0.1574	0.4678	0.1906	0.2518
55%	0.2438	0.2372	0.2296	0.2278	0.2270	0.22551088	0.2255	0.1853	0.1814	0.5955	0.1999	0.2563
60%	0.2641	0.2422	0.2367	0.2354	0.2346	0.23354830	0.2335	0.2022	0.2081	0.7738	0.2088	0.2600
65%	0.2641	0.2472	0.2442	0.2434	0.2427	0.24226038	0.2423	0.2190	0.2385	1.0335	0.2173	0.2629
70%	0.2641	0.2524	0.2523	0.2522	0.2515	0.25191418	0.2519	0.2359	0.2735	1.4333	0.2255	0.2652
75%	0.2641	0.2578	0.2612	0.2621	0.2614	0.26291186	0.2629	0.2527	0.3149	2.0959	0.2335	0.2669
80%	0.2641	0.2637	0.2714	0.2735	0.2729	0.27591744	0.2759	0.2696	0.3656	3.3154	0.2411	0.2681
85%	0.2696	0.2704	0.2835	0.2875	0.2869	0.29216960	0.2922	0.2864	0.4309	5.9498	0.2485	0.2689
90%	0.2696	0.2785	0.2993	0.3061	0.3054	0.31445596	0.3145	0.3033	0.5230	13.4762	0.2557	0.2693
95%	0.2696	0.2898	0.3238	0.3358	0.3349	0.35177024	0.3518	0.3201	0.6805	54.1182	0.2628	0.2695

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Figure 2.18 Reactive plant – forced, distribution percentiles

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.

2.2.1 Number of events > 0.05 system minutes

Using the AIC fit statistic, Figure 2.19 shows that the Poisson distribution is the best fit for the loss of supply events greater than 0.05 system minutes, providing a standard deviation of 1.14. The curve of second best fit is the IntUniform distribution, giving a standard deviation of 1.18, 2% lower, confirming that the curve of best fit is appropriate.

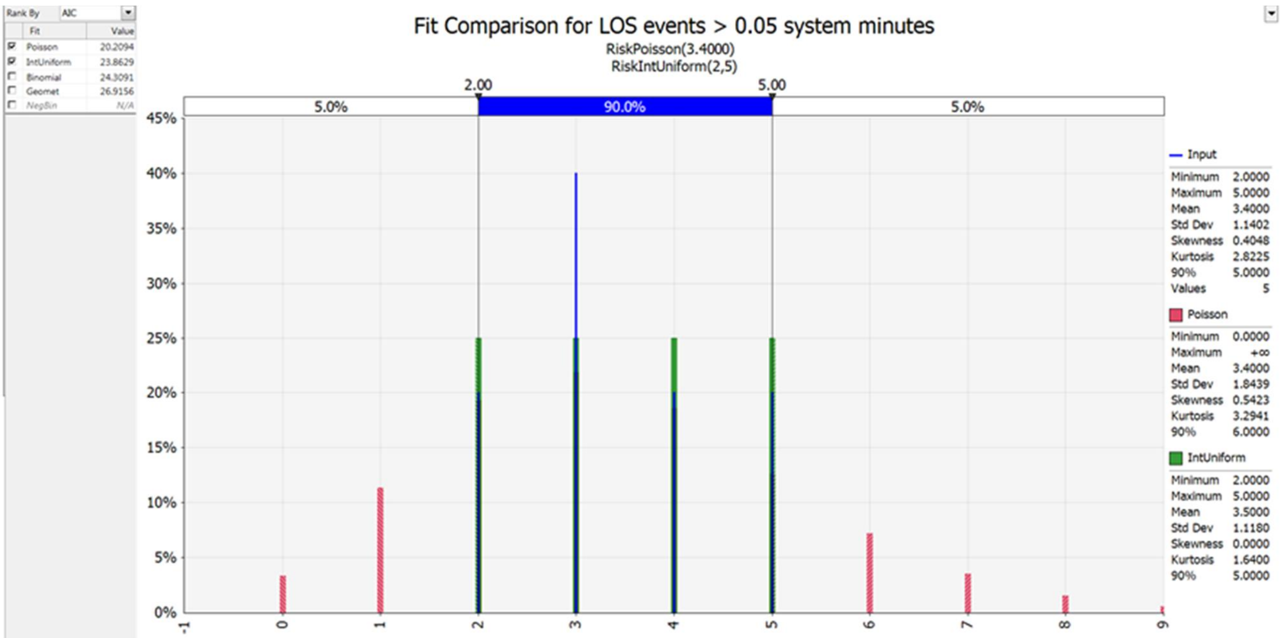

Figure 2.19 No. of events > 0.05 system minutes, curve of best fit

Rank By	AIC
Fit	**Value**
☑ Poisson	20.2094
☐ IntUniform	23.8629
☐ Binomial	24.3091
☐ Geomet	26.9156
☐ *NegBin*	*N/A*

	Input	Poisson	IntUniform	Binomial	Geomet
Fit					
Function		=RiskPoisson(3.40..	=RiskIntUniform(2,..	=RiskBinomial(5,0...	=RiskGeomet(0.22..
Method		MLE	MLE	MLE	MLE
Rankings By Fit Statistic [4 Valid Fits]					
Akaike (AIC)		#1	#2	#3	#4
Bayesian (BIC)		#3	#1	#2	#4
Chi-Sq Statistic		#3	#1	#2	#4
Parameters - [* Values unavailable without running a bootstrap]					
Num. Est. Parameters		1	2	2	1
Fitted Parameter #1		lambda	Min	n	p
Fitted Value		3.4000	2	5	0.22727
95% Lower Limit*		N/A	N/A	N/A	N/A
95% Upper Limit*		N/A	N/A	N/A	N/A
Conf. Interval Width*		N/A	N/A	N/A	N/A
Fitted Parameter #2			Max	p	
Fitted Value			5	0.68000	
95% Lower Limit*			N/A	N/A	
95% Upper Limit*			N/A	N/A	
Conf. Interval Width*			N/A	N/A	

Figure 2.20 No. of events > 0.05 system minutes, fit statistics

As shown in Figure 2.21, the 5th and 95th percentile parameters for the preferred curve are 1 and 7 respectively.

@RISK - Fit Results:7

Rank By	AIC
Fit	**Value**
☑ Poisson	20.2094
☑ IntUniform	23.8629
☐ Binomial	24.3091
☐ Geomet	26.9156
☐ *NegBin*	*N/A*

	Input	Poisson	IntUniform	Binomial	Geomet
Percentiles					
5%	2.0000	1.0000	2.0000	2.0000	0.0000
10%	2.0000	1.0000	2.0000	2.0000	0.0000
15%	2.0000	2.0000	2.0000	2.0000	0.0000
20%	2.0000	2.0000	2.0000	3.0000	0.0000
25%	3.0000	2.0000	2.0000	3.0000	1.0000
30%	3.0000	2.0000	3.0000	3.0000	1.0000
35%	3.0000	3.0000	3.0000	3.0000	1.0000
40%	3.0000	3.0000	3.0000	3.0000	1.0000
45%	3.0000	3.0000	3.0000	3.0000	2.0000
50%	3.0000	3.0000	3.0000	3.0000	2.0000
55%	3.0000	3.0000	4.0000	4.0000	3.0000
60%	3.0000	4.0000	4.0000	4.0000	3.0000
65%	4.0000	4.0000	4.0000	4.0000	4.0000
70%	4.0000	4.0000	4.0000	4.0000	4.0000
75%	4.0000	5.0000	4.0000	4.0000	5.0000
80%	4.0000	5.0000	5.0000	4.0000	6.0000
85%	5.0000	5.0000	5.0000	4.0000	7.0000
90%	5.0000	6.0000	5.0000	5.0000	8.0000
95%	5.0000	7.0000	5.0000	5.0000	11.0000

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Figure 2.21 No. of events > 0.05 system minutes, distribution percentiles

2.2.2 Number of events > 0.25 system minutes

Using the AIC fit statistic, Figure 2.22 shows that the Geometric distribution is the best fit providing a standard deviation of 1.14. The Poisson is the second best fit with a standard deviation of 0.89, 25% lower. The relatively high variation in standard deviations indicates some uncertainty in the curve fitting.

Examining the dataset shows that only three values occurred – 0 occurring in three of the years and 1 occurring in one year and 3 occurring in one year. This is consistent with the shape of the Geometrical distribution with a large number of zero values tapping off for increasing values. This shape aligns with expected performance hence confirming that the Geometric is the preferred distribution. In contrast, the Poisson distribution typically starts at a low value rising to a maximum and then falling. This shape is not consistent with expected performance.

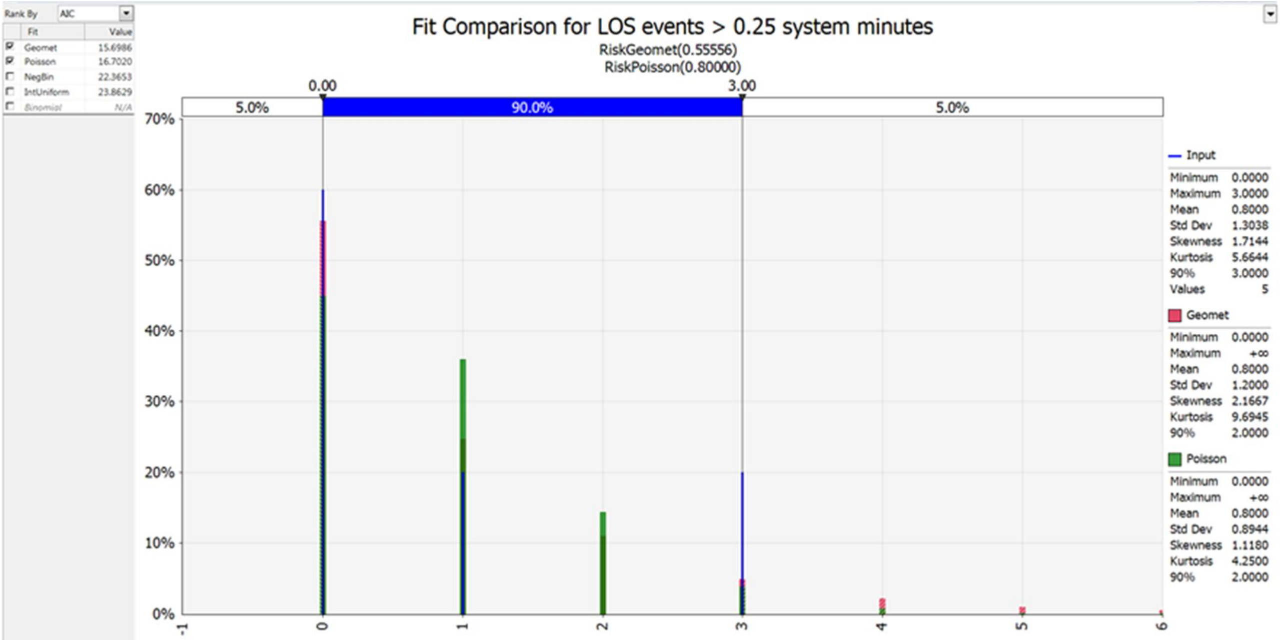

Figure 2.22 No. of events > 0.25 system minutes, curve of best fit

Rank By	AIC
Fit	Value
Geomet	15.6986
Poisson	16.7020
NegBin	22.3653
IntUniform	23.8629
Binomial	N/A

	Input	Geomet	Poisson	NegBin	IntUniform
Fit					
Function		=RiskGeomet(0.55..	=RiskPoisson(0.80..	=RiskNegBin(1,0.5..	=RiskIntUniform(0,...
Method		MLE	MLE	MLE	MLE
Rankings By Fit Statistic [4 Valid Fits]					
Akaike (AIC)		#1	#2	#3	#4
Bayesian (BIC)		#1	#2	#3	#4
Chi-Sq Statistic		#2 (Tie)	#1	#2 (Tie)	#4
Parameters - [* Values unavailable without running a bootstrap]					
Num. Est. Parameters		1	1	2	2
Fitted Parameter #1		p	lambda	s	Min
Fitted Value		0.55556	0.80000	1	0
95% Lower Limit*		N/A	N/A	N/A	N/A
95% Upper Limit*		N/A	N/A	N/A	N/A
Conf. Interval Width*		N/A	N/A	N/A	N/A
Fitted Parameter #2				p	Max
Fitted Value				0.55556	3
95% Lower Limit*				N/A	N/A
95% Upper Limit*				N/A	N/A
Conf. Interval Width*				N/A	N/A

Figure 2.23 No. of events > 0.25 system minutes, fit statistics

As shown in Figure 2.24, the 5th and 95th percentile parameters for the preferred curve are 0 and 3 respectively.

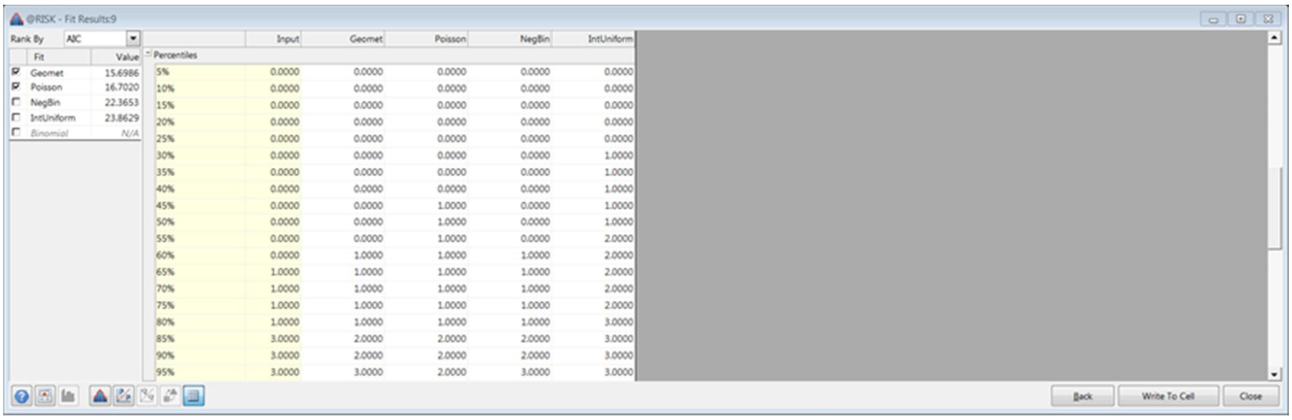

Figure 2.24 No. of events > 0.25 system minutes, distribution percentiles

2.3 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 is the LogLogistic distribution curve using both the K-S fit statistic (Figure 2.25) and the A-D fit statistic (Figure 2.26).

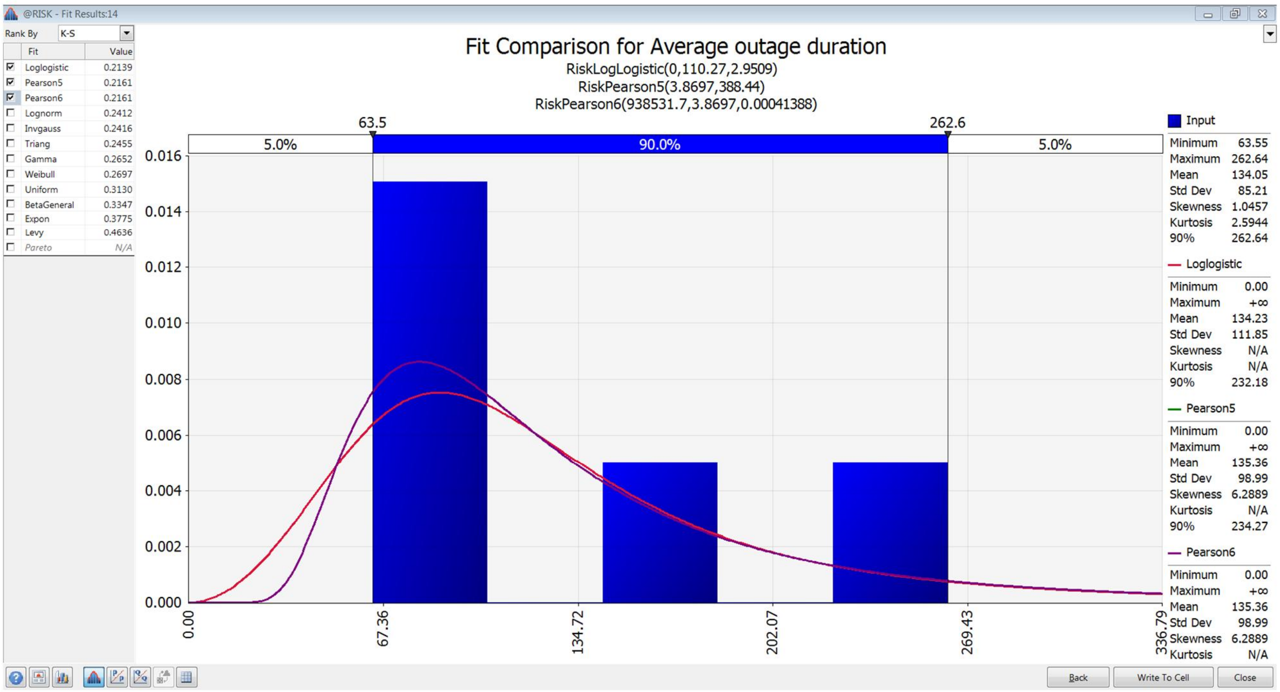

Figure 2.25 Average outage duration, comparison using K-S

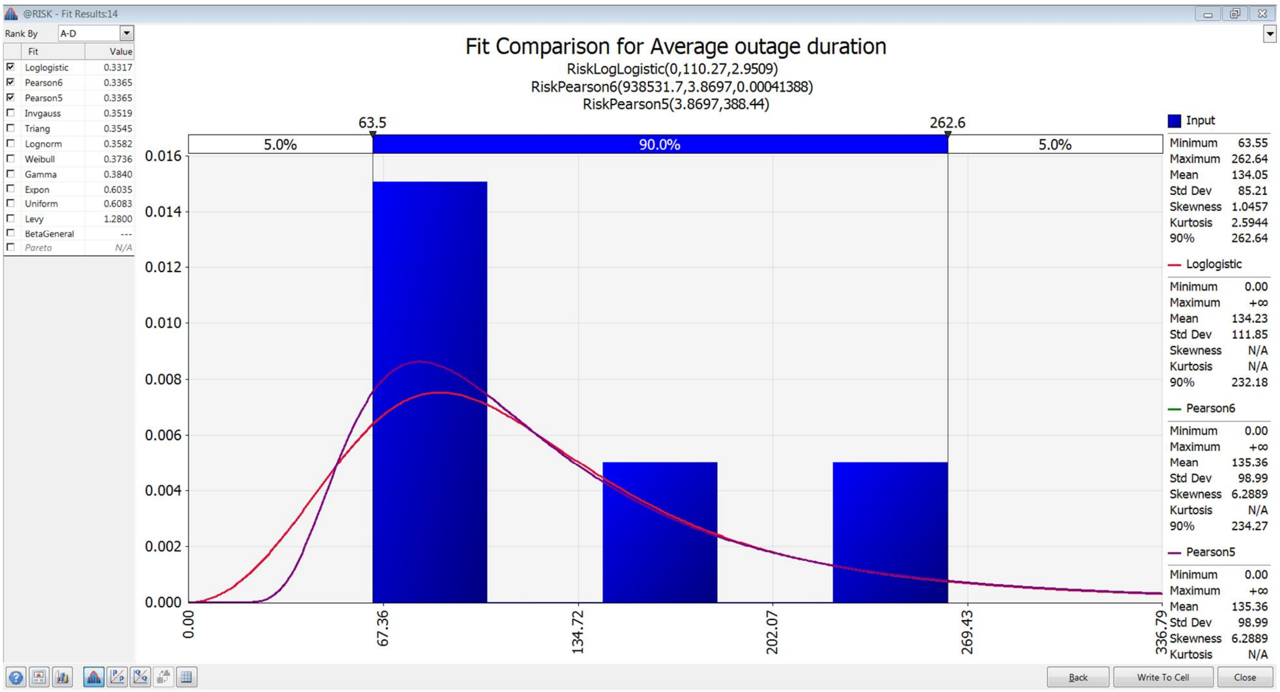

Figure 2.26 Average outage duration, comparison using A-D

As shown in Figure 2.27, the 5th and 95th percentile parameters for the preferred curve are 40.7 and 299.1 respectively.

Rank By: A-D	Value
Loglogistic	0.3317
Pearson6	0.3365
Pearson5	0.3365
Invgauss	0.3519
Triang	0.3545
Lognorm	0.3582
Weibull	0.3736
Gamma	0.3840
Expon	0.6035
Uniform	0.6083
Levy	1.2800
BetaGeneral	---
Pareto	N/A

Percentiles	Input	Loglogistic	Pearson6	Pearson5	Invgauss	Triang	Lognorm	Weibull	Gamma	Expon	Uniform	Levy
5%	63.5455	40.6551	51.330493	51.3305	48.1637	34.0005	46.6756	31.9879	40.5127	6.8758	16.4153	26.1309
10%	63.5455	52.3702	59.698400	59.6984	57.8094	48.0840	56.9467	46.6929	53.2642	14.1235	32.8305	37.1020
15%	63.5455	61.2590	66.425462	66.4255	65.6319	58.8906	65.1249	58.6346	63.3588	21.7856	49.2458	48.4405
20%	63.5455	68.9337	72.525506	72.5255	72.7388	68.0010	72.4545	69.2626	72.2985	29.9123	65.6610	61.1194
25%	71.1375	75.9924	78.377443	78.3774	79.5446	76.2469	79.3967	79.1536	80.6454	38.5637	82.0763	75.8563
30%	71.1375	82.7479	84.187609	84.1876	86.2723	84.6821	86.1960	88.6190	88.6937	47.8121	98.4915	93.4477
35%	71.1375	89.4027	90.099666	90.0997	93.0732	93.4244	93.0153	97.8602	96.6323	57.7463	114.9068	114.9237
40%	71.1375	96.1131	96.235102	96.2351	100.0711	102.5099	99.9844	107.0279	104.6037	68.4760	131.3220	141.7157
45%	94.2277	103.0203	102.713827	102.7138	107.3829	111.9825	107.2237	116.2494	112.7319	80.1398	147.7373	175.9058
50%	94.2277	110.2697	109.669398	109.6694	115.1341	121.8965	114.8597	125.6455	121.1387	92.9161	164.1525	220.6483
55%	94.2277	118.0292	117.264507	117.2645	123.4717	132.3198	123.0395	135.3436	129.9575	107.0397	180.5678	280.9295
60%	178.6935	126.5114	125.711960	125.7119	132.5816	143.3401	131.9480	145.4908	139.3481	122.8284	196.9830	365.0271
65%	178.6935	136.0072	135.308098	135.3080	142.7141	155.0737	141.8341	156.2718	149.5174	140.7283	213.3983	487.5225
70%	178.6935	146.9452	146.491889	146.4918	154.2279	167.6798	153.0552	167.9366	160.7527	161.3921	229.8135	676.0941
75%	178.6935	160.0081	159.961058	159.9610	167.6729	181.3882	166.1625	180.8520	173.4842	185.8323	246.2288	988.6724
80%	178.6935	176.3929	176.928326	176.9283	183.9670	196.5511	182.0832	195.6061	188.4158	215.7446	262.6440	1563.9375
85%	262.6440	198.4917	199.783552	199.7835	204.8318	213.7619	202.5760	213.2605	206.8419	254.3082	279.0593	2806.6198
90%	262.6440	232.1817	234.274735	234.2747	234.1483	234.1770	231.6684	236.1085	231.6194	308.6607	295.4745	6356.9363
95%	262.6440	299.0870	300.830433	300.8305	284.4013	260.7825	282.6473	271.1216	271.6876	401.5768	311.8898	25528.3243

Figure 2.27 Average outage duration, distribution percentiles

2.4 Proper operation of equipment – number of failure events

Proper operation of equipment events represent discrete occurrences of failure. In order to best fit the failure events data, discrete distribution curves are used with equal interval binning.

2.4.1 Failure of protection system

Using the AIC fit statistic, Figure 2.19 shows that the Poisson distribution is the best fit for the failure of protection systems, providing a standard deviation of 4.450. The curve of second best fit is the IntUniform, giving a standard deviation of 4.031, 9% lower, confirming that the use of the curve of best fit is appropriate.

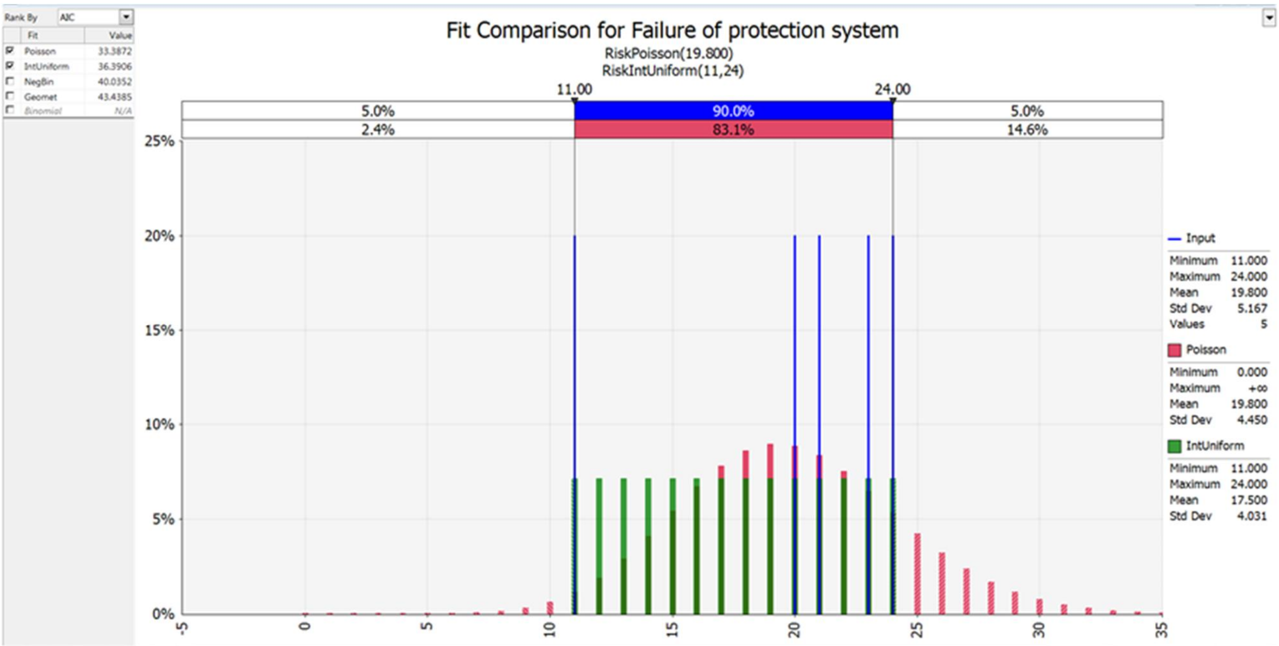

Figure 2.28 Failure of protection system, curve of best fit

Rank By: AIC

	Fit	Value
☑	Poisson	33.3872
☑	IntUniform	36.3906
☐	NegBin	40.0352
☐	Geomet	43.4385
☐	*Binomial*	*N/A*

	Input	Poisson	IntUniform	NegBin	Geomet
Fit					
Function		=RiskPoisson(19.8..	=RiskIntUniform(1..	=RiskNegBin(197,...	=RiskGeomet(0.04..
Method		MLE	MLE	MLE	MLE
Rankings By Fit Statistic [4 Valid Fits]					
Akaike (AIC)		#1	#2	#3	#4
Bayesian (BIC)		#2	#1	#3	#4
Chi-Sq Statistic		#1 (Tie)	#1 (Tie)	#1 (Tie)	#1 (Tie)
Parameters - [* Values unavailable without running a bootstrap]					
Num. Est. Parameters		1	2	2	1
Fitted Parameter #1		lambda	Min	s	p
Fitted Value		19.800	11	197	0.048077
95% Lower Limit*		N/A	N/A	N/A	N/A
95% Upper Limit*		N/A	N/A	N/A	N/A
Conf. Interval Width*		N/A	N/A	N/A	N/A
Fitted Parameter #2			Max	p	
Fitted Value			24	0.90867	
95% Lower Limit*			N/A	N/A	
95% Upper Limit*			N/A	N/A	
Conf. Interval Width*			N/A	N/A	

Figure 2.29 Failure of protection system, fit statistics

As shown in Figure 2.30, the 5th and 95th percentile parameters for the preferred curve are 13 and 27 respectively.

Rank By: AIC

	Fit	Value
☑	Poisson	33.3872
☑	IntUniform	36.3906
☐	NegBin	40.0352
☐	Geomet	43.4385
☐	*Binomial*	*N/A*

Percentiles	Input	Poisson	IntUniform	NegBin	Geomet
5%	11.0000	13.0000	11.0000	12.0000	1.0000
10%	11.0000	14.0000	12.0000	14.0000	2.0000
15%	11.0000	15.0000	13.0000	15.0000	3.0000
20%	11.0000	16.0000	13.0000	16.0000	4.0000
25%	20.0000	17.0000	14.0000	17.0000	5.0000
30%	20.0000	17.0000	15.0000	17.0000	7.0000
35%	20.0000	18.0000	15.0000	18.0000	8.0000
40%	20.0000	19.0000	16.0000	18.0000	10.0000
45%	21.0000	19.0000	17.0000	19.0000	12.0000
50%	21.0000	20.0000	17.0000	20.0000	14.0000
55%	21.0000	20.0000	18.0000	20.0000	16.0000
60%	21.0000	21.0000	19.0000	21.0000	18.0000
65%	23.0000	21.0000	20.0000	21.0000	21.0000
70%	23.0000	22.0000	20.0000	22.0000	24.0000
75%	23.0000	23.0000	21.0000	23.0000	28.0000
80%	23.0000	23.0000	22.0000	24.0000	32.0000
85%	24.0000	24.0000	22.0000	25.0000	38.0000
90%	24.0000	26.0000	23.0000	26.0000	46.0000
95%	24.0000	27.0000	24.0000	28.0000	60.0000

Figure 2.30 Failure of protection system, distribution percentiles

2.4.2 Material failure of Supervisory Control and Data Acquisition (SCADA) system

Using the AIC fit statistic, Figure 2.19 shows that the Geometric distribution is the best fit for the material failure of SCADA systems, providing a standard deviation of 8.08. The curve of second best fit is the IntUniform distribution, giving a standard deviation of 5.477, 32% higher. The high variation in standard deviations indicates some uncertainty in the curve fitting.

Examining the dataset shows that four values occurred – 21, 5 and 6 each occurring in one year and 3 occurring in two years. This is consistent with the choice of the Geometric distribution, indicating in-consistent service performance.

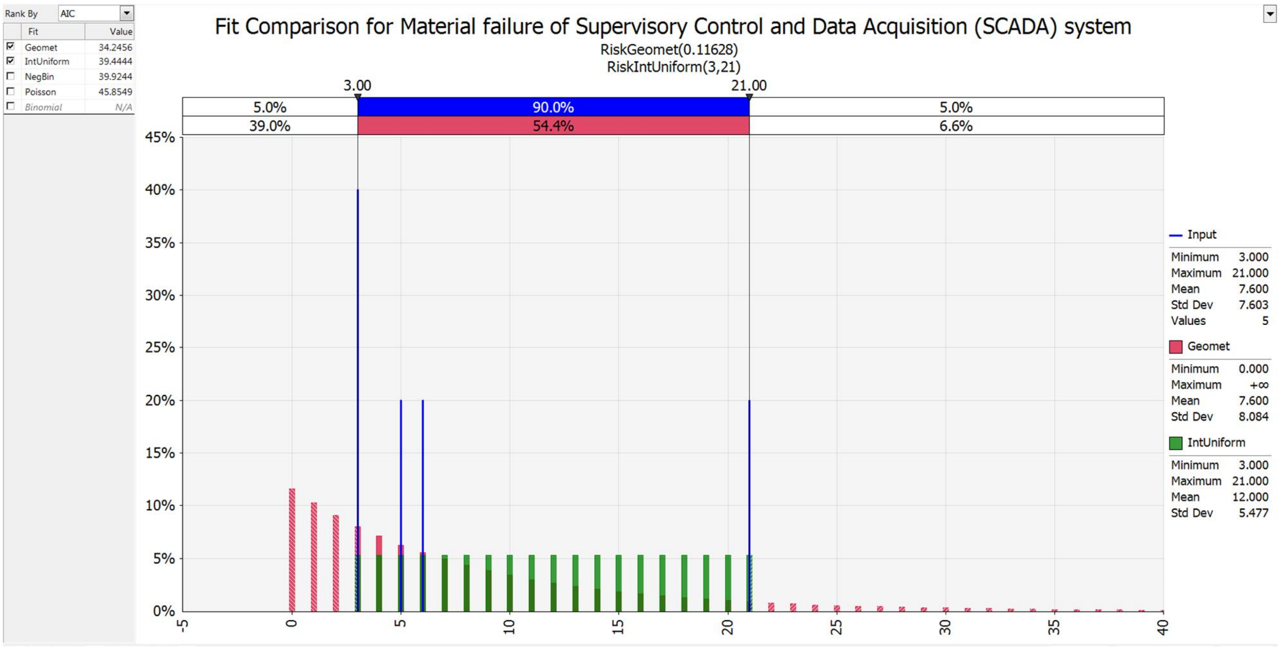

Figure 2.31 Material failure of Supervisory Control and Data Acquisition (SCADA) system, curve of best fit

Rank By: AIC

Fit	Value
☑ Geomet	34.2456
☑ IntUniform	39.4444
☐ NegBin	39.9244
☐ Poisson	45.8549
☐ *Binomial*	*N/A*

	Input	Geomet	IntUniform	NegBin	Poisson
Fit					
Function		=RiskGeomet(0.11..	=RiskIntUniform(3,..	=RiskNegBin(2,0.2..	=RiskPoisson(7.60..
Method		MLE	MLE	MLE	MLE
Rankings By Fit Statistic [4 Valid Fits]					
Akaike (AIC)		#1	#2	#3	#4
Bayesian (BIC)		#1	#2	#3	#4
Chi-Sq Statistic		#1 (Tie)	#1 (Tie)	#1 (Tie)	#1 (Tie)
Parameters - [* Values unavailable without running a bootstrap]					
Num. Est. Parameters		1	2	2	1
Fitted Parameter #1		p	Min	s	lambda
Fitted Value		0.11628	3	2	7.6000
95% Lower Limit*		N/A	N/A	N/A	N/A
95% Upper Limit*		N/A	N/A	N/A	N/A
Conf. Interval Width*		N/A	N/A	N/A	N/A
Fitted Parameter #2			Max	p	
Fitted Value			21	0.20833	
95% Lower Limit*			N/A	N/A	
95% Upper Limit*			N/A	N/A	
Conf. Interval Width*			N/A	N/A	

Figure 2.32 Material failure of Supervisory Control and Data Acquisition (SCADA) system, fit statistics

As shown in Figure 2.33, the 5th and 95th percentile parameters for the preferred curve are 0 and 24 respectively.

@RISK - Fit Results:12

Rank By: AIC

Fit	Value
☑ Geomet	34.2456
☑ IntUniform	39.4444
☐ NegBin	39.9244
☐ Poisson	45.8549
☐ *Binomial*	*N/A*

Percentiles	Input	Geomet	IntUniform	NegBin	Poisson
5%	3.0000	0.0000	3.0000	1.0000	3.0000
10%	3.0000	0.0000	4.0000	1.0000	4.0000
15%	3.0000	1.0000	5.0000	2.0000	5.0000
20%	3.0000	1.0000	6.0000	3.0000	5.0000
25%	3.0000	2.0000	7.0000	3.0000	6.0000
30%	3.0000	2.0000	8.0000	4.0000	6.0000
35%	3.0000	3.0000	9.0000	4.0000	6.0000
40%	3.0000	4.0000	10.0000	5.0000	7.0000
45%	5.0000	4.0000	11.0000	6.0000	7.0000
50%	5.0000	5.0000	12.0000	6.0000	7.0000
55%	5.0000	6.0000	13.0000	7.0000	8.0000
60%	5.0000	7.0000	14.0000	8.0000	8.0000
65%	6.0000	8.0000	15.0000	9.0000	9.0000
70%	6.0000	9.0000	16.0000	9.0000	9.0000
75%	6.0000	11.0000	17.0000	11.0000	9.0000
80%	6.0000	13.0000	18.0000	12.0000	10.0000
85%	21.0000	15.0000	19.0000	13.0000	10.0000
90%	21.0000	18.0000	20.0000	16.0000	11.0000
95%	21.0000	24.0000	21.0000	19.0000	12.0000

Back | Write To Cell | Close

Figure 2.33 Material failure of Supervisory Control and Data Acquisition (SCADA) system, distribution percentiles

2.4.3 Incorrect operational isolation of primary or secondary equipment

Using the AIC fit statistic, Figure 2.19 shows that the Poisson distribution is the best fit for the incorrect operational isolation of primary or secondary equipment, providing a standard deviation of 2.65. The curve of second best fit is the IntUniform distribution, giving a standard deviation of 2.29, 13% lower. The high variation in standard deviations indicates some uncertainty in the curve fitting.

Examining the dataset shows that five different values occurred. This is consistent with the choice of the Poisson distribution, which typically starts at a low value, rising to a maximum and then falling. In contrast, the IntUniform distribution is typically a constant value, which does not reflect the expected performance.

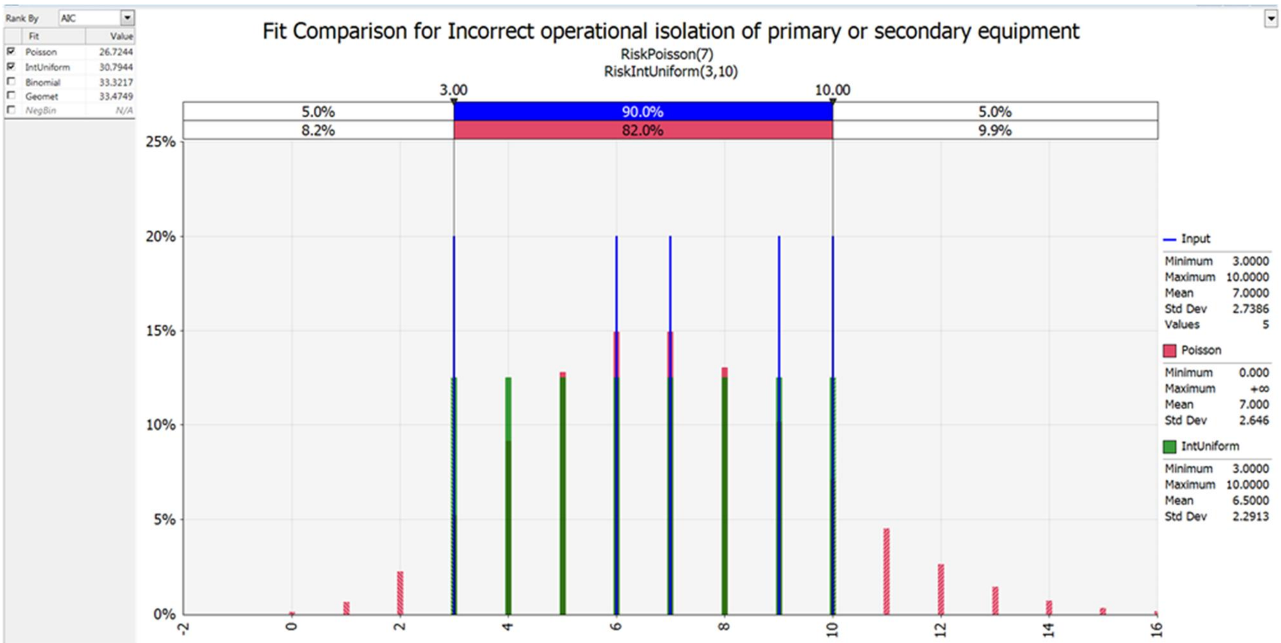

Figure 2.34 Incorrect operational isolation of primary or secondary equipment, curve of best fit

Rank By: AIC

	Fit	Value
☑	Poisson	26.7244
☑	IntUniform	30.7944
☐	Binomial	33.3217
☐	Geomet	33.4749
☐	NegBin	N/A

	Input	Poisson	IntUniform	Binomial	Geomet
Fit					
Function		=RiskPoisson(7)	=RiskIntUniform(3,..	=RiskBinomial(41,..	=RiskGeomet(0.12..
Method		MLE	MLE	MLE	MLE
Rankings By Fit Statistic [4 Valid Fits]					
Akaike (AIC)		#1	#2	#3	#4
Bayesian (BIC)		#2	#1	#3	#4
Chi-Sq Statistic		#1 (Tie)	#1 (Tie)	#1 (Tie)	#1 (Tie)
Parameters - [* Values unavailable without running a bootstrap]					
Num. Est. Parameters		1	2	2	1
Fitted Parameter #1		lambda	Min	n	p
Fitted Value		7.0000	3	41	0.12500
95% Lower Limit*		N/A	N/A	N/A	N/A
95% Upper Limit*		N/A	N/A	N/A	N/A
Conf. Interval Width*		N/A	N/A	N/A	N/A
Fitted Parameter #2			Max	p	
Fitted Value			10	0.17073	
95% Lower Limit*			N/A	N/A	
95% Upper Limit*			N/A	N/A	
Conf. Interval Width*			N/A	N/A	

Figure 2.35 Incorrect operational isolation of primary or secondary equipment, fit statistics

As shown in Figure 2.36, the 5th and 95th percentile parameters for the preferred curve are 4 and 13 respectively.

Rank By	AIC
Fit	**Value**
☑ Poisson	26.7244
☑ IntUniform	30.7944
☐ Binomial	33.3217
☐ Geomet	33.4749
☐ *NegBin*	*N/A*

Percentiles	Input	Poisson	IntUniform	Binomial	Geomet
5%	3.0000	3.0000	3.0000	3.0000	0.0000
10%	3.0000	4.0000	3.0000	4.0000	0.0000
15%	3.0000	4.0000	4.0000	5.0000	1.0000
20%	3.0000	5.0000	4.0000	5.0000	1.0000
25%	6.0000	5.0000	4.0000	5.0000	2.0000
30%	6.0000	5.0000	5.0000	6.0000	2.0000
35%	6.0000	6.0000	5.0000	6.0000	3.0000
40%	6.0000	6.0000	6.0000	6.0000	3.0000
45%	7.0000	7.0000	6.0000	7.0000	4.0000
50%	7.0000	7.0000	6.0000	7.0000	5.0000
55%	7.0000	7.0000	7.0000	7.0000	5.0000
60%	7.0000	8.0000	7.0000	8.0000	6.0000
65%	9.0000	8.0000	8.0000	8.0000	7.0000
70%	9.0000	8.0000	8.0000	8.0000	9.0000
75%	9.0000	9.0000	8.0000	9.0000	10.0000
80%	9.0000	9.0000	9.0000	9.0000	12.0000
85%	10.0000	10.0000	9.0000	9.0000	14.0000
90%	10.0000	10.0000	10.0000	10.0000	17.0000
95%	10.0000	12.0000	10.0000	11.0000	22.0000

Figure 2.36 Incorrect operational isolation of primary or secondary equipment, distribution percentiles

2.5 Summary of findings

Table 2.1 summarises the probability distribution functions that have been chosen to best fit the parameter data (Table 1.1). In WSP | 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 either close for the next best fit distributions or confirmed through analysis of the data. The approach is also consistent with the Australian Energy Regulator's previous regulatory decisions to use a curve of best fit approach.

Table 2.1 Summary of best fit distributions

PARAMETER	BEST FIT DISTRIBUTION	STANDARD DEVIATION	5% POE	95% POE
LINES OUTAGE RATE - FAULT	Loglogistic	0.036	9.1%	20.4%
TRANSFORMERS OUTAGE RATE - FAULT	Weibull	0.032	10.1%	20.5%
REACTIVE PLANT OUTAGE RATE – FAULT	Loglogistic	0.032	7.9%	17.9%
LINES OUTAGE RATE - FORCED OUTAGE	Uniform	0.082	1.4%	27.1%
TRANSFORMERS OUTAGE RATE - FORCED OUTAGE	Loglogistic	0.085	15.3%	41.0%
REACTIVE PLANT OUTAGE RATE - FORCED OUTAGE	Weibull	0.041	15.6%	29.0%
NO. OF EVENTS >0.05 SYSTEM MINUTES	Poisson	1.14	1	7
NO. OF EVENTS >0.25 SYSTEM MINUTES	Geometric	1.20	0	3
AVERAGE OUTAGE DURATION	Loglogistic	112	41	299
FAILURE OF PROTECTION SYSTEM	Poisson	4.5	13	27
MATERIAL FAILURE OF SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA) SYSTEM	Geometric	8.1	0	24
INCORRECT OPERATIONAL ISOLATION OF PRIMARY OR SECONDARY EQUIPMENT	Poisson	2.7	3	12

3 VALUES FOR PARAMETERS

3.1 STPIS requirements for parameter values

STPIS Clause 3.2 sets out the requirements for parameter values. For each parameter, the TNSP must propose values for:

- a performance target
- a collar
- a cap

Specific requirements are:

- A performance target may take the form of a deadband (3.2(c)).
- Proposed performance targets must be equal to average performance over the most recent five years (3.2(g)).
- Proposed performance targets may be subject to reasonable adjustment to allow for statistical outliers, volume of capital works, changes in the age and ratings of the assets and changes in regulatory obligations.
- A proposed cap and collar may result in symmetric or asymmetric incentives (3.2(f)).
- Proposed values must be consistent with the objectives for the scheme (3.2(m)).

WSP | Parsons Brinckerhoff's views on these requirements are summarised in Table 3.1.

Table 3.1 Recommendations on scheme requirements for parameter values

REQUIREMENT	DISCUSSIONS	RECOMMENDATION
DEADBANDS	Deadbands are used to remove the impact of small variations in performance around the average performance. Because performance in a 5-year period is most often four "good" years with a single year of lower performance, deadbands most often have the effect of removing a net positive value.	Don't apply
MOST RECENT 5-YEAR PERIOD	The years 2012-2016 meet the requirement.	2012 to 2016 data is acceptable.
ADJUSTMENTS	Statistical outliers – these must be in the underlying reliability data rather than one of the 5 years of performance. WSP | Parsons Brinckerhoff has not undertaken any audit of this data. Removal of outliers can have a small but material impact on a single year's performance, but little effect on the 5-year average. As outliers are typically related to poor performance, removing them has the impact of making targets harder to achieve, noting that the same outliers should they occur in future performance are not removed. Volume of capital works – applies only where the parameter includes planned outages. As all of the service component parameters exclude planned outages, no adjustment applies. Change in age/ratings – would require a material change, not usually evident in aggregated reliability performance.	No adjustments
ASYMMETRIC INCENTIVES	Symmetric incentives are consistent with the objectives for the scheme, as they usually provide a cost neutral position for natural variation around the average. Where better performance is more difficult (costly) to achieve than a decline, the incentive to improve is weakened. This may be inconsistent with NER clause 6A.7.4(b)(ii), which requires that the scheme should "provide incentives …to:	Symmetric incentives should be adopted unless this results in an incentive that is inconsistent with scheme objectives.

	(i) provide greater reliability of the transmission system … at all times when Transmission Network Users place greatest value on the reliability of the transmission system; and (ii) improve and maintain the reliability of those elements of the transmission system that are most important to determining spot prices;" The counter argument is that improvements should only be made when economic to do so.

3.2 Caps and collars

The following factors are considered when setting caps and collar values:

- The expected range of performance should be within the cap and collar values, 5th and 95th percentile, meaning that the probability of performance being outside of the cap/collar is approximately 1 in 20 years.
- Performance should be bounded at zero where the curve of best fit has been bounded at zero.
- The loss of supply event frequency parameters should be rounded to an integer before applying a standard deviation, in accordance with the AER's recent determinations.

Table 3.2 compares the caps and collars set at 5th and 95th percentile with the maximum and minimum performance in the 2012 to 2016 period. It demonstrates that caps and collars are best set at 5th and 95th percentile.

Table 3.2 Caps and collars comparisons with 2012 to 2016 data

PARAMETER	TARGET	COLLAR	CAP	MAX	MIN	COMMENT	RECOMMENDATION
LINES OUTAGE RATE - FAULT	14.0%	20.4%	9.1%	18.4%	10.2%		
TRANSFORMER OUTAGE RATE - FAULT	15.6%	20.5%	10.1%	19.8%	10.8%		
REACTIVE PLANT OUTAGE RATE - FAULT	12.4%	17.9%	7.9%	15.7%	9.5%		
LINES OUTAGE RATE - FORCED OUTAGE	15.4%	27.1%	1.4%	22.8%	7.6%		
TRANSFORMER OUTAGE RATE - FORCED OUTAGE	26.6%	41.0%	15.3%	39.0%	18.7%		
REACTIVE PLANT OUTAGE RATE - FORCED OUTAGE	22.7%	29.0%	15.6%	27.0%	13.5%	The minimum performance in 2012-2016 is 16% under the collar. The performance during 2012 is significantly lower than the other 4 years of the period and is likely to be an anomaly.	Utilise the calculated caps and collars
LOSS OF SUPPLY EVENT FREQUENCY (EVENTS > 0.05 SYSTEM MINUTES)	3	7	1	5	2		
LOSS OF SUPPLY EVENT FREQUENCY (EVENTS > 0.25 SYSTEM MINUTES)	1	3	0	3	0		
AVERAGE OUTAGE DURATION	134	299	41	263.00	63.55		
FAILURE OF PROTECTION SYSTEM	20	27	13	23	11	The minimum performance in 2012-2016 is 18% under the collar. The performance during 2013 is significantly lower than the other 4 years of the period and is likely to be an anomaly.	Utilise the calculated caps and collars
MATERIAL FAILURE OF SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA) SYSTEM	8	24	0	21	3		
INCORRECT OPERATIONAL ISOLATION OF PRIMARY OR SECONDARY EQUIPMENT	7	12	3	10	3		

3.3 Recommended parameter values

The recommended parameter values are shown in Table 3.3. These are based on:

- Targets set at the average of 5-year performance
- Caps and collars set at 5% and 95% POE for all parameters and bounded at zero where appropriate
- Loss of supply targets, caps and collars rounded to nearest integer.

Weightings as set out in STPIS clause 3.4 are also shown in the table.

Table 3.3 Parameter values

PARAMETER	COLLAR	TARGET	CAP	WEIGHTING
LINES OUTAGE RATE - FAULT	20.4%	14.0%	9.1%	0.20
TRANSFORMER OUTAGE RATE - FAULT	20.5%	15.6%	10.1%	0.20
REACTIVE PLANT OUTAGE RATE - FAULT	17.9%	12.4%	7.9%	0.10
LINES OUTAGE RATE - FORCED OUTAGE	27.1%	15.4%	1.4%	0.00
TRANSFORMER OUTAGE RATE - FORCED OUTAGE	41.0%	26.6%	15.3%	0.00
REACTIVE PLANT OUTAGE RATE - FORCED OUTAGE	29.0%	22.7%	15.6%	0.00
LOSS OF SUPPLY EVENT FREQUENCY (EVENTS > 0.05 SYSTEM MINUTES)	7	3	1	0.15
LOSS OF SUPPLY EVENT FREQUENCY (EVENTS > 0.25 SYSTEM MINUTES)	3	1	0	0.15
AVERAGE OUTAGE DURATION	299	134	41	0.20
FAILURE OF PROTECTION SYSTEM	27	20	13	0
MATERIAL FAILURE OF SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA) SYSTEM	24	8	0	0
INCORRECT OPERATIONAL ISOLATION OF PRIMARY OR SECONDARY EQUIPMENT	12	7	3	0