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Fitting Probability Distribution Curves to Reliability Data

TransGrid

Fitting probability distribution curves to reliability data

31 March 2014



**PARSONS
BRINCKERHOFF**

Document information

Client: TransGrid
Title: Fitting probability distribution curves to reliability data
Document No: 2204015A-DMS-RPT-001 RevB
Date: 31 March 2014

Rev	Date	Details
A	18/12/2013	Draft
B	28/03/2014	Final

Author, Reviewer and Approver details

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Approved by:	Peter Walshe	Date: 31/03/2014	Signature: 

Distribution

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A GRI Rating: Sustainability Report 2011

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1. Introduction

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.

The Proper Operation of Equipment parameter has not been considered in this review. We note that it has an incentive weighting of zero and hence has no financial impact.

Parsons Brinckerhoff determined a curve of best fit to TransGrid's reliability data from the past five years 2009-2013 for each of the parameters and calculated the standard deviation 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

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.

The chi-square fit statistic is often used for discrete distributions; however, 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, some uncertainty in the fitted distribution will occur. AIC is considered to provide a more appropriate methodology for determining the curve of best fit to small datasets.

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.

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).

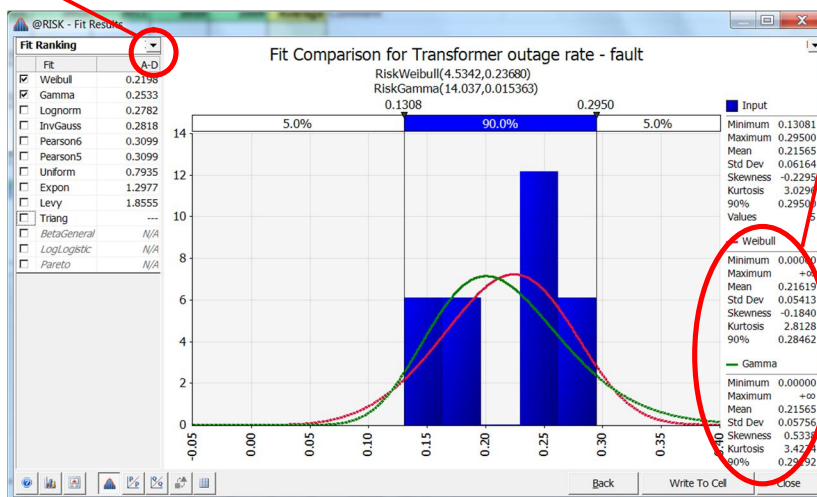
Once the probability distribution function of best fit was determined for each parameter the standard deviation of the probability distribution functions were calculated.

Because a probability distribution is being fitted to a dataset of five values only for each 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.

Once the distribution function of best fit was determined for each parameter, the target, caps and collars were calculated from the mean and standard deviation of the distribution function. The diagram below shows where the information about the fit statistic and distribution is located on the charts that are produced by @RISK.

Fit statistic

Distribution information



1.2 Parameter data

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

Table 1.1 Reliability Data 2009-2013

Parameter	2013	2012	2011	2010	2009
Lines outage rate – fault	18.36%	16.65%	16.06%	15.71%	22.51%
Transformers outage rate – fault	18.14%	16.38%	9.67%	16.76%	13.66%
Reactive plant outage rate – fault	9.90%	15.71%	18.27%	12.77%	21.05%
Lines outage rate - forced outage	21.34%	8.07%	6.21%	17.80%	21.47%
Transformers outage rate - forced outage	23.64%	20.33%	20.47%	21.97%	14.84%
Reactive plant outage rate - forced outage	24.38%	13.47%	17.51%	29.29%	17.29%
No. of events >0.05 system minutes	4	3	3	3	3
No. of events >0.25 system minutes	0	1	0	1	1
Average outage duration	180.32	94.23	137.11	225.83	84.96

2. Results of distribution fitting

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.

Lines outage rate – fault performance

The data for Lines outage rate is best fitted with a Weibull distribution (Figure 2.1) according to the K-S fit statistic and best fitted with a Pearson 5 distribution (Figure 2.2) according to the A-D fit statistic. As the data is distributed across both the middle and tails of the distribution, the A-D fit statistic is preferred (Pearson 5), giving a standard deviation of 0.023. This is also the curve of second best fit for the K-S fit statistic.

The standard deviation for the curve of second best fit for the A-D fit statistic (Lognormal) is 0.024, being only slightly lower than for the preferred curve.

Figure 2.1 Lines – fault, comparison using K-S

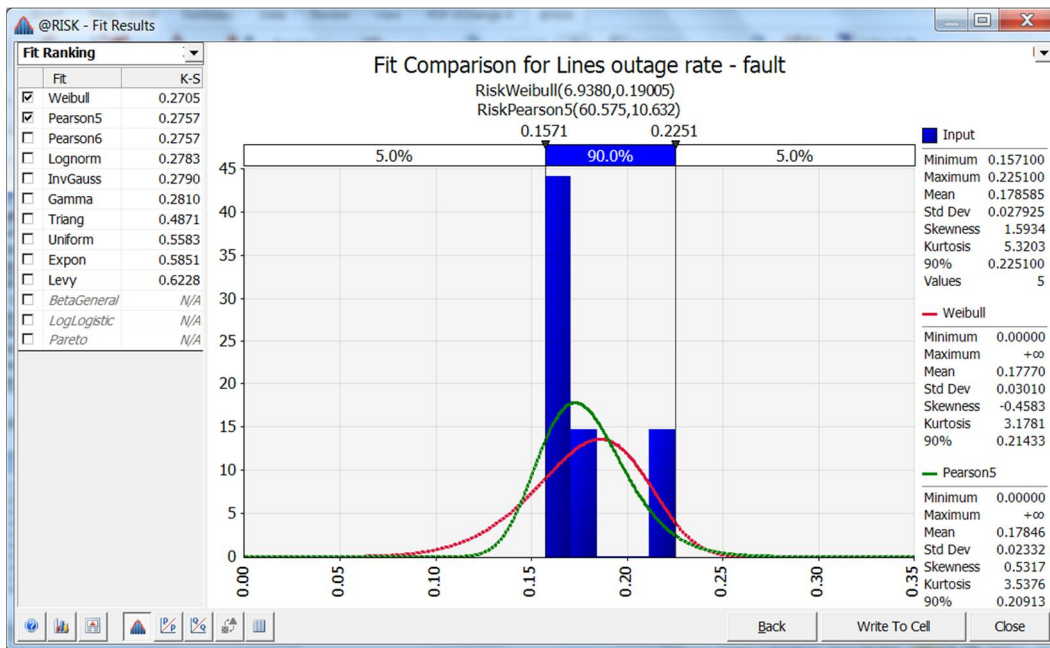
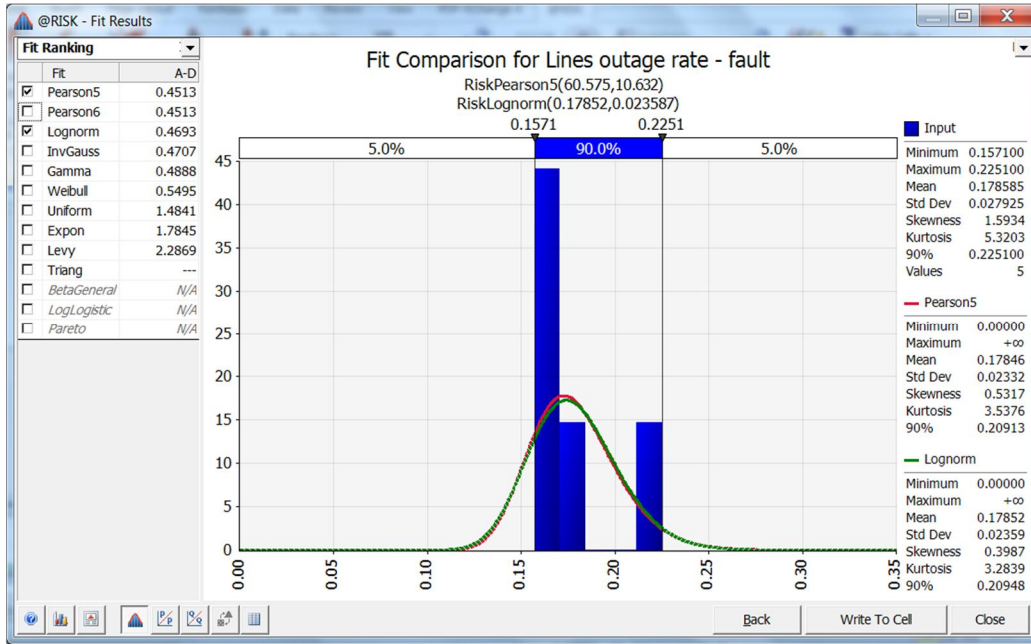


Figure 2.2 Lines – fault, comparison using A-D



Transformers outage rate – fault performance

The data for Transformer outage rate is best fitted with a BetaGeneral distribution (Figure 2.3) according to the K-S fit statistic and best fitted with a Weibull distribution (Figure 2.4) according to the A-D fit statistic. 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 0.027. This is also the curve of second best fit for the K-S fit statistic.

The standard deviation for the curve of second best fit using the A-D statistic (Gamma) is 0.032, 21% higher than the preferred curve. However, the standard deviation of the curve of best fit using the K-S statistic (BetaGeneral) is 0.029, only slightly higher than the preferred curve, confirming that the use of the standard deviation from the Weibull distribution is appropriate.

Figure 2.3 Transformers – fault, comparison using K-S

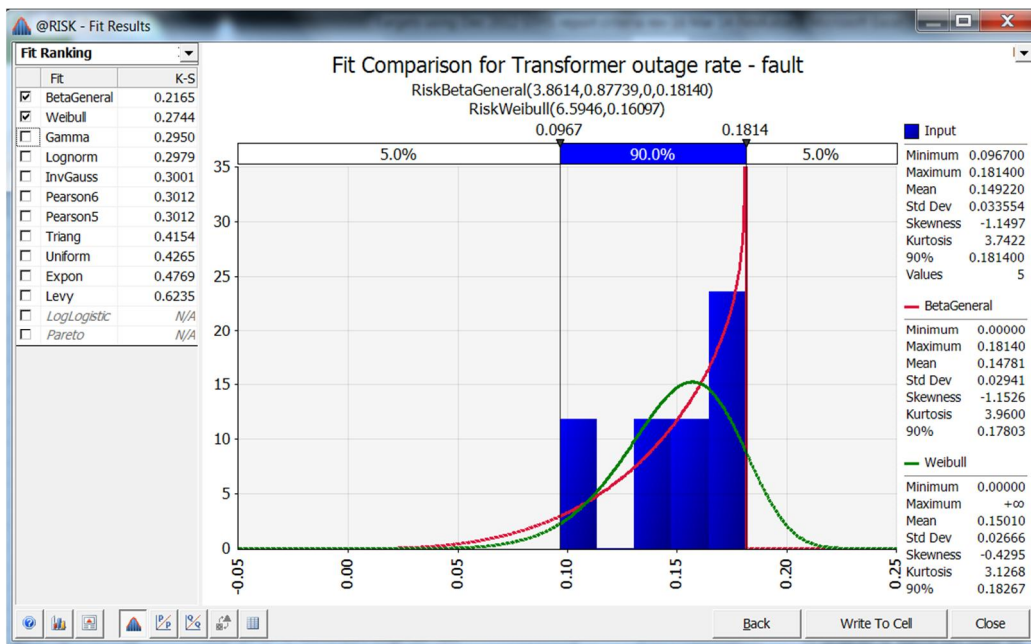
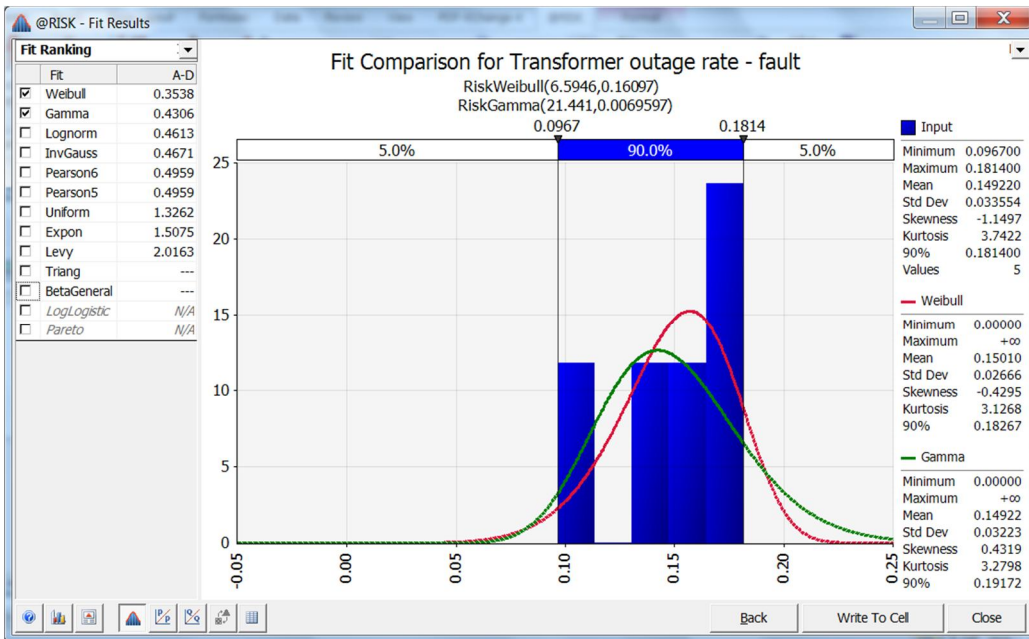


Figure 2.4 Transformers – fault, comparison using A-D



Reactive plant outage rate – fault performance

The data for Reactive plant unavailability due to fault is best fitted with a Gamma distribution curve (Figure 2.5) according to the K-S fit statistic. The A-D fit statistic has the Weibull distribution curve as the best fit (Figure 2.6). 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 0.039.

For comparison the standard deviation for the curve of second best fit using the A-D statistic (Gamma) is 0.040, slightly higher than the preferred curve.

Figure 2.5 Reactive plant – fault, comparison using K-S

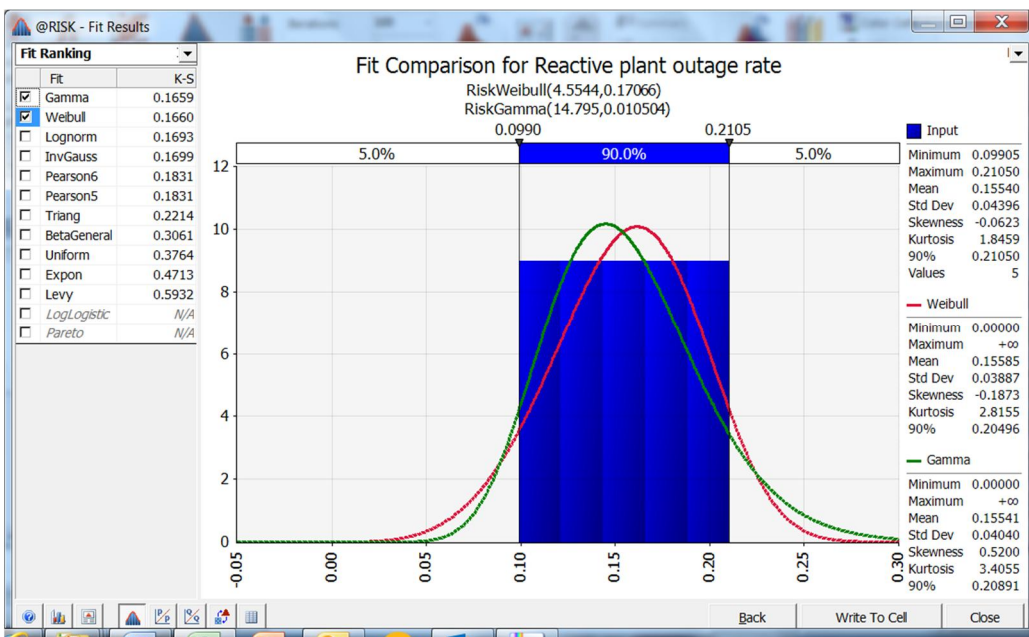
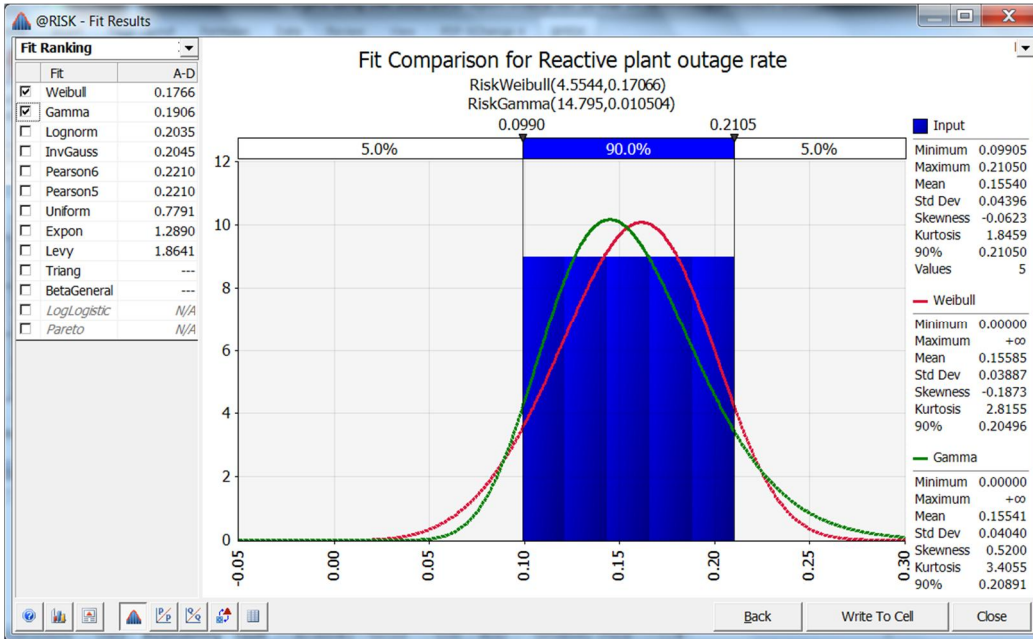


Figure 2.6 Reactive plant – fault, comparison using A-D



Lines outage rate – forced outage performance

The data for lines forced to be unavailable is best fitted with a Uniform distribution (Figure 2.7 and Figure 2.8) using both the K-S and A-D fit statistics, giving a standard deviation of 0.078. For comparison the standard deviation for the curve of second best fit (Gamma) for the A-D fit statistic is 19% lower at 0.063. However, given that the best fit distributions are the same for both the K-S and A-D statistic use of the Uniform distribution is confirmed.

Figure 2.7 Lines – forced, comparison using K-S

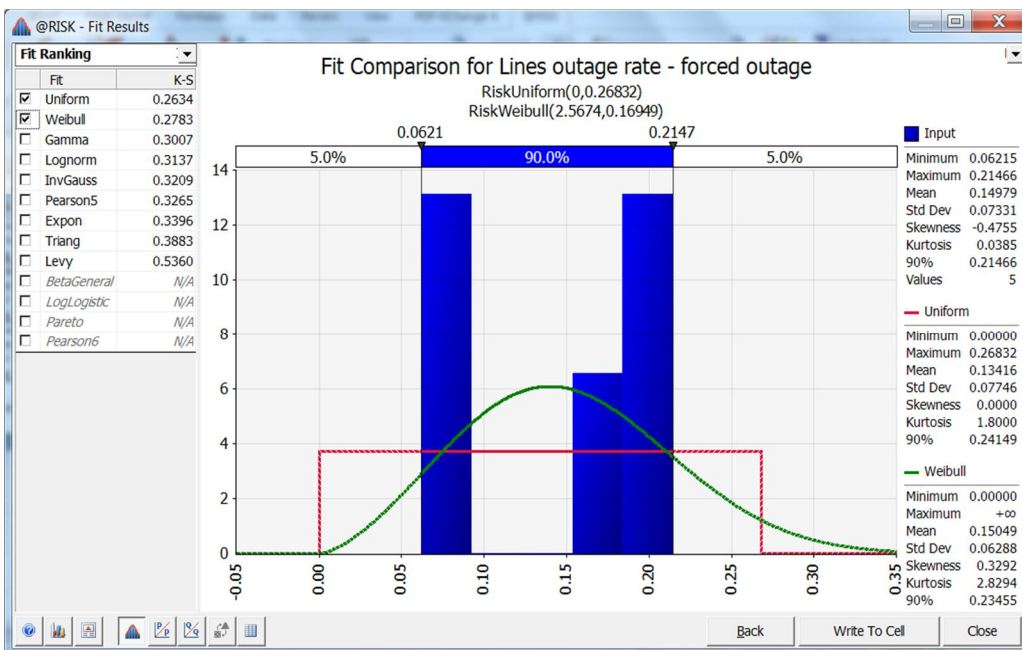
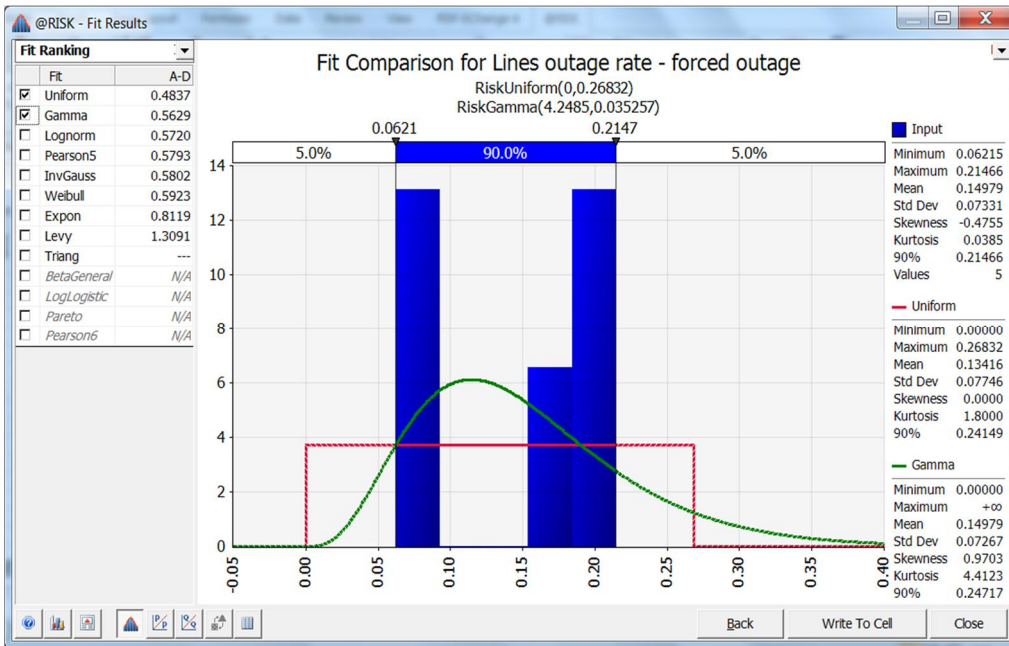


Figure 2.8 Lines – forced, comparison using A-D



Transformers outage rate – forced outage performance

The data for forced unavailability of transformers is best fitted with a Weibull distribution curve (Figure 2.9 and Figure 2.10) according to both the K-S and A-D fit statistics, giving a standard deviation of 0.026.

The standard deviation for the curve of second best fit for the A-D statistic (Gamma) is 19% higher at 0.031. However, given that the best fit distributions are the same for both the K-S and A-D statistic use of the Weibull distribution is confirmed.

Figure 2.9 Transformers – forced, comparison using K-S

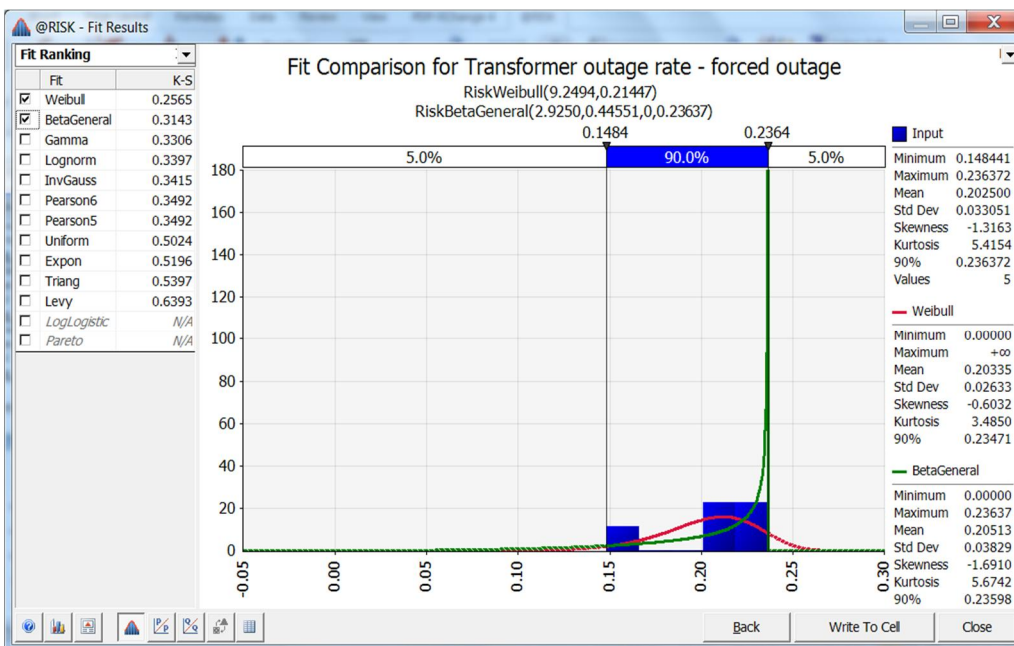
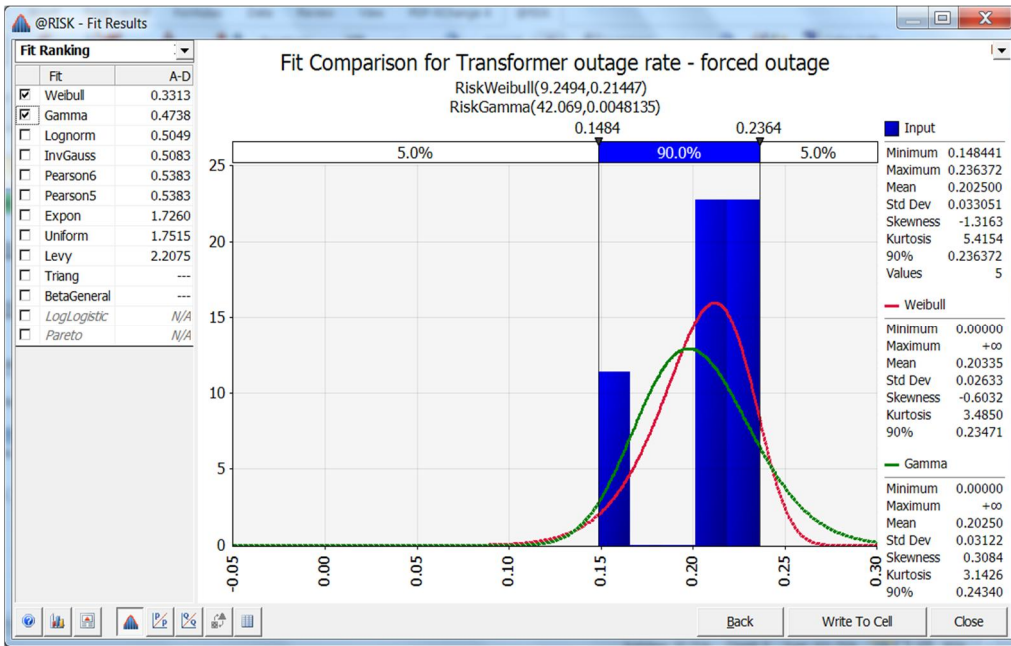


Figure 2.10 Transformers – forced, comparison using A-D



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 Triang distribution (Figure 2.11), while the A-D fit statistic indicates a Loglogistic distribution (Figure 2.12). 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 0.066.

For comparison the standard deviation for the curve of second best fit using the A-D statistic (Pearson 5) is 0.060, slightly lower than the preferred curve.

Figure 2.11 Reactive plant – forced, comparison using K-S

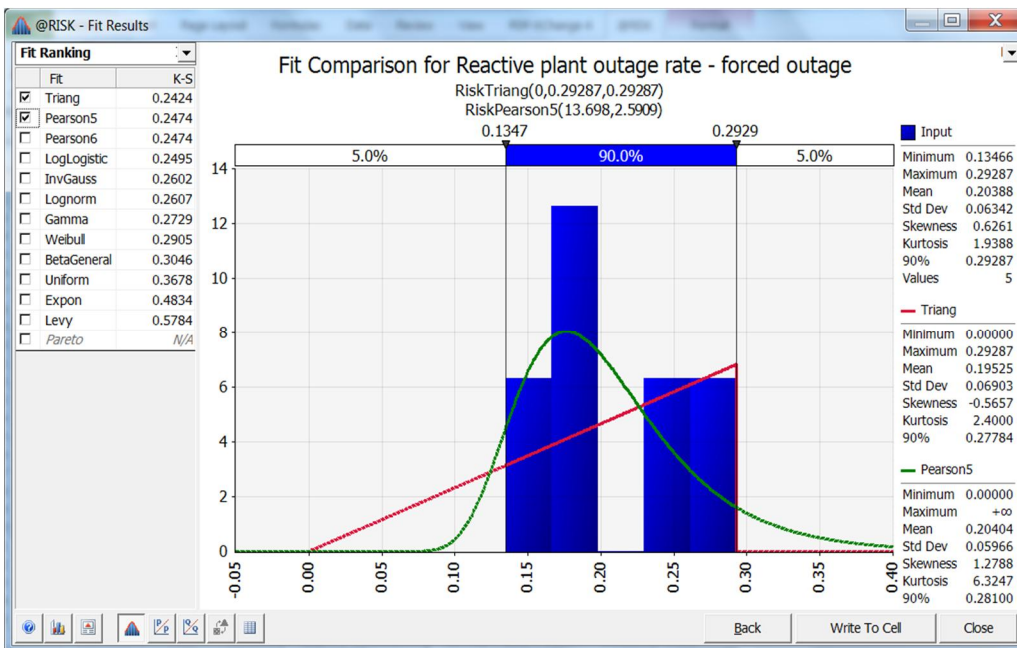
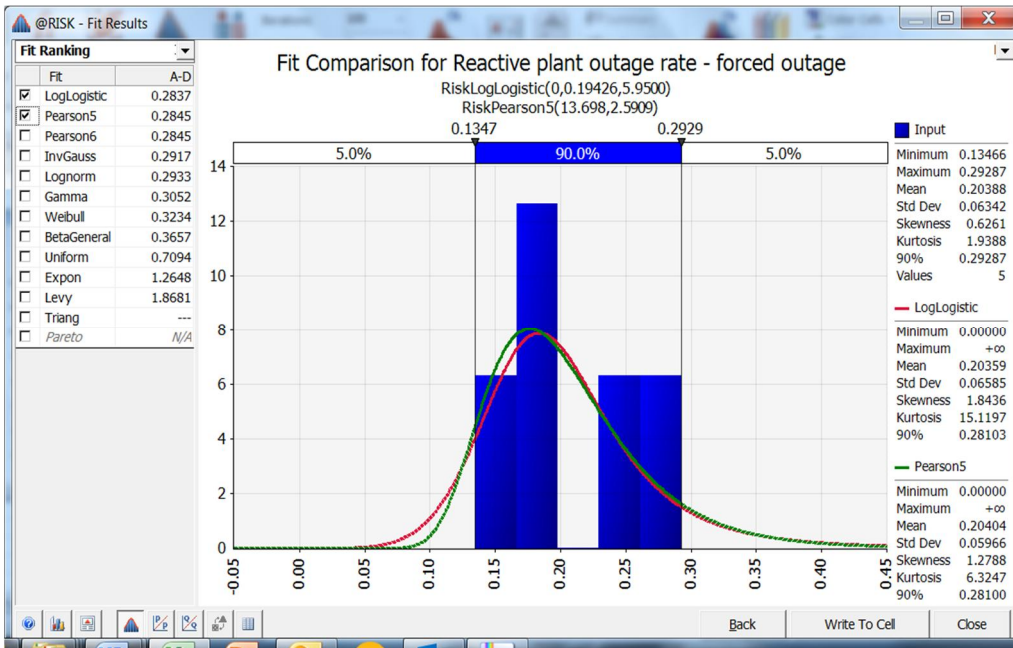


Figure 2.12 Reactive plant – forced, comparison using A-D



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

Using the AIC fit statistic, Figure 2.13 shows that the IntUniform distribution is the best fit for the loss of supply events greater than 0.05 system minutes, providing a standard deviation of 0.500. The curve of second best fit is the Poisson distribution, giving a standard deviation of 1.789, 258% higher. The high variation in standard deviations indicates some uncertainty in the curve fitting.

Examining the dataset shows that only two values occurred – 3 occurring in four of the years and 4 occurring in one year. This is consistent with the choice of the IntUniform distribution, indicating consistent service performance. Substituting data that varies around three (from 2 to 4) indicates that the Poisson distribution becomes the preferred distribution. As there is no reason, however, to believe that the consistent performance should not continue, the values in the dataset confirm that the IntUniform distribution is appropriate, providing a standard deviation of 0.500.

Figure 2.13 No. of events > 0.05 system minutes, curve of best fit

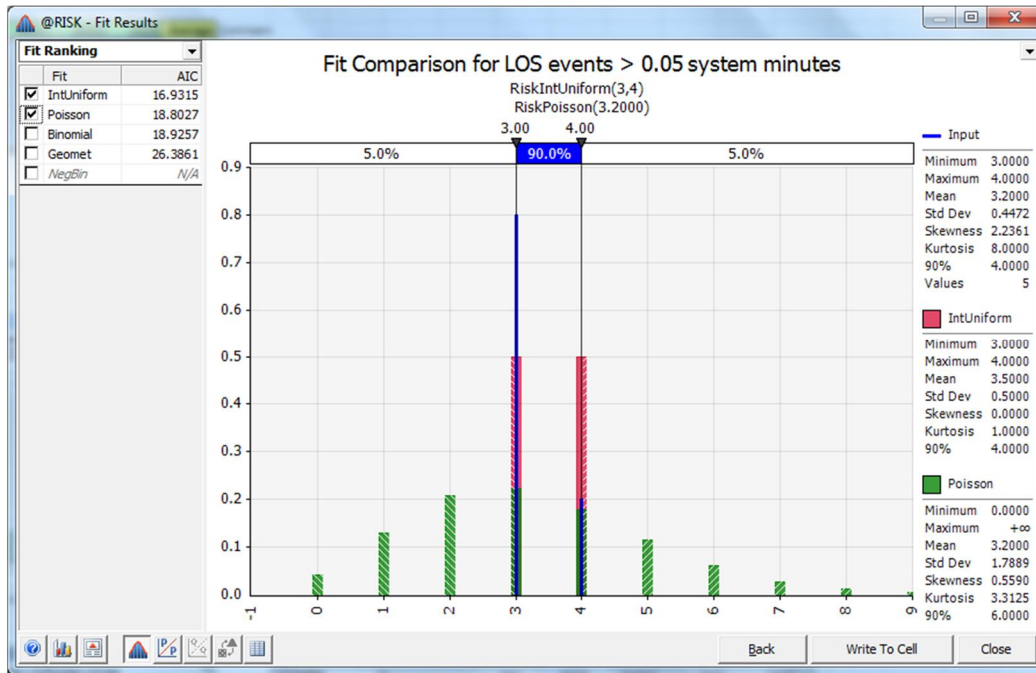


Table 2.1 No. of events > 0.05 system minutes, fit statistics

	Input	IntUniform	Poisson	Binomial	Geomet
- Rankings By Fit Statistic [4 Valid Fits]					
Akaike (AIC)		#1	#2	#3	#4
Bayesian (BIC)		#1	#3	#2	#4
Chi-Sq Statistic		#1	#3	#2	#4
+ Parameters - [* Values unavailable without running a bootstrap]					
- Distribution Statistics					
Minimum	3.0000	3.0000	0.0000	0.0000	0.0000
Maximum	4.0000	4.0000	+Infinity	4.0000	+Infinity
Mean	3.2000	3.5000	3.2000	3.2000	3.2000
Mode	3.0000	3.0000	3.0000	3.0000	0.0000
Median	3.0000	3.0000	3.0000	3.0000	2.0000
Std. Deviation	0.4472	0.5000	1.7889	0.8000	3.6661
Skewness	2.2361	0.0000	0.5590	-0.7500	2.0185

Number of events > 0.25 system minutes

Figure 2.14 shows that, using the AIC fit statistic, the Poisson distribution is the best fit providing a standard deviation of 0.775. The Geometrical is the second best fit with a standard deviation of 0.980, 26% higher. The relatively high variation in standard deviations indicates some uncertainty in the curve fitting.

Examining the dataset shows that only two values occurred – 0 occurring in two of the years and 1 occurring in three years. This is consistent with the choice of the Poisson distribution, a curve rising in value to a maximum then falling. The Geometrical distribution would have most years having 0 values, which does not

align with expected performance. Alignment with expected values confirms that the Poisson is the preferred distribution, providing a standard deviation of 0.775.

Figure 2.14 No. of events > 0.25 system minutes, curve of best fit

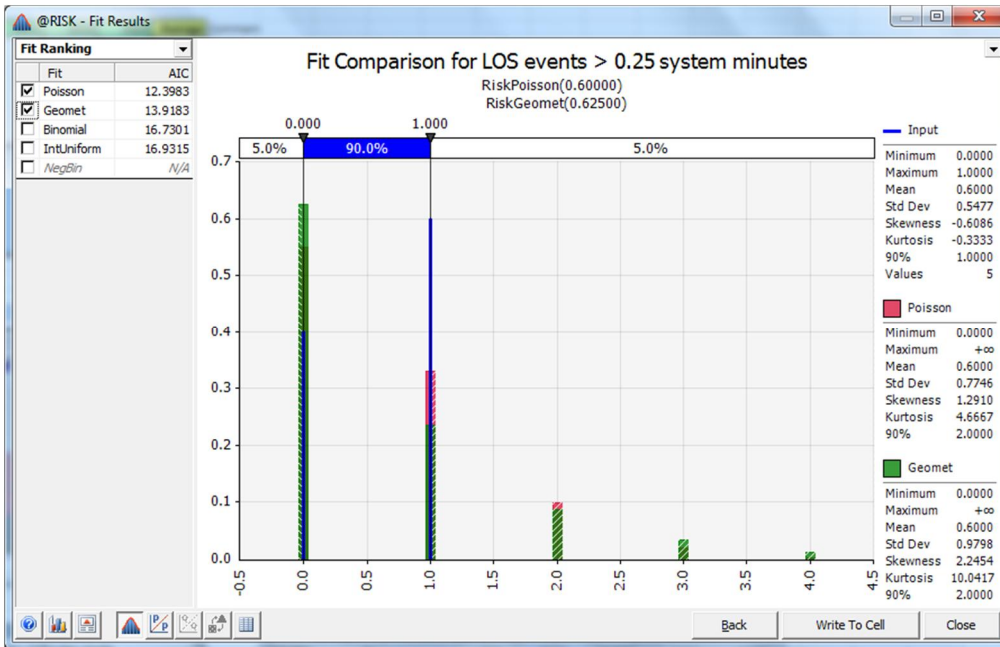


Table 2.2 No. of events > 0.25 system minutes, fit statistics

	Input	Poisson	Geomet	Binomial	IntUniform
Rankings By Fit Statistic [4 Valid Fits]					
Akaike (AIC)		#1	#2	#3	#4
Bayesian (BIC)		#3	#4	#1	#2
Chi-Sq Statistic		#3	#4	#1	#2
Parameters - [* Values unavailable without running a bootstrap]					
Distribution Statistics					
Minimum	0.0000	0.0000	0.0000	0.0000	0.0000
Maximum	1.0000	+Infinity	+Infinity	1.0000	1.0000
Mean	0.6000	0.6000	0.6000	0.6000	0.5000
Mode	1.0000	0.0000	0.0000	1.0000	0.0000
Median	1.0000	0.0000	0.0000	1.0000	0.0000
Std. Deviation	0.5477	0.7746	0.9798	0.4899	0.5000
Skewness	-0.6086	1.2910	2.2454	-0.4082	0.0000
Kurtosis	-0.3333	4.6667	10.0417	1.1667	1.0000

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 using both the K-S and the A-D fit statistics is the LogLogistic distribution curve (Figure 2.15 and Figure 2.16), providing a standard deviation of 69.88. The standard deviation for the curve of second best fit for both fit statistics (Weibull) is 25% lower at 52.56. However, given that the best fit distributions are the same for both the K-S and A-D statistic use of the LogLogistic distribution is confirmed.

Figure 2.15 Average outage duration, comparison using K-S

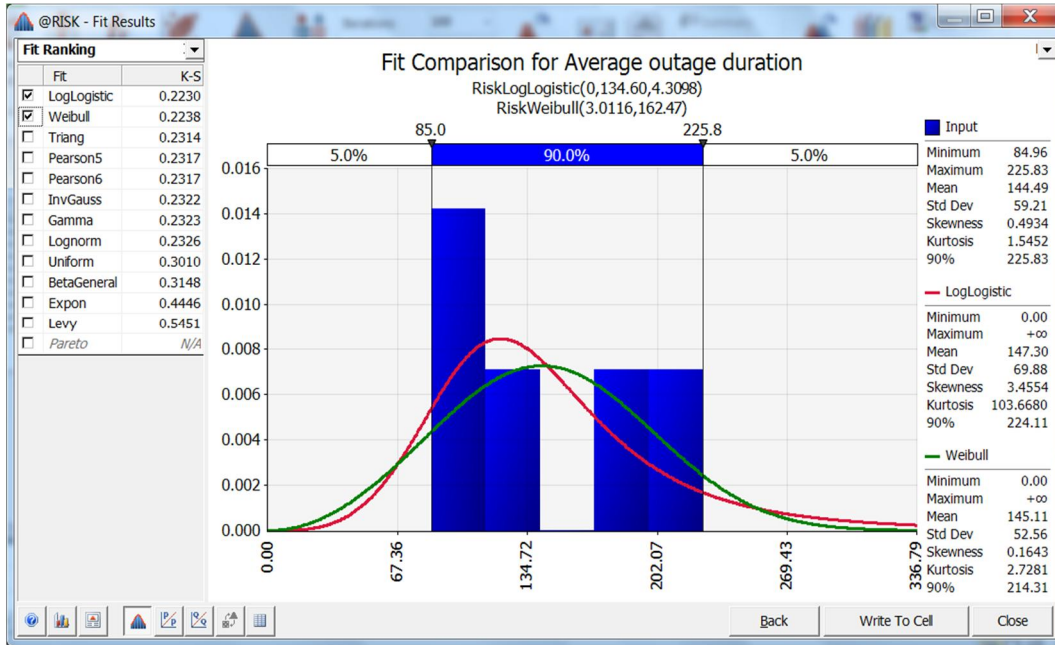
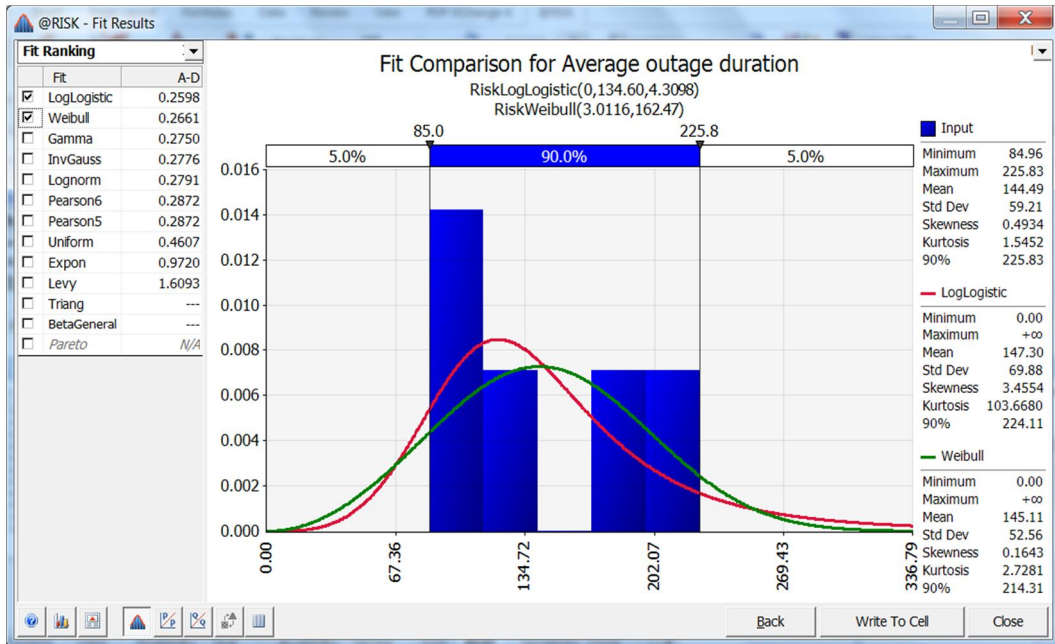


Figure 2.16 Average outage duration, comparison using A-D



2.4 Summary of findings

Table 2.3 summarises the probability distribution functions that have been chosen to best fit the parameter data (Table 1.1). 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 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 2.3 Summary of best fit distributions

Parameter	Best fit distribution	Standard Deviation
Lines outage rate - fault	Pearson 5	2.30%
Transformers outage rate - fault	Weibull	2.67%
Reactive plant outage rate – fault	Weibull	3.89%
Lines outage rate - forced outage	Uniform	7.75%
Transformers outage rate - forced outage	Weibull	2.63%
Reactive plant outage rate - forced outage	Loglogistic	6.59%
No. of events >0.05 system minutes	IntUniform	0.500
No. of events >0.25 system minutes	Poisson	0.775
Average outage duration	LogLogistic	69.88

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)).

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 2009-2013 meet the requirement.	2009 to 2013 data is acceptable.
Adjustments	<p>Statistical outliers – these must be in the underlying reliability data rather than one of the 5 years of performance. PB has not seen 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.</p> <p>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.</p> <p>Change in age/ratings – would require a material change, not usually evident in aggregated reliability performance.</p>	No adjustments

Requirement	Discussions	Recommendation
Asymmetric incentives	<p>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:</p> <p>(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</p> <p>(ii) improve and maintain the reliability of those elements of the transmission system that are most important to determining spot prices;"</p> <p>The counter argument is that improvements should only be made when economic to do so.</p>	Symmetric incentives should be adopted unless this results in an incentive that is inconsistent with scheme objectives.

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, typically 2 standard deviations from the target value, meaning that the probability of performance being outside of the cap/collar is approximately 1 in 22 years. The use of one standard deviation (1 in 3 years) means that the cap or collar value might be reached through normal year on year variations, while the use of 2.5 standard deviations (1 in 83 years) weakens the incentive by accruing rewards/penalties too slowly.
- 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 one and two standard deviations from the target value with the maximum and minimum performance in the 2009 to 2013 period. It demonstrates that caps and collars are best set at two standard deviation, except for the Loss of supply (events > 0.25 system minutes) and the Lines outage rate - forced outage, where the lower bound of zero results in an asymmetrical incentive.

Table 3.2 Caps and collars comparisons at one and two standard deviations from the target

Parameter	Target	Std Dev	1 std dev		2 std dev		2009-2013 Data		Comment	Recommendation
			Collar	Cap	Collar	Cap	Max	Min		
lines outage rate - fault	17.86%	2.30%	20.2%	15.6%	22.5%	13.3%	22.5%	15.7%	Max & Min values exceeds 1SD	use 2 std deviations
transformer outage rate - fault	14.92%	2.67%	17.6%	12.3%	20.3%	9.6%	18.1%	9.7%	Max & Min values exceeds 1SD	use 2 std deviations
reactive plant outage rate - fault	15.54%	3.89%	19.4%	11.7%	23.3%	7.8%	21.1%	9.9%	Max value exceeds 1SD collar, min is near 1SD cap	use 2 std deviations
lines outage rate - forced outage	14.98%	7.75%	22.7%	7.2%	30.5%	-0.5%	21.5%	6.2%	Max & Min values near 1SD	use 2 std deviations, bound at zero
transformer outage rate - forced outage	20.25%	2.63%	22.9%	17.6%	25.5%	15.0%	23.6%	14.8%	Max & Min values exceeds 1SD	use 2 std deviations
reactive plant outage rate - forced outage	20.39%	6.59%	27.0%	13.8%	33.6%	7.2%	29.3%	13.5%	Max & Min values exceeds 1SD	use 2 std deviations
loss of supply event frequency (Events > 0.05 system minutes)	3	1	4	2	5	1	4	3	Max value equals 1SD collar, min is ok	use 2 std deviations
loss of supply event frequency (Events > 0.25 system minutes)	1	1	2	0	3	-1	1	0	Max and Min values are within 1SD	use 2 std deviations, bound at zero
average outage duration	144.49	69.88	214	75	284	5	226	84.96	Max value exceeds 1SD collar, min is near 1SD cap	use 2 std deviations

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 two standard deviations above and below the average performance 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	22.46%	17.86%	13.26%	0.20
transformer outage rate - fault	20.26%	14.92%	9.58%	0.20
reactive plant outage rate - fault	23.32%	15.54%	7.76%	0.10
lines outage rate - forced outage	30.48%	14.98%	0%	0.00
transformer outage rate - forced outage	25.51%	20.25%	14.99%	0.00
reactive plant outage rate - forced outage	33.57%	20.39%	7.21%	0.00
loss of supply event frequency (Events > 0.05 system minutes)	5	3	1	0.15
loss of supply event frequency (Events > 0.25 system minutes)	3	1	0	0.15
average outage duration	284.25	144.49	4.73	0.20