MSPI False Indication Probability Simulations

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Overview

The purpose of this exercise was to examine false indication probabilities in the context of MSPI, in order to investigate pros and cons of different approaches to resolving two coupled issues: (1) what prior to use for updating, and (2) whether (in a particular plant configuration) to model the fuel oil transfer pump (FOTP) as a separate component, or integrally to its emergency diesel generator (EDG). False indication probabilities were quantified for the following situations: (1) all components at baseline, so that the true indication is green, and white or above would be false positive; (2) one or more components degraded to the extent that the true indication would be (mid) white, and "false" would be green (negative) or yellow (negative) or red (negative). In key respects, this was the approach taken in NUREG-1753.

Simulations were performed for a single EDG "train," as was done for NUREG-1753. Two paradigms were explored: 1) failures to start (FTS) of the EDG FOTP were counted as EDG failure to run (FTR), 2) failures on demand of the FOTP were counted as failures of a separate component. For both paradigms, only the unreliability index (URI) portion of the Mitigating System Performance Index (MSPI) was examined; no changes in the unavailability index (UAI) were considered. Thus, the change in core damage frequency (CDF) was approximated as

$$\Delta CDF \approx URI = \sum I_B \left(p_1 - p_0\right) \qquad (1)$$

In this equation, I_B is the Birnbaum importance of the failure mode under consideration, with the summation being across the failure modes that contribute to URI (cf. Eq. 3 in App. F to NEI 99-02), p_0 is the baseline failure probability, and p_1 is the Bayesian-corrected failure probability, using the terminology of NEI 99-02. In the case of FTR, p_1 is approximated by $\lambda_1 t_m$, where λ_1 is the posterior mean failure rate and t_m is the mission time, and p_0 by $\lambda_0 t_m$, where λ_0 is the baseline failure rate.

All calculations were performed using the R package (R Development Core Team, 2010).

Base case parameter values

I_B in the base case simulation was taken to be 5×10^{-5}/yr for EDG FTS, EDG FTR, EDG failure to load (FTL), and FOTP FTS, per direction of Bruce Mrowca. The baseline mean values of p and λ were taken from Table 8 in App. F of NEI 99-02. For EDG FTS, p_0 is 0.005. For EDG FTL, p_0 is 0.003. For EDG FTR, λ_0 is 8×10^{-4}/hr. Finally, for the FOTP, p_0 is 0.0019.

The mission time of the EDG in the base case was taken to be 8 hr. There were assumed to be 2 demands on the FOTP for each hour of EDG operation. Over the MSPI evaluation period, there were assumed to be 69 demands for the EDG to start and load, and 105 hr of EDG operating time. There were assumed to be 210 demands on the FOTP over the evaluation period. All of these values are per direction of Bruce Mrowca.

Prior distributions

In its present form, MSPI uses constrained noninformative (CNI) prior distributions to represent the variability in the baseline industry parameter values. A CNI prior has a designated mean value, and uncertainty characteristics that are otherwise "noninformative" in a particular sense. The associated distributions are listed in Table 8 in App. F to NEI 99-02. For EDG FTS, The CNI prior is approximated as a beta(0.492, 97.9) distribution. For EDG FTL, the CNI prior is approximated as a beta(0.495, 164) distribution. For EDG FTR the CNI prior is a gamma(0.5, 625 hr) distribution. Finally, for the FOTP , the CNI prior is approximated as a beta(0.497, 261) distribution.

Four other prior distributions were considered. The Jeffreys prior is a beta(0.5, 0.5) distribution for failures on demand, and is an improper gamma(0.5, 0) prior for FTR. It is used to provide a reference point that is almost completely data-driven. The two heavy-tailed nonconjugate priors examined were a logistic-normal and logistic-Cauchy distribution for failures on demand, and a lognormal and log-Cauchy distribution for FTR.

The density function of the logistic-normal distribution is given by

$$g(p) = \frac{1}{\sqrt{2\pi}\sigma p(1-p)} \exp\left\{ -\frac{\left[\log\left(\frac{p}{1-p}\right) - \mu\right]^2}{2\sigma^2} \right\} \quad -\infty < \mu < \infty, \sigma > 0 \qquad (2)$$

For the logistic-Cauchy distribution, the density function is

$$g(\theta) = \frac{1}{\pi\sigma\left[1 + \left(\frac{\theta - \mu}{\sigma}\right)^2\right]} \quad -\infty < \mu < \infty, \sigma > 0 \qquad (3)$$

In this equation, $\theta = \log[p/(1-p)]$.

The lognormal density function is

$$g(\lambda) = \frac{1}{\sqrt{2\pi}\sigma\lambda} exp\left[-\frac{(log\,\lambda - \mu)^2}{2\sigma^2} \right] \qquad (4)$$

The log-Cauchy density function is given by Eq. 3 with $\theta = \log\lambda$.

A CNI prior is completely specified by the mean value to which the distribution is "constrained." For the distributions considered here other than the CNI and the Jeffreys, it is necessary to choose additional parameters. In the case of the logistic-normal and lognormal priors, the mean and 95th percentiles of the CNI priors were used to determine the distribution parameters. For the logistic-normal distribution, the mean cannot be written in closed form, so the resulting equations were solved numerically for μ and σ. In the case of the lognormal distribution, the

resulting equations are algebraic and can be solved in closed form for μ and σ. For the logistic-Cauchy and log-Cauchy distributions, the parameters of the CNI prior were used directly. For the logistic-Cauchy distribution, the parameters μ and σ are related to the parameters of the CNI prior (α and β) by the following equations:

$$\mu = \psi(\alpha) - \psi(\beta)$$
$$\sigma = \sqrt{\psi'(\alpha) + \psi'(\beta)} \qquad (5)$$

In this equation ψ(•) is the digamma function and ψ'(•) is the trigamma function, the first and second derivatives of the logarithm of the gamma function. In the case of the log-Cauchy prior for FTR, the equations for μ and σ are

$$\mu = \psi(\alpha) - \log \beta$$
$$\sigma = \sqrt{\psi'(\alpha)} \qquad (6)$$

The fourth type of prior distribution examined was a mixture of conjugate priors, as described in (Atwood, *et al.*, 2005). The baseline mean from NEI 99-02 was taken as the mean of the normal state, with the first parameter of the beta or gamma distribution taken to be 0.5. The mean of the degraded state was taken to be a factor of 10 larger. The shape parameter for the beta or gamma distribution representing the degraded state was taken to be 1.5, following (Youngblood, *et al.*, 2005). The other parameter is then determined from the mean. The mixing coefficients were taken to be 0.99 for the normal state and 0.01 for the degraded state.

Description of the simulations

Over an MSPI evaluation period, failures of an EDG or its associated FOTP are assumed to occur randomly, in accordance with the assumed likelihood function (i.e., aleatory model). For failures on demand (FTS, FTL, or FOTP), the aleatory model is assumed to be a binomial distribution with parameters p and n_{eval} , where p is the probability of failure on each demand, and n_{eval} is the number of demands during the evaluation period (69 for EDG FTS and FTL, and 210 for the FOTP). For EDG FTR, the aleatory model for the number of failures during the evaluation period is assumed to be a Poisson distribution with parameter λt_{oper}, where λ is the EDG failure rate and t_{oper} is the cumulative operating time over the evaluation period (105 hr).

100,000 "time histories" were simulated. For each time history, a failure count was generated for each failure mode from its associated distribution (binomial or Poisson). The prior distribution for p or λ was updated with the simulated data and this updated value was used in the calculation of the URI, per Eq. 1. For EDG FTS or FTL this is straightforward. For the case in which the FOTP is "lumped" together with the EDG, the simulated FTR failures and FOTP failures over the evaluation period are summed to give an aggregate failure count, and λ for EDG FTR is updated with this aggregate failure count. The contribution to the URI from FTR is then just $(\lambda_1 - \lambda_0)t_m$.

For the case where the FOTP is treated as a separate component, the updated value of p for the FOTP is used to calculate the probability that the FOTP fails during an EDG mission time, which is given by $1 - (1 - p)^n$, where n is the number of FOTP demands during the EDG mission (16 in

the base case). The contribution to URI from FOTP failures during the evaluation period in this case is given by

$$I_B\left[(1-p_0)^n-(1-p_1)^n\right] \tag{7}$$

The parameter values used to generate the failure counts were set as follows. For those cases in which only one parameter was being varied, the baseline parameter value (p_0 or λ_0) was multiplied by a factor so that the URI contribution from that failure mode alone would be sufficient to reach the desired threshold for ΔCDF. For the case of failure on demand, this gives

$$p_1 = p_0 + \frac{\Delta CDF}{I_B} \tag{8}$$

For FTR, the relation is

$$\lambda_1 = \lambda_0 + \frac{\Delta CDF}{I_B t_m} \tag{9}$$

A case was also run in which all parameters were increased by a factor, *f*, to bring ΔCDF to the threshold value. The following equation is used to determine *f* for a specified ΔCDF:

$$f = 1 + \frac{\Delta CDF}{I_B(\,p_0^{FTS} + p_0^{FTL} + \lambda_0 t_m + p_0^{FOTP} n\,)} \tag{10}$$

In this equation, we have approximated $(1-p)^n$ by np, where n is the number of FOTP demands during the mission time of the EDG.

The mid-white performance state was set at ΔCDF = $\sqrt{10} \times 10^{-6}$/yr. For each time history, a check is made of whether the calculated ΔCDF is above or below 10^{-6}/yr. If the parameters were at their baseline values, and ΔCDF > 10^{-6}/yr, this is counted as a false positive. Conversely, if one or all of the parameters are set to values corresponding to ΔCDF > 10^{-6}/yr but that time history's ΔCDF < 10^{-6}/yr, this is counted as a false negative indication. The false indication (positive or negative) probability is then estimated as the number of false positive or negative counts divided by the number of time histories (100,000).

As an example, consider a time history in which *p* for the FOTP has increased sufficiently that ΔCDF is at the mid-white threshold listed above, even though all other components are at baseline. Thus, the value of *p* used to simulate FOTP failures is 0.066, with all other parameters at their baseline values. For this time history, there was 1 failure of the EDG to start (FTS) and 2 failures of the FOTP; no other failures were observed. Thus, there is a positive contribution to URI from FTS and FOTP (FTR) and a negative contribution from FTL. Under the lumped paradigm, the 2 FOTP failures would be treated as 2 FTR failures in 105 hr of EDG operation. With the Jeffreys prior, the posterior mean of p^{FTS} will be 0.021, and the posterior mean of λ^{FTR} will be 0.024/hr. For FTL, the posterior mean will be 0.007; this is larger than the baseline value of 0.003 and reflects the shape parameter of 0.5 in the Jeffreys prior. With 0 FTL failures, this

increase above the baseline is artificial and so the contribution to URI from FTL will be taken to be 0. Therefore, with the Jeffreys prior, URI for this time history will be

$$URI_{Jeff} = \left(5\times10^{-5}/yr\right)\left[\left(0.021-0.005\right)+\left(0.024/hr-0.0008/hr\right)8hr\right] = 1.0\times10^{-5}/yr \qquad (11)$$

This is > 10^{-6}/yr, so it would not count as a false negative indication. However, because it is at the white-yellow threshold, it would count as a false positive indication for yellow.

With the CNI priors, the posterior mean of p^{FTS} will be 0.0089, and the posterior mean of λ^{FTR} will be 0.0034/hr. With 0 failures in 69 demands, the posterior mean of p^{FTL} decreases to 0.002, making the contribution to URI from FTL negative. Therefore, with the CNI prior, URI for this time history will be

$$URI_{CNI} = \left(5\times10^{-5}/yr\right)\left[\left(0.0089-0.005\right)+(0.002-0.003)+\left(0.0034/hr-0.0008/hr\right)8hr\right] = 5.2\times10^{-6}/yr \qquad (12)$$

This is > 10^{-6}/yr, so it would not count as a false negative indication.

Under the paradigm of separate treatment of the FOTP, the URI with the CNI prior will be different. The 2 FOTP failures occur in 210 demands of the FOTP, and the posterior mean of p^{FOTP} would be 0.0053. Assuming 16 demands on the FOTP during the 8-hr EDG mission time, the URI for this time history becomes

$$URI_{CNI} = \left(5\times10^{-5}/yr\right)\left[\left(0.0089-0.005\right)+(0.002-0.003)+16\left(0.0053-0.0019\right)\right] = 6.9\times10^{-6}/yr \qquad (13)$$

This is also > 10^{-6}/yr, so it would not count as a false negative indication.

The results for the base case are shown on the following pages. Note that the results have been rounded to two decimal places and thus the columns in each table may not sum exactly to unity.

Three sensitivity cases were run, in which the number of FOTP demands were reduced, along with the Birnbaum importance of the FOTP. The parameter values (i.e., number of FOTP demands per hour of EDG operation and FOTP Birnbaum importance) for these three sensitivity cases were supplied by Bruce Mrowca. The results are shown in Tables 7-12. Only results for the CNI prior are reported for the lumped paradigm. The results for the log(istic)-Cauchy prior are shown in parentheses for the separate paradigm. Note that for the lumped paradigm, the revised FOTP Birnbaum value played no role, as the EDG Birnbaum value was used in the adjustment of parameter values and the calculation of URI. In the separate paradigm, the revised values of FOTP Birnbaum importance were used. In the separate paradigm, the factor, *f*, by which all parameter values were multiplied in Case 5, is given by a modified version of Eq. 10:

$$f = 1 + \frac{\Delta CDF}{I_B^{EDG}\left(p_0^{FTS} + p_0^{FTL} + \lambda_0 t_m\right) + I_B^{FOTP} p_0^{FOTP} n} \qquad (14)$$

One issue is worth some discussion, as it illustrates what is perhaps an important issue with how the MSPI is calculated. What has to be kept in mind is that URI can be < 0, and it will be so whenever the failure count is 0, because the new mean failure probability will be less than the baseline value, causing Δp to be < 0. However, this is not the case with the Jeffreys and log(istic)-Cauchy priors. For these priors, even with 0 failures, $\Delta p > 0$. Thus, there is no negative contribution to URI with 0 failures with these priors. However, $\Delta p > 0$ is unreasonable in the case of 0 failures, so in the simulation of the Jeffreys and log(istic)-Cauchy priors, URI is set equal to 0 whenever the failure count is 0.

From a broad perspective, with the parameter at its baseline value, 0 is the most likely failure count, and so it does not seem appropriate to have URI < 0 in this case, because 0 failures are consistent with the baseline parameter value, not evidence of performance that is better than the baseline. However, URI was allowed to be < 0 for the other priors in the simulation, as this is how MSPI has been implemented.

References

Atwood Corwin L. and Youngblood Robert W. Mixture Priors for Bayesian Performance Monitoring 2: Variable-Constituent Model [Journal] // Reliability Engineering and System Safety. - 2005. - pp. 164-176.

R Development Core Team R: A language and environment for statistical computing. - Vienna : R Foundation for Statistical Computing, 2010.

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Table 1 Base case results

Paradigm 1, FOTP Lumped into EDG FTR

Case 0: All Components of Train at Baseline					
	Mixture	Logistic-Normal/Lognormal	Logistic-Cauchy/log-Cauchy	CNI	Jeffreys
P(G|G)	0.91	0.78	0.6	0.95	0.55
P(W|G)	0.09	0.22	0.39	0.05	0.41
P(Y|G)	0	0	0.01	0	0.04
P(R|G)	0	0	0	0	0

Paradigm 2, Separate FOTP

Case 0: All Components of Train at Baseline					
	Mixture	Logistic-Normal/Lognormal	Logistic-Cauchy/log-Cauchy	CNI	Jeffreys
P(G|G)	0.89	0.66	0.60	0.81	0.55
P(W|G)	0.11	0.34	0.40	0.19	0.43
P(Y|G)	0	0	0	0	0.02
P(R|G)	0	0	0	0	0

Table 2 Elevated EDG FTS probability

Case 1: EDG FTS at 1E-6 * sqrt(10). All others at Baseline					
	Mixture	Logistic-Normal	Logistic-Cauchy	CNI	Jeffreys
P(G|1E-6*sqrt(10))	0.22	0.08	0.08	0.22	0.02
P(W|1E-6*sqrt(10))	0.78	0.92	0.89	0.78	0.82
P(Y|1E-6*sqrt(10))	0.00015	0	0.03	0	0.15
P(R|1E-6*sqrt(10))	0	0	0	0	0

Case 1: EDG FTS at 1E-6 * sqrt(10). All others at Baseline					
	Mixture	Logistic-Normal	Logistic-Cauchy	CNI	Jeffreys
P(G|1E-6*sqrt(10))	0.33	0.09	0.08	0.51	0.02
P(W|1E-6*sqrt(10))	0.67	0.90	0.91	0.49	0.86
P(Y|1E-6*sqrt(10))	0.0002	0.01	0.01	0	0.12
P(R|1E-6*sqrt(10))	0	0	0	0	0

Table 3 Elevated EDG FTL probability

Case 2: EDG FTL at 1E-6 * sqrt(10). All others at Baseline					
	Mixture	Logistic-Normal	Logistic-Cauchy	CNI	Jeffreys
P(G|1E-6*sqrt(10))	0.23	0.08	0.03	0.46	0.02
P(W|1E-6*sqrt(10))	0.77	0.92	0.94	0.54	0.83
P(Y|1E-6*sqrt(10))	0	0	0.03	0	0.15
P(R|1E-6*sqrt(10))	0	0	0	0	0

Case 2: EDG FTL at 1E-6 * sqrt(10). All others at Baseline					
	Mixture	Logistic-Normal	Logistic-Cauchy	CNI	Jeffreys
P(G|1E-6*sqrt(10))	0.34	0.09	0.03	0.62	0.02
P(W|1E-6*sqrt(10))	0.66	0.89	0.96	0.38	0.86
P(Y|1E-6*sqrt(10))	0.0001	0.01	0.01	0	0.12
P(R|1E-6*sqrt(10))	0	0	0	0	0

Table 4 Elevated EDG failure rate

Case 3: EDG FTR at 1E-6 * sqrt(10). All others at Baseline					
	Mixture	Logistic-Normal	Logistic-Cauchy	CNI	Jeffreys
P(G|1E-6*sqrt(10))	0.62	0.47	0.26	0.75	0.24
P(W|1E-6*sqrt(10))	0.38	0.52	0.65	0.25	0.52
P(Y|1E-6*sqrt(10))	0	0.01	0.09	0	0.24
P(R|1E-6*sqrt(10))	0	0	0	0	0

Case 3: EDG FTR at 1E-6 * sqrt(10). All others at Baseline					
	Mixture	Logistic-Normal	Logistic-Cauchy	CNI	Jeffreys
P(G|1E-6*sqrt(10))	0.71	0.49	0.26	0.71	0.24
P(W|1E-6*sqrt(10))	0.29	0.50	0.69	0.29	0.52
P(Y|1E-6*sqrt(10))	0.0004	0.01	0.05	0	0.24
P(R|1E-6*sqrt(10))	0	0	0	0	0

Table 5 Elevated FOTP failure probability

Case 4: FOTP FTS at 1E-6 * sqrt(10). All others at Baseline					
	Mixture	Logistic-Normal	Logistic-Cauchy	CNI	Jeffreys
P(G|1E-6*sqrt(10))	0.62	0.47	0.26	0.75	0.24
P(W|1E-6*sqrt(10))	0.38	0.52	0.65	0.25	0.52
P(Y|1E-6*sqrt(10))	0	0.01	0.09	0	0.24
P(R|1E-6*sqrt(10))	0	0	0	0	0

Case 4: FOTP FTS at 1E-6 * sqrt(10). All others at Baseline					
	Mixture	Logistic-Normal	Logistic-Cauchy	CNI	Jeffreys
P(G|1E-6*sqrt(10))	0.59	0.29	0.26	0.48	0.24
P(W|1E-6*sqrt(10))	0.41	0.67	0.695	0.52	0.6
P(Y|1E-6*sqrt(10))	0.002	0.04	0.04	0.0003	0.16
P(R|1E-6*sqrt(10))	0	0	0	0	0

Table 6 All parameters elevated above baseline

Case 5: All Components of Train at factor F * Baseline					
	Mixture	Logistic-Normal	Logistic-Cauchy	CNI	Jeffreys
P(G|BL*f)	0.62	0.36	0.25	0.67	0.19
P(W|BL*f)	0.38	0.63	0.66	0.33	0.54
P(Y|BL*f)	0	0.008	0.09	0	0.27
P(R|BL*f)	0	0	0	0	0

Case 5: All Components of Train at factor F * Baseline					
	Mixture	Logistic-Normal	Logistic-Cauchy	CNI	Jeffreys
P(G|BL*f)	0.56	0.33	0.25	0.46	0.19
P(W|BL*f)	0.43	0.64	0.71	0.54	0.62
P(Y|BL*f)	0.001	0.03	0.03	0.0002	0.18
P(R|BL*f)	0	0	0	0	0

Table 7 Results of sensitivity cases, base case (CNI prior + log(istic)-Cauchy for paradigm 2)

Paradigm 1, FOTP Lumped into EDG FTR

Case 0: All Components of Train at Baseline				
	Base	1 FOTP demand/hr Birnbaum = 5E-5/yr	1 FOTP demand/4 hr Birnbaum = 5E-5/yr	1 FOTP demand/ 8 hr Birnbaum = 5E-5/yr
P(G|G)	0.95	0.98	0.99	0.995
P(W|G)	0.05	0.02	0.01	0.005
P(Y|G)	0	0	0	0
P(R|G)	0	0	0	0

Paradigm 2, Separate FOTP

Case 0: All Components of Train at Baseline				
	Base	1 FOTP demand/hr Birnbaum = 4E-5/yr	1 FOTP demand/4 hr Birnbaum = 1E-5/yr	1 FOTP demand/ 8 hr Birnbaum = 5E-6/yr
P(G|G)	0.81	0.95 (0.73)	0.997 (0.89)	0.997 (0.89)
P(W|G)	0.19	0.05 (0.27)	0.003(0.11)	0.003(0.11)
P(Y|G)	0	0 (0)	0 (0)	0 (0)
P(R|G)	0	0 (0)	0 (0)	0 (0)

Table 8 Results of sensitivity cases, elevated EDG FTS (CNI prior + log(istic)-Cauchy for paradigm 2)

Paradigm 1, FOTP Lumped into EDG FTR

Case 1: EDG FTS at 1E-6 * sqrt(10). All others at Baseline				
	Base	1 FOTP demand/hr Birnbaum = 5E-5/yr	1 FOTP demand/4 hr Birnbaum = 5E-5/yr	1 FOTP demand/ 8 hr Birnbaum = 5E-5/yr
P(G|1E-6*sqrt(10))	0.22	0.25	0.27	0.28
P(W|1E-6*sqrt(10))	0.78	0.75	0.73	0.72
P(Y|1E-6*sqrt(10))	0	0	0	0
P(R|1E-6*sqrt(10))	0	0	0	0

Paradigm 2, Separate FOTP

Case 1: EDG FTS at 1E-6 * sqrt(10). All others at Baseline				
	Base	1 FOTP demand/hr Birnbaum = 4E-5/yr	1 FOTP demand/4 hr Birnbaum = 1E-5/yr	1 FOTP demand/ 8 hr Birnbaum = 5E-6/yr
P(G|1E-6*sqrt(10))	0.51	0.35 (0.09)	0.28 (0.11)	0.28 (0.11)
P(W|1E-6*sqrt(10))	0.49	0.65 (0.91)	0.72 (0.89)	0.72 (0.89)
P(Y|1E-6*sqrt(10))	0	0 (0)	0 (0)	0 (0)
P(R|1E-6*sqrt(10))	0	0 (0)	0 (0)	0 (0)

Table 9 Results of sensitivity cases, elevated EDG FTL (CNI prior + log(istic)-Cauchy for paradigm 2)

Paradigm 1, FOTP Lumped into EDG FTR

Case 2: EDG FTL at 1E-6 * sqrt(10). All others at Baseline				
	Base	1 FOTP demand/hr Birnbaum = 5E-5/yr	1 FOTP demand/4 hr Birnbaum = 5E-5/yr	1 FOTP demand/ 8 hr Birnbaum = 5E-5/yr
P(G|1E-6*sqrt(10))	0.46	0.52	0.57	0.58
P(W|1E-6*sqrt(10))	0.54	0.48	0.43	0.42
P(Y|1E-6*sqrt(10))	0	0	0	0
P(R|1E-6*sqrt(10))	0	0	0	0

Paradigm 2, Separate FOTP

Case 2: EDG FTL at 1E-6 * sqrt(10). All others at Baseline				
	Base	1 FOTP demand/hr Birnbaum = 4E-5/yr	1 FOTP demand/4 hr Birnbaum = 1E-5/yr	1 FOTP demand/ 8 hr Birnbaum = 5E-6/yr
P(G|1E-6*sqrt(10))	0.62	0.58 (0.04)	0.59 (0.05)	0.59 (0.05)
P(W|1E-6*sqrt(10))	0.38	0.42 (0.96)	0.41 (0.95)	0.41 (0.95)
P(Y|1E-6*sqrt(10))	0	0 (0)	0 (0)	0 (0)
P(R|1E-6*sqrt(10))	0	0 (0)	0 (0)	0 (0)

Table 10 Results of sensitivity cases, elevated EDG FTR (CNI prior + log(istic)-Cauchy for paradigm 2)

Paradigm 1, FOTP Lumped into EDG FTR

Case 3: EDG FTR at 1E-6 * sqrt(10). All others at Baseline				
	Base	1 FOTP demand/hr Birnbaum = 5E-5/yr	1 FOTP demand/4 hr Birnbaum = 5E-5/yr	1 FOTP demand/ 8 hr Birnbaum = 5E-5/yr
P(G|1E-6*sqrt(10))	0.75	0.80	0.84	0.85
P(W|1E-6*sqrt(10))	0.25	0.20	0.16	0.15
P(Y|1E-6*sqrt(10))	0	0	0	0
P(R|1E-6*sqrt(10))	0	0	0	0

Paradigm 2, Separate FOTP

Case 3: EDG FTR at 1E-6 * sqrt(10). All others at Baseline				
	Base	1 FOTP demand/hr Birnbaum = 4E-5/yr	1 FOTP demand/4 hr Birnbaum = 1E-5/yr	1 FOTP demand/ 8 hr Birnbaum = 5E-6/yr
P(G|1E-6*sqrt(10))	0.71	0.78 (0.32)	0.86 (0.39)	0.86 (0.39)
P(W|1E-6*sqrt(10))	0.29	0.22 (0.64)	0.14 (0.59)	0.14 (0.59)
P(Y|1E-6*sqrt(10))	0	0 (0.04)	0 (0.03)	0 (0.03)
P(R|1E-6*sqrt(10))	0	0 (0)	0 (0)	0 (0)

Table 11 Results of sensitivity cases, elevated FOTP FTS (CNI prior + log(istic)-Cauchy for paradigm 2)

Paradigm 1, FOTP Lumped into EDG FTR

Case 4: FOTP FTS at 1E-6 * sqrt(10). All others at Baseline				
	Base	1 FOTP demand/hr Birnbaum = 5E-5/yr	1 FOTP demand/4 hr Birnbaum = 5E-5/yr	1 FOTP demand/ 8 hr Birnbaum = 5E-5/yr
P(G|1E-6*sqrt(10))	0.75	0.81	0.85	0.85
P(W|1E-6*sqrt(10))	0.25	0.19	0.15	0.15
P(Y|1E-6*sqrt(10))	0	0	0	0
P(R|1E-6*sqrt(10))	0	0	0	0

Paradigm 2, Separate FOTP

Case 4: FOTP FTS at 1E-6 * sqrt(10). All others at Baseline				
	Base	1 FOTP demand/hr Birnbaum = 4E-5/yr	1 FOTP demand/4 hr Birnbaum = 1E-5/yr	1 FOTP demand/ 8 hr Birnbaum = 5E-6/yr
P(G|1E-6*sqrt(10))	0.48	0.59 (0.26)	0.98 (0.05)	0.99 (0)
P(W|1E-6*sqrt(10))	0.52	0.41 (0.71)	0.2 (0.95)	0.01 (1.0)
P(Y|1E-6*sqrt(10))	0.0003	0 (0.04)	0 (0)	0 (0)
P(R|1E-6*sqrt(10))	0	0 (0)	0 (0)	0 (0)

Table 12 Results of sensitivity cases, all parameters elevated (CNI prior + log(istic)-Cauchy for paradigm 2)

Paradigm 1, FOTP Lumped into EDG FTR

Case 5: All Components of Train at factor F * Baseline				
	Base	1 FOTP demand/hr Birnbaum = 5E-5/yr	1 FOTP demand/4 hr Birnbaum = 5E-5/yr	1 FOTP demand/ 8 hr Birnbaum = 5E-5/yr
P(G|BL*f)	0.67	0.70	0.68	0.67
P(W|BL*f)	0.33	0.30	0.32	0.33
P(Y|BL*f)	0	0	0	0
P(R|BL*f)	0	0	0	0

Paradigm 2, Separate FOTP

Case 5: All Components of Train at factor F * Baseline				
	Base	1 FOTP demand/hr Birnbaum = 4E-5/yr	1 FOTP demand/4 hr Birnbaum = 1E-5/yr	1 FOTP demand/ 8 hr Birnbaum = 5E-6/yr
P(G|BL*f)	0.46	0.59 (0.26)	0.68 (0.29)	0.65 (0.24)
P(W|BL*f)	0.54	0.41 (0.73)	0.32 (0.70)	0.35 (0.75)
P(Y|BL*f)	0.0002	0 (0.01)	0 (0.01)	0 (0.01)
P(R|BL*f)	0	0 (0)	0 (0)	0 (0)