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Flexible Burn-In Sampling Plans

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Contents

- Burn-in (BI) Concepts
- BI Model approach
- BI Sampling Plans

BI Concepts

- Two major tools in QM
  - 100 % control
  - Sampling
- At BI
  - 100 % BI
    - Typically, BI time reductions
  - BI studies
    - Random sample to BI
    - As long as the random sample is not fully assessed → 100 % BI of the rest of the population
    - Once BI study is pass → BI monitoring

BI Model Approach

- Limited failure population lifetime model

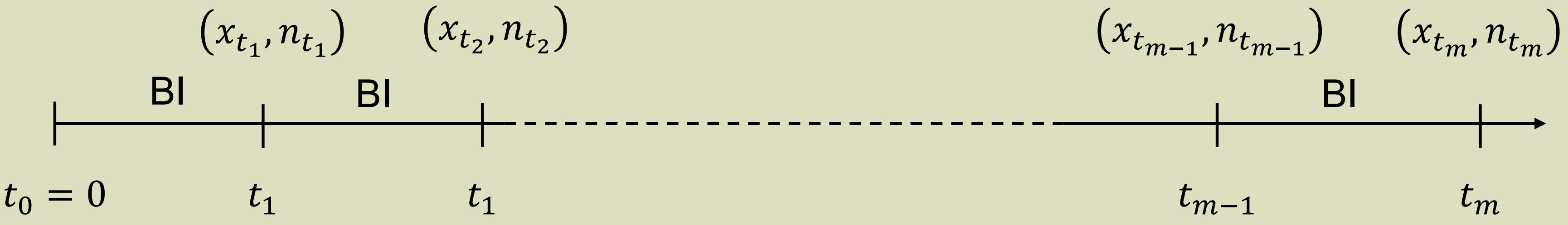
$$\pi_{(t,\infty)} = P\left(T_{ef} > t\right) \cdot \pi$$

with

- π: probability of failures in the overall population
- $P\left(T_{ef} > t\right)$ = 1- $P\left(T_{ef} < t\right)$: probability of early failures after time t
  - → knowledge about lifetime distribution of early failures is needed.
  - E.g., $T_{ef} \sim Weibull(3{,}0.5)$ (ReliaSoft).

Data Structure

- Interval censored data:



  - $\boldsymbol{n_t} = (n_{t_1}, \ldots, n_{t_m})$: vector of stressed devices at each BI time interval (t_{j-1}, t_j], $j=1,\ldots, m$;
  - $\boldsymbol{x_t} = (x_{t_1}, \ldots, x_{t_m})$: vector of BI failures at each BI time interval (t_{j-1}, t_j], $j=1,\ldots, m$;
  - $\boldsymbol{S}(\boldsymbol{x_t}, \boldsymbol{n_t})$: data from a BI study.

Estimation of Early Failure Probability

1. Calculate the likelihood function of π based on the data set $\mathcal{S} = \mathcal{S}(x_t, n_t)$.
2. Assign a prior distribution to π ensuring compliance with the Clopper-Pearson estimator.
3. Determine the posterior distribution of $\hat{\pi}$ and calculate its $(1 - \alpha)$-quantile.

Likelihood Function

1. Calculate the likelihood function of π based on the data set $\boldsymbol{\mathcal{S}} = \boldsymbol{\mathcal{S}}(\boldsymbol{x_t}, \boldsymbol{n_t})$.

- $n_{t_{j+1}}$ devices in the interval $(t_j, t_{j+1}]$ are a subset of the n_{t_j} devices in the interval $(t_{j-1}, t_j]$, $j = r+1, \ldots, m-1$.
  - → devices are not stochastically independent.
  - → Likelihood function as product of conditional probabilities:

$$\mathcal{L}(\pi, \mathcal{S}) = \prod_{j=r+1}^{m} MN\left(\left(x_{t_j}, n_{t_j} - x_{t_j}\right)^T; n_{t_j}; \left(\pi_{(t_{j-1},t_j]}, 1 - \pi_{(t_{j-1},t_j]}\right)^T \middle| x_{t_r}, \ldots, x_{t_{j-1}} = 0\right).$$

Likelihood Function

2. Assign a prior distribution to π ensuring compliance with the Clopper-Pearson estimator.

   – We set $\pi_{(t_r,t_m]} \sim Be(1,0)$,

$$f\left(\pi_{(t_r,t_m]}\right) \propto \frac{1}{1-\pi_{(t_r,t_m]}}.$$

   – Needed: prior distribution function for π:

$$\pi_{(t_r,t_m]} = P\left(t_r < T_{ef} \leq t_r\right) \cdot \pi.$$

   – Utilizing the change of variable theorem

$$f(\pi) \propto \frac{P\left(t_r < T_{ef} \leq t_r\right)}{1-P\left(t_r < T_{ef} \leq t_r\right) \cdot \pi}.$$

Posterior Distribution

3. Determine the posterior distribution of $\hat{\pi}$ and calculate its $(1-\alpha)$-quantile.

   – The posterior density $f(\pi|\mathcal{S})$ is calculated via Bayes' rule.

   – Devices in the interval $(t_j, t_{j+1}]$ are a subset of the n_{t_j} devices in the interval $(t_{j-1}, t_j]$, $j = r+1, \dots, m-1$.

     - → devices are not stochastically independent.
     - → Likelihood function as product of conditional probabilities:

$$f(\pi|\mathcal{S}) = \frac{\mathcal{L}(\pi;\mathcal{S}) \cdot f(\pi)}{\int_0^1 \mathcal{L}(\pi;\mathcal{S}) \cdot f(\pi) \cdot \pi}.$$

BI Sampling Plans

- $\boldsymbol{n}_{\boldsymbol{t}}^{(t_i)} = \left(n_{t_1}^{(t_i)}, \dots, n_{t_m}^{(t_i)}\right)$: vector of required numbers of passed devices after each readout time t_j in order to reduce the BI time from t_i to t_{i-1}.
- $\boldsymbol{x}_{\boldsymbol{t}}^{(t_i)} = \left(x_{t_1}^{(t_i)}, \dots, x_{t_m}^{(t_i)}\right)$: vector of possible failures in each interval $(t_{j-1}, t_j]$ before the BI time is reduced from t_i to t_{i-1}.
- $n_{t_1}^{b}$: planned number of devices that are put to BI for a batch with BI time t_i.

- Find vectors, such that

$$\left\{\hat{\pi}_{(t_{i-1},\infty)}\left(\mathcal{S}\left(\mathbf{0}_{\boldsymbol{t}}, \boldsymbol{n}_{\boldsymbol{t}}^{(t_i)}\right)\right) \leq \pi_{target}\right\} \text{ AND } \left\{P\left(\hat{\pi}_{(t_{i-1},\infty)} > \pi_{target}; \mathcal{S}\left(\mathbf{0}_{\boldsymbol{t}}, \boldsymbol{n}_{\boldsymbol{t}}^{(t_i)}\right)\right) \leq \gamma\right\}$$

Delaying Factor

- Probability to increase the BI time after a BI time reduction

$$P\left(\hat{\pi}_{(t_{i-1,\infty})} > \pi_{target}; \mathcal{S}\left(\mathbf{0}_t, \boldsymbol{n}_t^{(t_i)}\right)\right)$$
$$= \sum_{j=1}^{i-1} P\left\{\hat{\pi}_{(t_{i-1,\infty})} > \pi_{target}; \mathcal{S}\left(\mathbf{0}_t, \boldsymbol{n}_t^{(t_{j+1})}\right)\right\} \cdot P\left(\mathcal{S}\left(\mathbf{0}_t, \boldsymbol{n}_t^{(t_{j+1})}\right)\right)$$

with

$$P\left\{\hat{\pi}_{(t_{i-1,\infty})} > \pi_{target}; \mathcal{S}\left(\mathbf{0}_t, \boldsymbol{n}_t^{(t_{j+1})}\right)\right\}$$
$$= \sum_{\boldsymbol{x}_t^{(t_j)}} I\left\{\hat{\pi}_{(t_{i-1,\infty})}\left(\mathcal{S}\left(\boldsymbol{x}_t^{(t_j)}, \boldsymbol{n}_t^{(t_j)}\right)\right) > \pi_{target}\right\} \cdot P\left(\boldsymbol{X}_t^{(t_j)} = \boldsymbol{x}_t^{(t_j)}; \mathcal{S}\left(\mathbf{0}_t, \boldsymbol{n}_t^{(t_{j+1})}\right)\right)$$

BI Time Reduction Strategies

Reduction Strategy	BI time	$(0, t_1]$	$(t_1, t_2]$	$(t_2, t_3]$
R_1	t_3	i	i	i
	t_2	ii	ii	
	t_1	iii		
R_2	t_3	ii	i	i
	t_2	ii	ii	
	t_1	iii		
R_3	t_3	iii	i	i
	t_2	iii	ii	
	t_1	iii		
R_4	t_3	iii	ii	i
	t_2	iii	ii	
	t_1	iii		

BI Time Reduction Strategy - Example

- Reduction Strategy R_1
  - Acceptance criterion: 0 failures.
  - Reduction to t_2: the intervals $(t_0, t_1]$, $(t_1, t_2]$, and $(t_2, t_3]$ are analyzed.
  - Reduction to t_1: the intervals $(t_0, t_1]$ and $(t_1, t_2]$ are analyzed.
  - $$\left(\boldsymbol{x}_{\boldsymbol{t}}^{(t_j)}, \boldsymbol{n}_{\boldsymbol{t}}^{(t_j)}\right) = \begin{cases} \left(\left(x_{t_1}^{(t_3)}, x_{t_2}^{(t_3)}, x_{t_3}^{(t_3)}\right), \left(n_{t_3}^b, n_{t_3}^b, n_{t_3}^b\right)\right) & i = 3 \\ \left(\left(x_{t_1}^{(t_2)}, x_{t_2}^{(t_2)}, 0\right), \left(n_{t_2}^b + n_{t_3}^b, n_{t_2}^b + n_{t_3}^b, n_{t_3}^b\right)\right) & i = 2 \\ \left(\left(x_{t_1}^{(t_1)}, 0, 0\right), \left(n_{t_1}^b + n_{t_2}^b + n_{t_3}^b, n_{t_2}^b + n_{t_3}^b, n_{t_3}^b\right)\right) & i = 1 \end{cases}$$

BI Time Reduction Strategy - Example

- Reduction Strategy R_1 (cont.)

$$P\left(\boldsymbol{x}_{\boldsymbol{t}}^{(t_j)}, \boldsymbol{n}_{\boldsymbol{t}}^{(t_j)}\right)$$

$$= \begin{cases} NMN\left(\left(x_{t_1}^{(t_3)}, x_{t_2}^{(t_3)}, x_{t_3}^{(t_3)}, n_{t_3}^{b} - \sum_{j=1}^{3} x_{t_j}^{(t_3)}\right)^{\mathsf{T}}, n_{t_3}^{b}, \left(\hat{\pi}_{(0,t_1]}, \hat{\pi}_{(t_1,t_2]}, \hat{\pi}_{(t_2,t_3]}, 1 - \hat{\pi}_{(0,t_3]}\right)^{\mathsf{T}}\right) & i = 3 \\ NMN\left(\left(x_{t_1}^{(t_2)}, x_{t_2}^{(t_2)}, n_{t_2}^{b} + n_{t_3}^{b} - \sum_{j=1}^{2} x_{t_j}^{(t_2)}\right)^{\mathsf{T}}, n_{t_2}^{b} + n_{t_3}^{b}, \left(\hat{\pi}_{(0,t_1]}, \hat{\pi}_{(t_1,t_2]}, 1 - \hat{\pi}_{(0,t_2]}\right)^{\mathsf{T}}\right) & i = 2 \\ NB\left(x_{t_1}^{(t_1)}, n_{t_1}^{b} + n_{t_2}^{b} + n_{t_3}^{b}, \hat{\pi}_{(0,t_1]}\right) & i = 1 \end{cases}$$

Case Study

- Initial Sampling Plan
  - Readout times:
    - t_1 = 7 h,
    - t_2 = 19 h,
    - t_3 = 48 h.
  - Quality target:
    - 25 ppm @ 90 % CL.
  - Delaying factor:
    - 10 %.

Reduction Strategy	BI time	(0, 7 h]	(7 h, 19 h]	(19 h, 48 h]
R_1	48 h	0/13 k	0/13 k	0/13 k
	19 h	0/36.4 k	0/36.4 k	
	7 h	0/110.3 k		
R_2	48 h	x/62.4 k	0/62.4 k	0/62.4 k
	19 h	0/62.4 k	0/62.4 k	
	7 h	0/101.8 k		
R_3	48 h	x/69.3 k	0/69.3 k	0/69.3 k
	19 h	x/207.4 k	0/207.4 k	
	7 h	0/207.4 k		
R_4	48 h	x/211.2 k	x/211.2 k	0/211.2 k
	19 h	x/211.2 k	0/211.2 k	
	7 h	0/211.2 k		

Case Study

- Deviations at the 1st readout

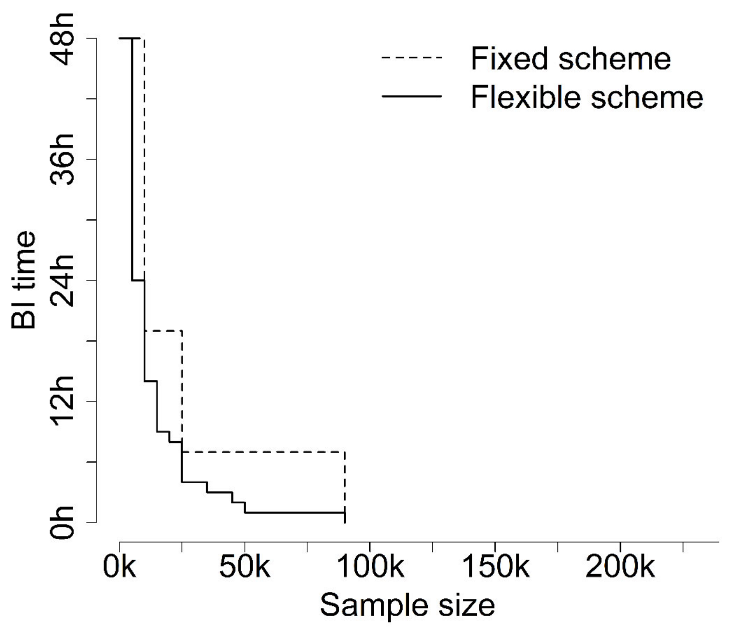
Reduction Strategy	BI time	(0, 7 h]	(7 h, 19 h]	(19 h, 48 h]
R_1	48 h	1-3/14 k	0/13.5 k	0/13 k

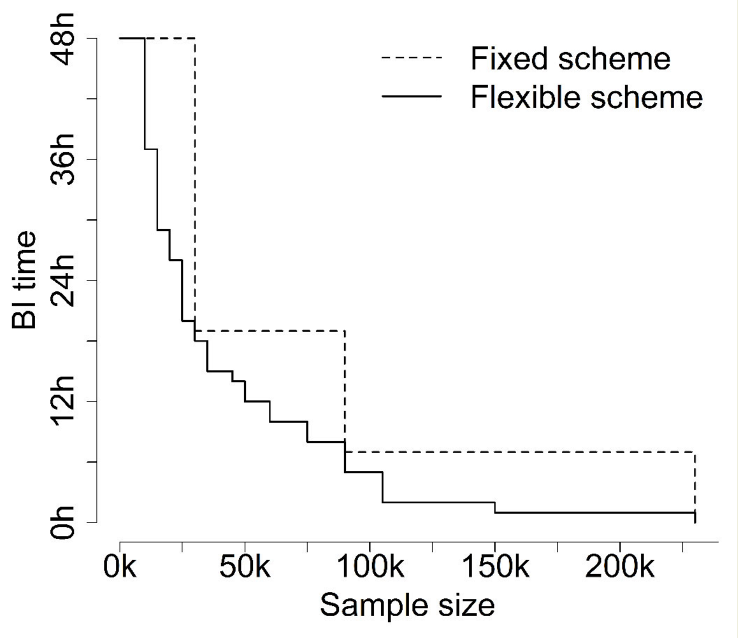
- Update of the sampling plan:

$$\left(\boldsymbol{t}, \boldsymbol{n}_{\boldsymbol{t}}^{(t_j)}\right) = \begin{cases} \big((7\,h, 19\,h, 26\,h), (110.8\,k, 36.9\,k, 13.5\,k)\big) \text{ for } x_{t_1}^{(t_3)} = 1 \\ \big((7\,h, 19\,h, 30\,h), (110.6\,k, 36.7\,k, 13.3\,k)\big) \text{ for } x_{t_1}^{(t_3)} = 2 \\ \big((7\,h, 19\,h, 34\,h), (110.5\,k, 36.6\,k, 13.2\,k)\big) \text{ for } x_{t_1}^{(t_3)} = 3 \end{cases}$$

Case Study

- Follower products
  - Area product A: 0.5 x reference product
  - Area product B: 2.0 x reference product





Reference

- Kurz, D, Lewitschnig, H, Pilz, J. Flexible time reduction method for burn-in of high-quality products. *Qual Reliab Eng Int*. 2021; 37: 2900– 2915.