Evaluation of Life Testing Schemes

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Contents

Background

- We will explore the age-old question: What reliability can we infer from a qualification life test with zero failures? Moreover, we will offer an alternate and more pragmatic way to approach this problem.

- Notional Situation:
  - If we test 4 Units to 2x Lives without failure, can we infer the same reliability as if we tested 1 Unit to 4x Lives?

- Ground rules:
  - The life distribution is Weibull
  - The failure mode of interest is wear-out
  - The reliability requirement is 0.99
  - The Notional Program has high tolerance for risk

Weibull Distribution Overview

$$f(x) = \frac{\beta}{\eta}\left(\frac{x}{\eta}\right)^{\beta-1} e^{-(x/\eta)^{\beta}}$$

$$F(x) \stackrel{\text{def}}{=} \int_0^x f(t)\,dt = 1 - e^{-(x/\eta)^{\beta}}$$

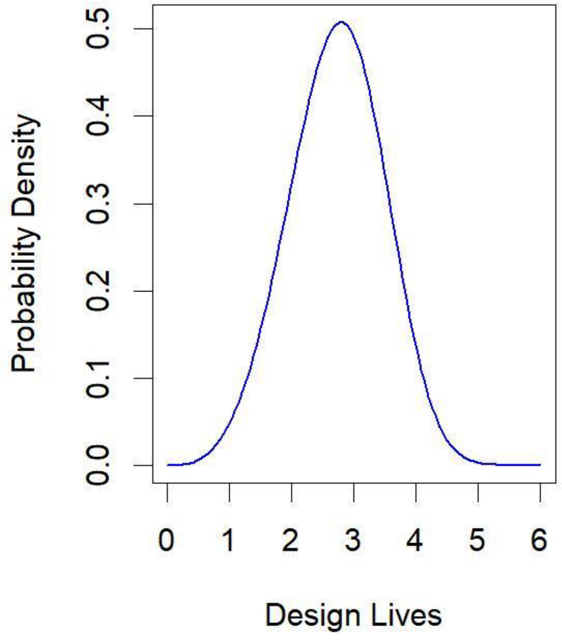
Example Weibull plots for beta = 4, eta = 3

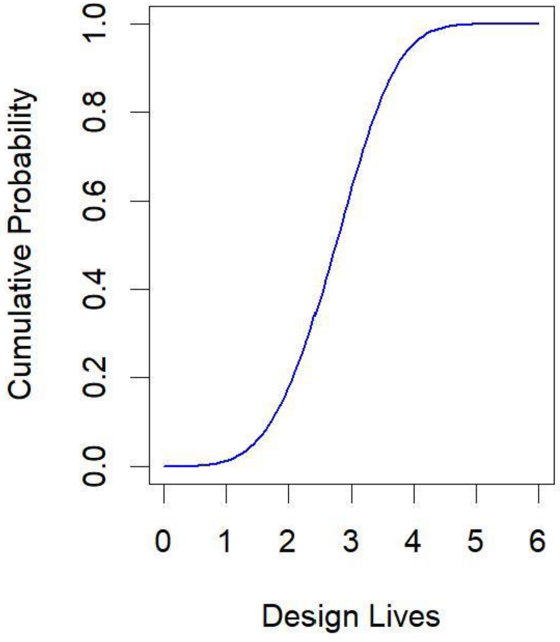
- beta represents the acceleration of failure rate
- eta represents characteristic life independent of beta

Note1: $F(\eta) \cong 0.63\ and\ S(\eta) \cong 0.37$

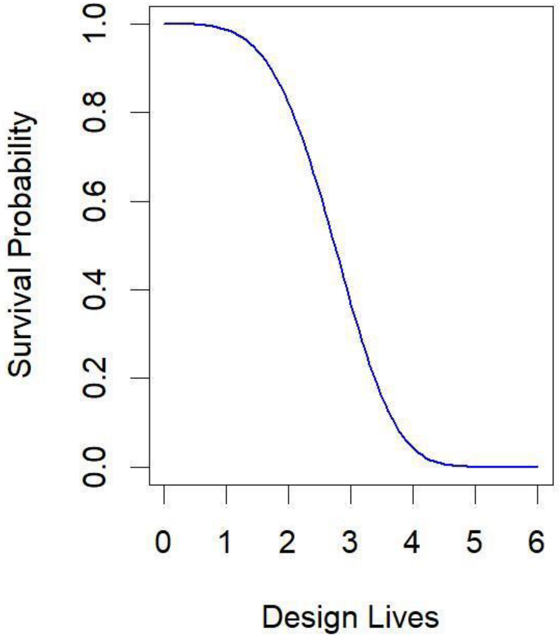
Note2: $For\ \beta > 1,\ h(x)\ increases\ over\ time$

f(x) ← Failure Space → **F(x)**

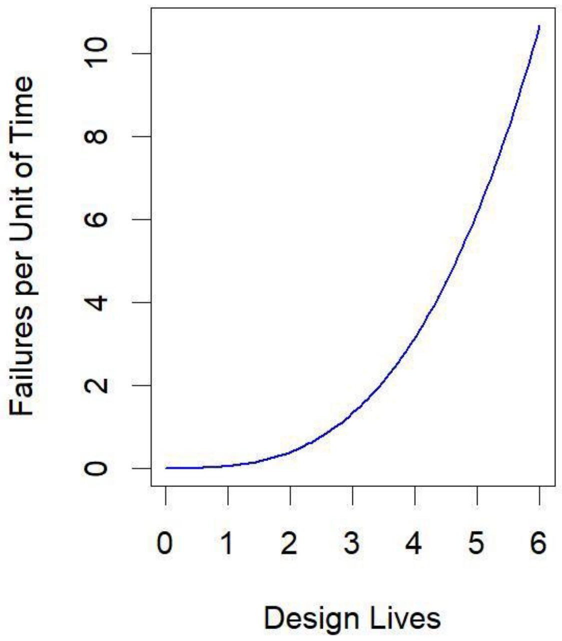




S(x) = 1 - F(x)



h(x) = f(x) / S(x)



Problem Statement

- Given that design life qualification is successful, what reliability can we infer?

- Misconception: Design life qualification tests informs reliability

Default Approach

- This requires finding the optimal Weibull fit using the data from the qualification test
- Mathematically, this optimization problem has unbounded solutions, at best, if not undefined
- However, if we *fix the shape parameter beta*, then a solution for eta can be found; and reliability can be calculated at a given confidence level
- **The issue** with this approach is that it makes a weakly supported yet a very specific defining assumption to obtain a solution

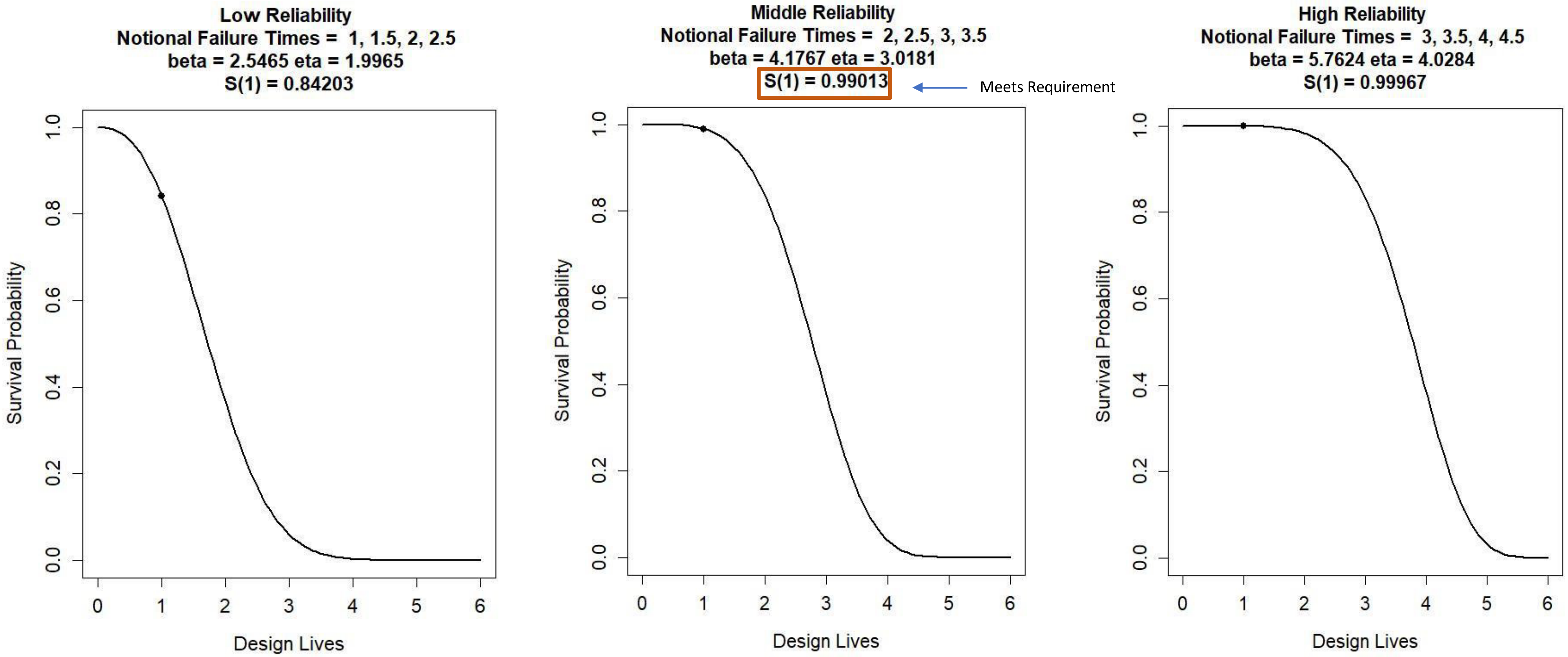
A More Pragmatic and Useful Approach

- Qualification success criteria is pass/fail in nature
  - To minimize false positive and false negative test errors we follow the structured procedure below

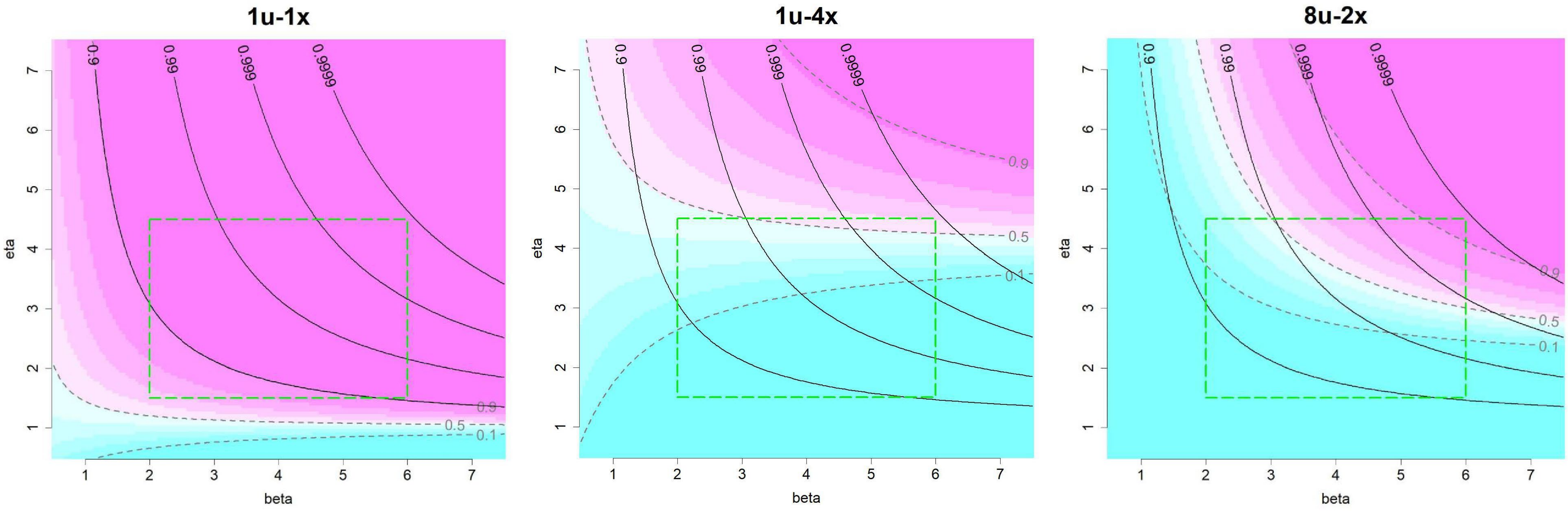
- Use engineering judgment and a bootstrapping strategy to make data driven steps towards useful conclusions
  - Step 0) Solicit Program reliability thresholds and risk posture
  - Step 1) Collect development and failure mode data
  - Step 2) Perform Weibull Analysis on anticipated Qualification test results
  - Step 3) Construct contour overlays based on Weibull Analysis
  - Step 4) Evaluate Qualification Test Effectiveness against objective measures
  - Step 5) Iterate on Qualification success criteria, if needed

Measuring Reliability from Data

- Survival curve fits, based on three sets of hypothetical 4-Unit Qualification Tests using Median Rank Regression
- For these sets, the ranges **beta = [2, 6] and eta = [1.5, 4.5]** establish a **focus region** of anticipated Weibull parameters



Visualization of Qualification Effectiveness



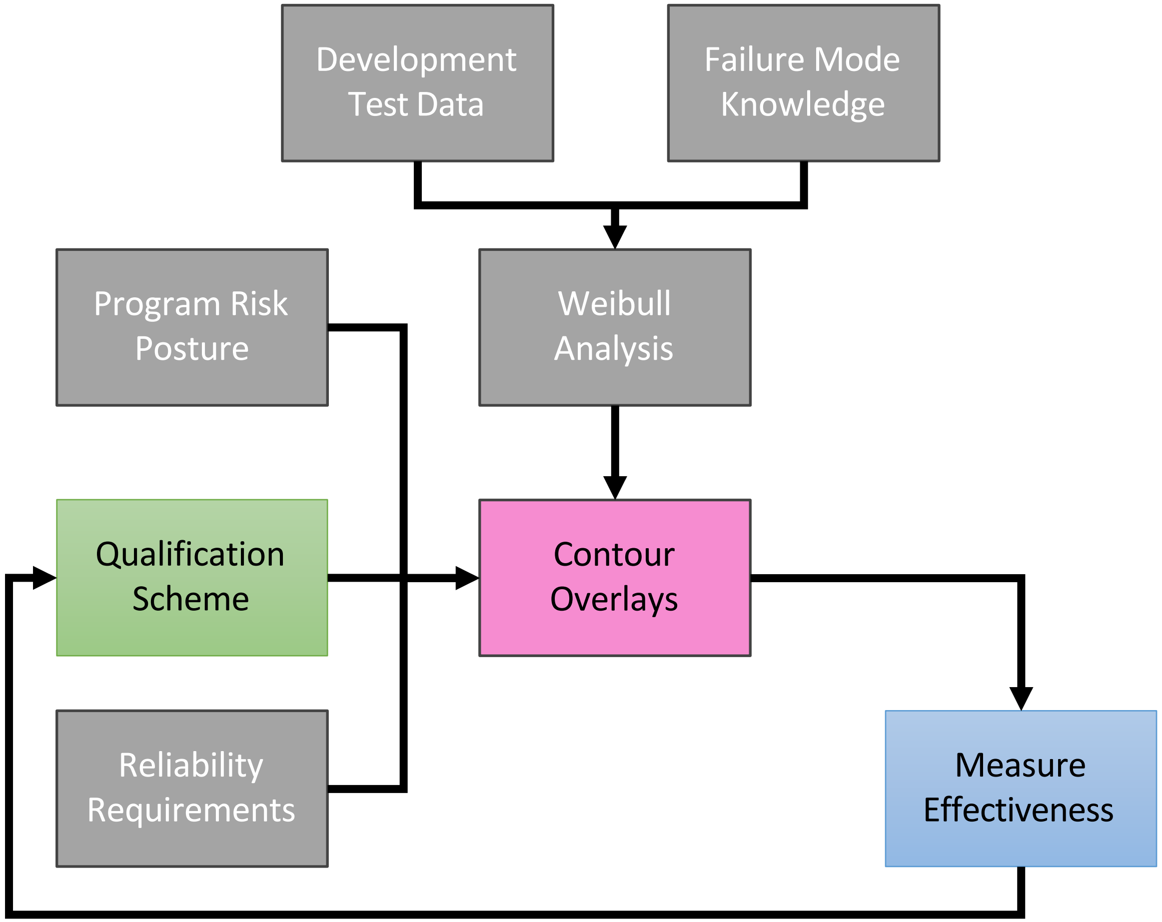
- **1x Mission Reliability (S(1))** overlaid onto **Probability of Successful Qualification (S(x)^n)** reveals the landscape of false positives and false negatives for different qualification test schemes
- The **focus region (beta = [2, 6] and eta = [1.5, 4.5])** , derived from data that is likely to be representative of anticipated designs

Revised Problem Statement

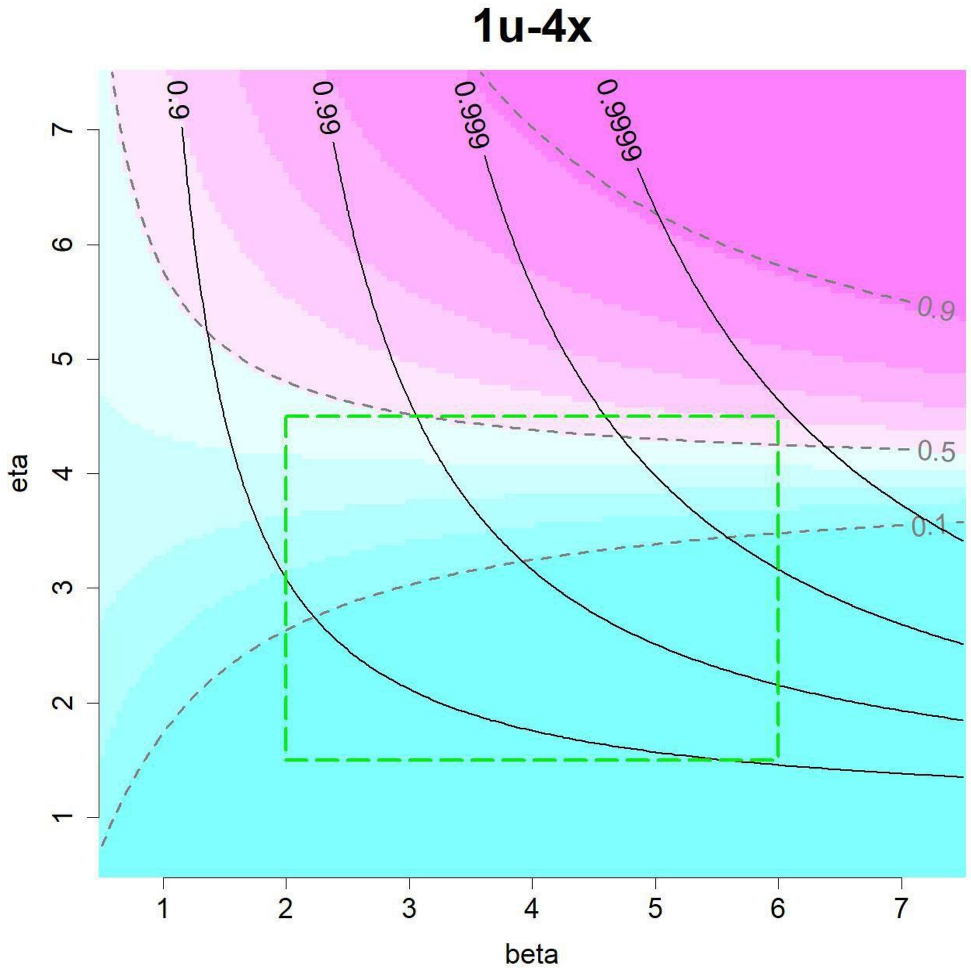
- Optimize Cost, Schedule and ~~Reliability~~ Qualification Test Effectiveness

- **Solution:** Given a reliability threshold and risk posture for false negatives and false positive risk, contour overlays can aid in objectively measure the effectiveness of a qualification test scheme

Summary



Development Test Data
Failure Mode Knowledge
Program Risk Posture
Weibull Analysis
Qualification Scheme
Contour Overlays
Reliability Requirements
Measure Effectiveness

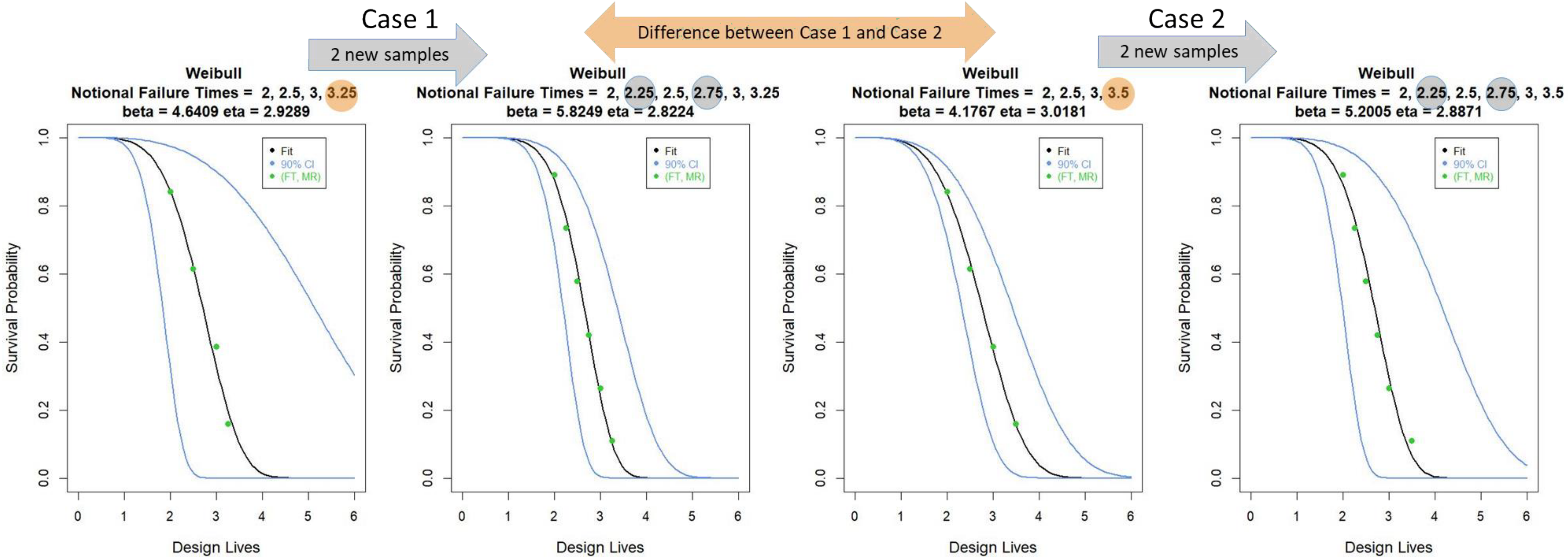


1u-4x
eta
beta
0.9
0.99
0.999
0.9999
0.9
0.5
0.1
1
2
3
4
5
6
7

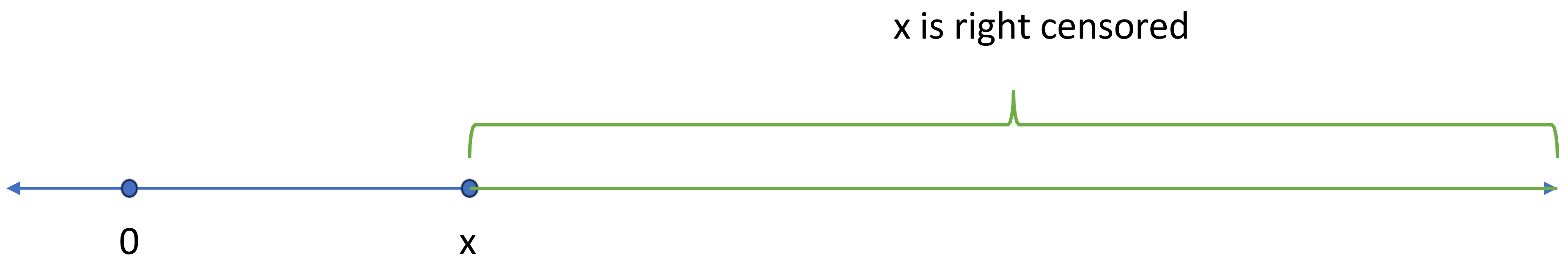
Backup

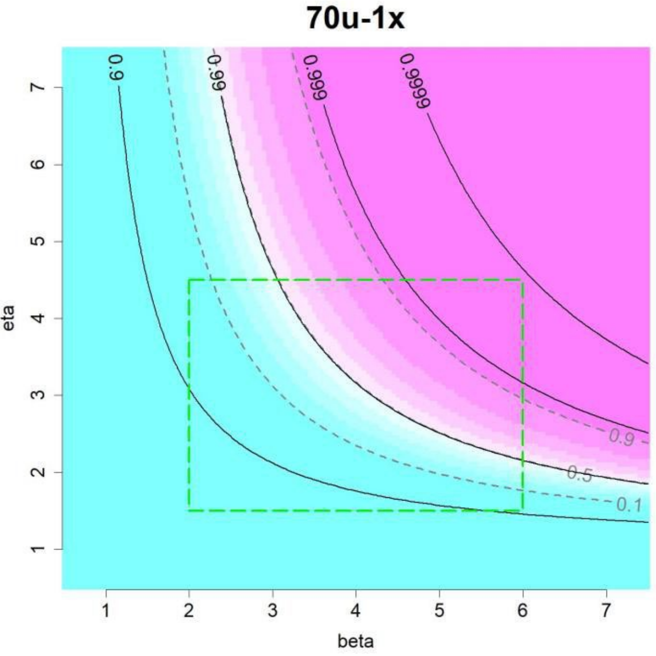
Uncertainty in Reliability Estimation

- Comparison of notional Median Rank Regression **survival curve fits** with **90% confidence intervals** and **(Failure Time, Median Rank) points**
- Estimated uncertainty is sensitive to the sample size, goodness of fit, and variability in sampled values



Censored Data

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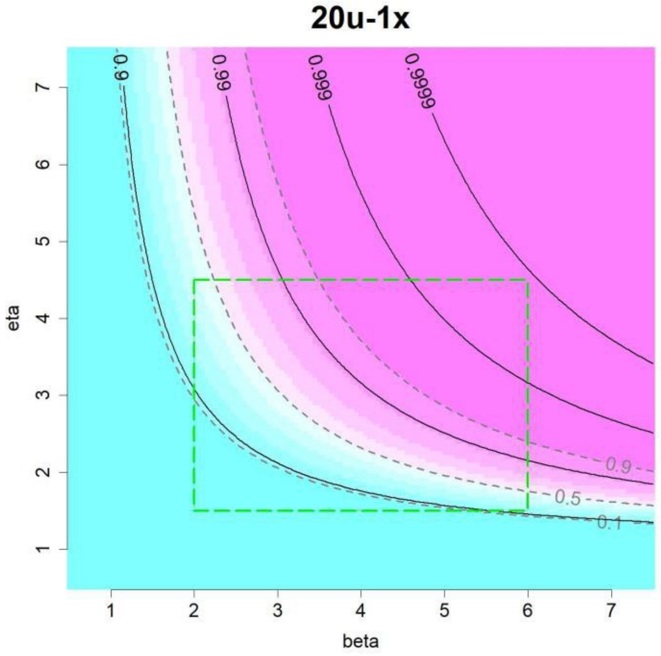
0.999
0.9999
0.9
0.5
0.1
eta
beta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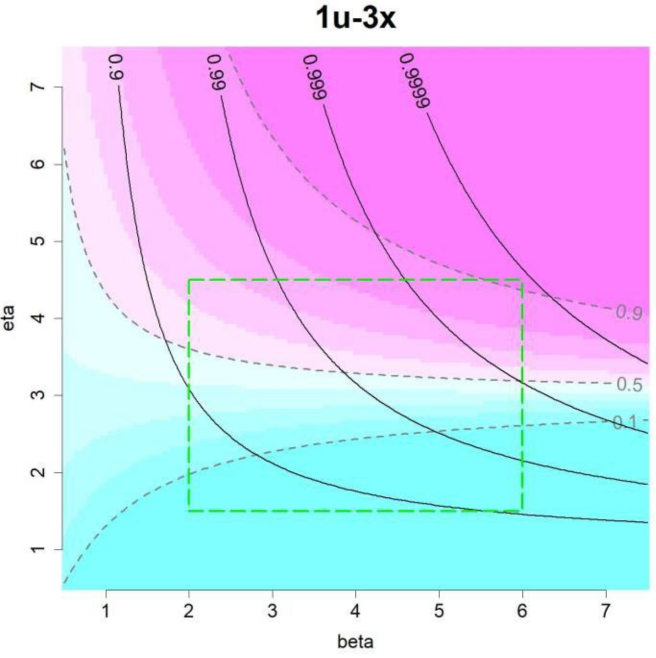
0.5
0.1
eta
beta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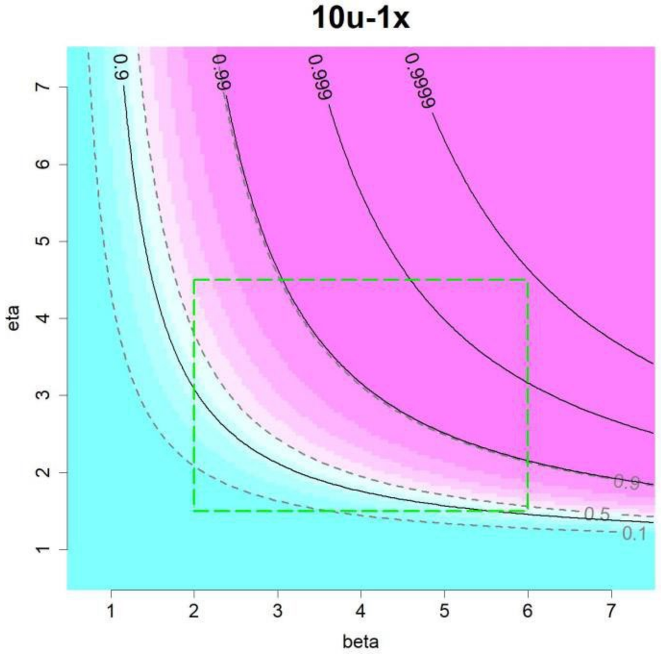
0.9
0.5
0.1
eta
beta


10u-1x
0.9
0.99
0.999
0.9999
0.9
0.5
0.1
eta
beta