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Estimation Of Reliability Parameters For PSA Using Bayesian Analysis

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Overview

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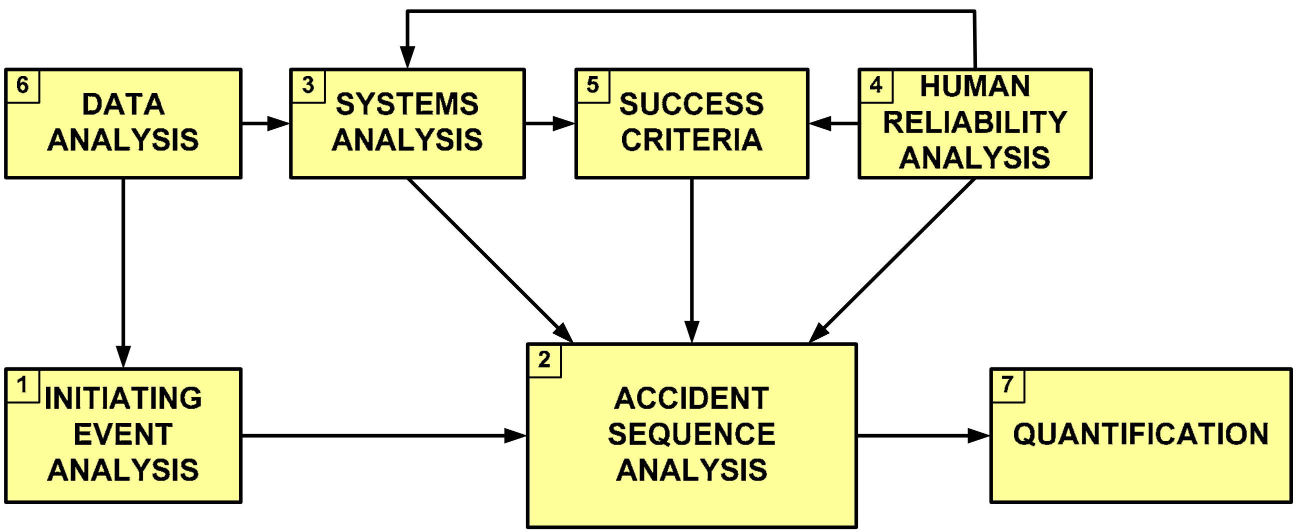
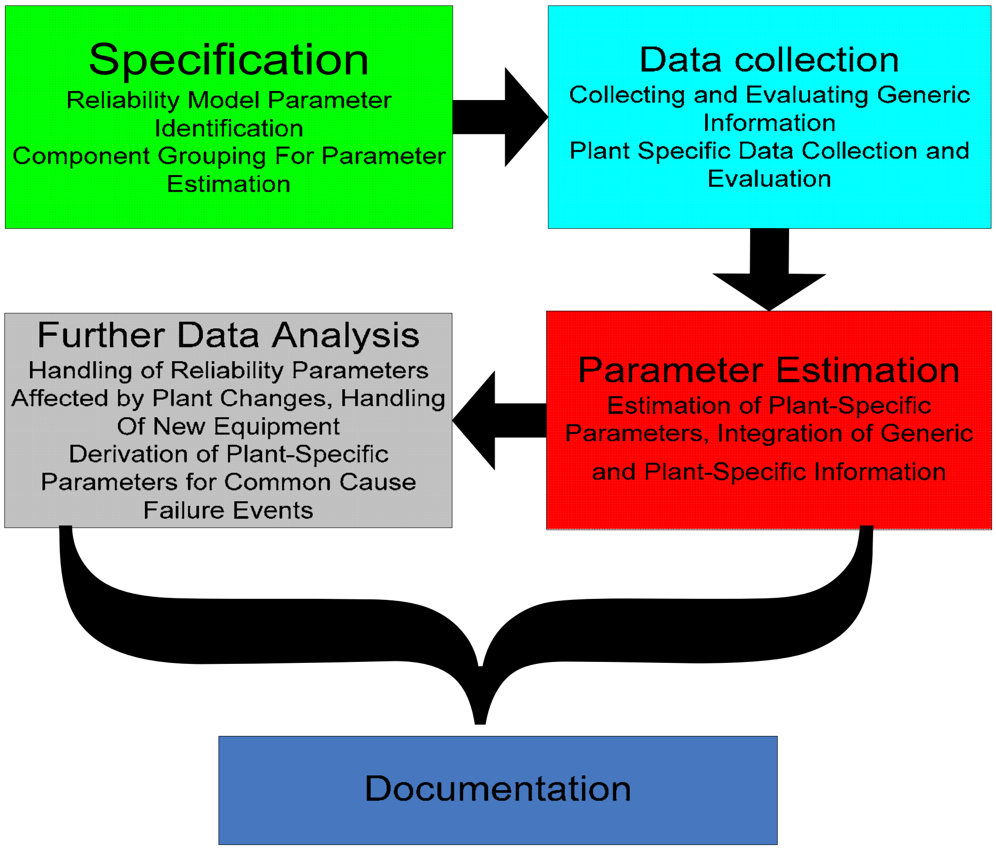
PSA Context	Failure Rate Estimation & Bayesian Analysis	Homogeneous & Non-Homogeneous Analysis	Method Comparison

Probabilistic Safety Analysis In the Nuclear Industry

- **Probabilistic Safety Analysis (PSA) quantifies degrees of risk at nuclear power plants**
- **PSA has several crucial elements**



Parameter Estimation In PSA Data Analysis



- **Parameter estimation is vital in data analysis**
- **Bayesian analysis is now industry standard**

Failure Rates

- **Components have very low failure rates (By design!)**
- **Few failures make precise estimation difficult**
- **Stochastic effects have a large influence on the estimate**
  - **Pump example:**
    - A pump operatres with no failures for 999 hours
    - During the 1000th hour the pump fails
    - The MLE changes dramatically due to a single observed event

Bayesian Analysis

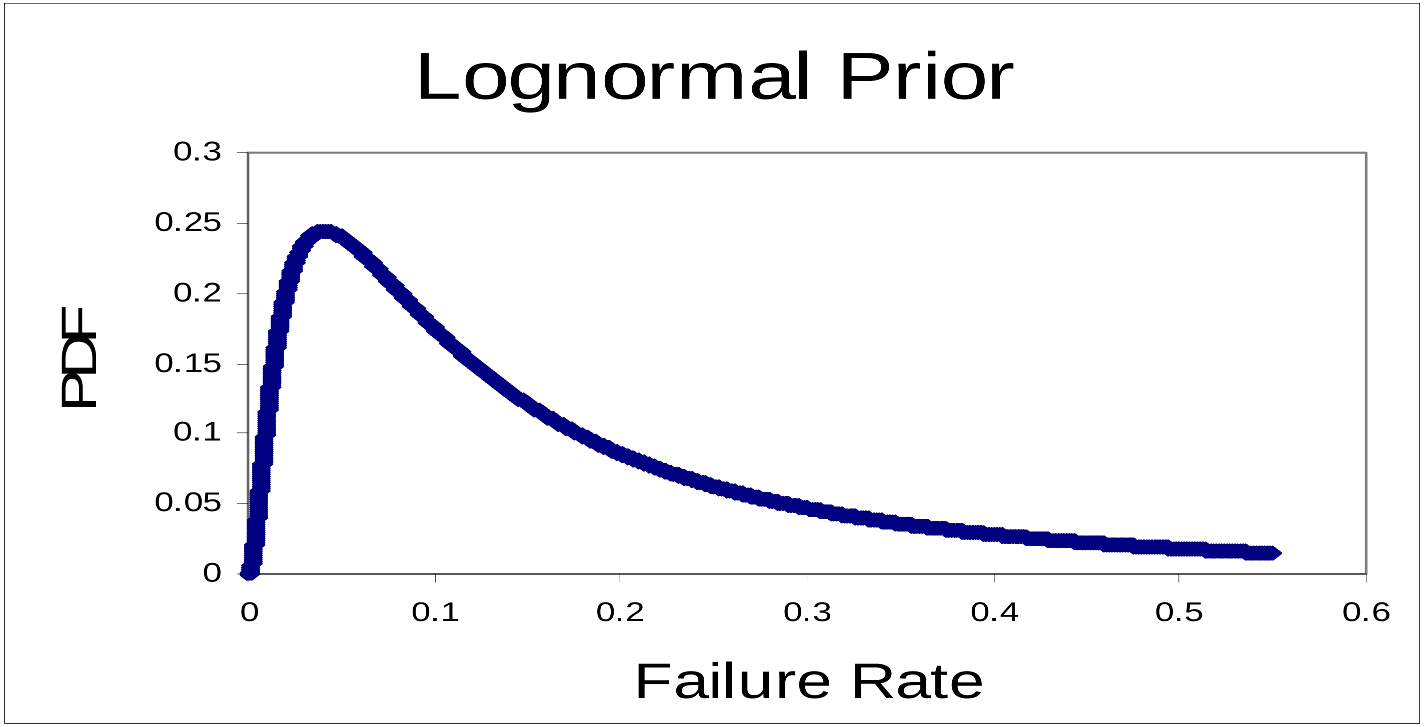
- Parameter values are unknown variables rather than point estimates

- Prior estimates

- Likelihood and observed data

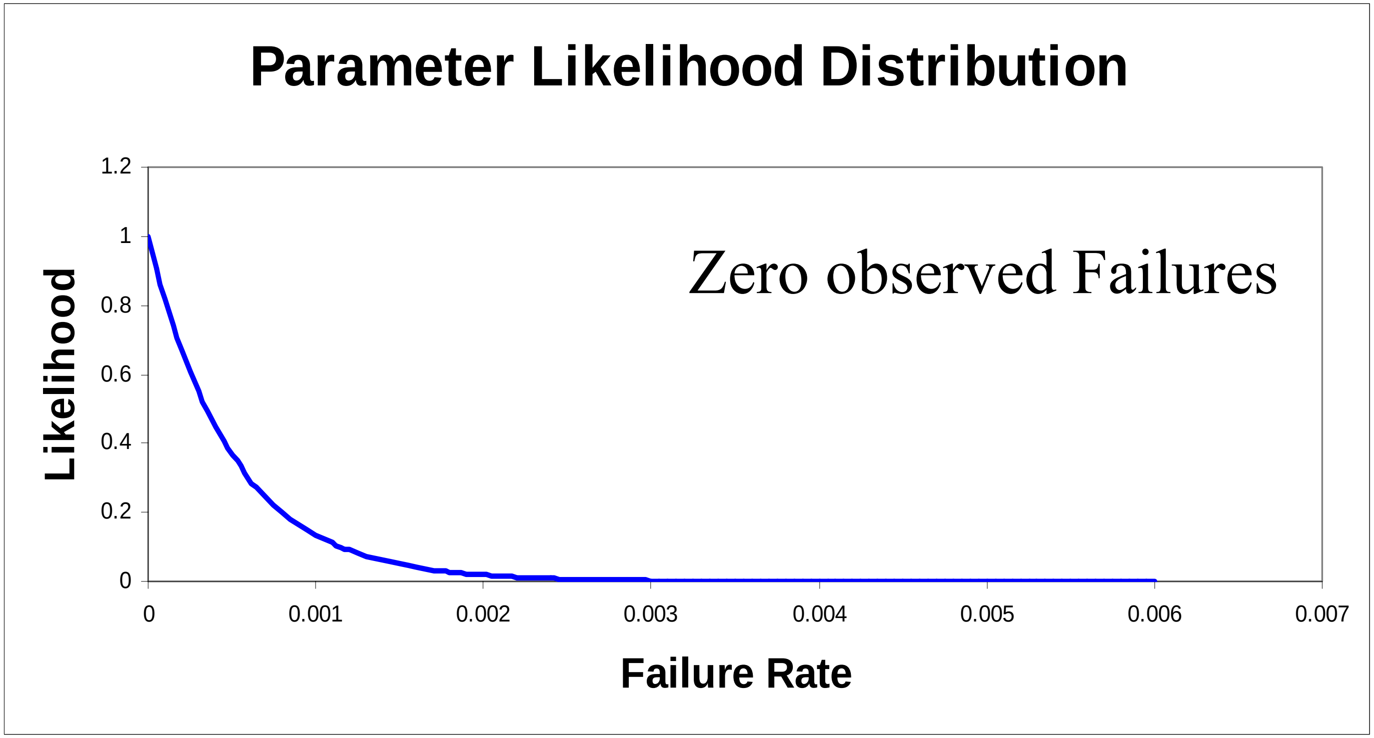
- Posterior Distribution

- **Prior estimate**



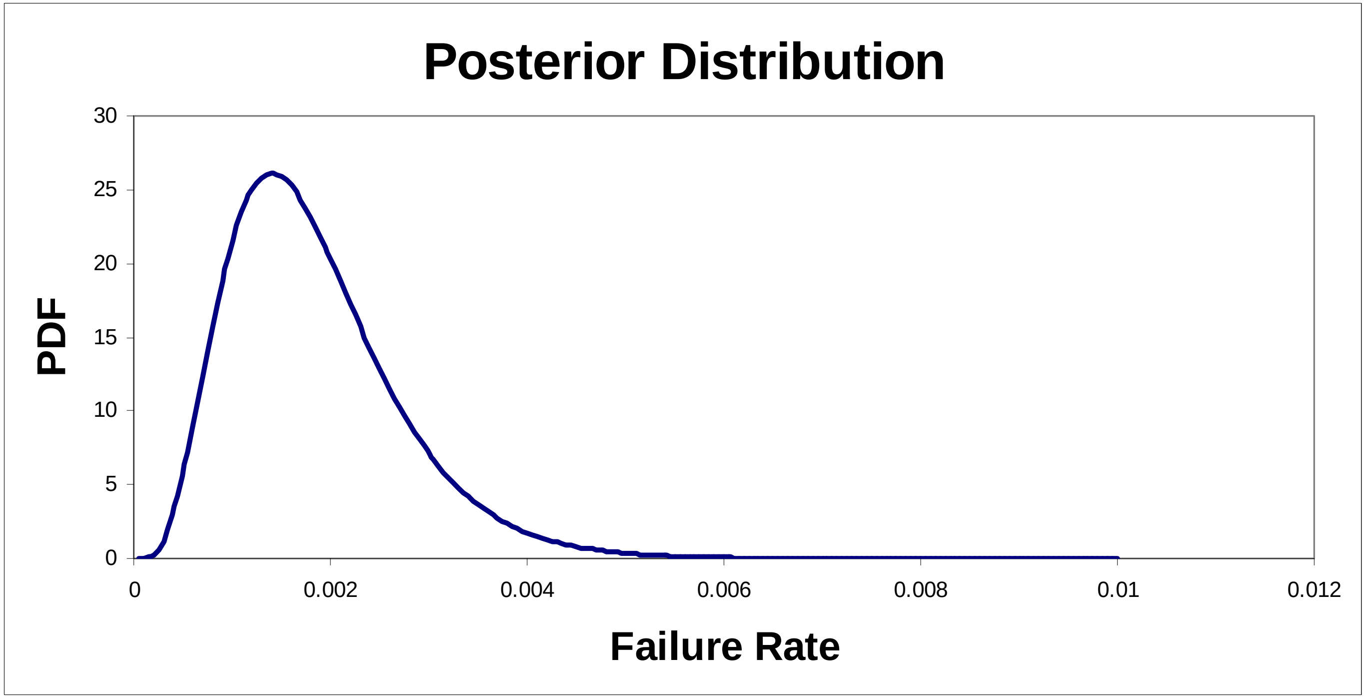
Bayesian Analysis

- **Likelihood and observed data**



Bayesian Analysis

Posterior Distribution



Bayesian Analysis

- **Parameter values are unknown variables rather than point estimates**
- **Prior estimates**
- **Likelihood and observed data**
- **Posterior Distribution**

Bayes' Theorem

Bayes' Theorem: Relates the conditional and marginal probabilities of events A and B.

$$P(A_i|B) = \frac{P(B|A_i)P(A_i)}{P(B)}$$

where:

$P(A_i \mid B)$ is the posterior (or a posteriori) probability for the event A_i, i.e. the probability of A_i once B is known. The event B is the observation.

$P(B \mid A_i)$ is the likelihood function, i.e. the probability of the observation, B, given that the parameter takes value A_i

$P(A_i)$ is the prior (or a priori) probability of the event A_i before experimentation or observation.

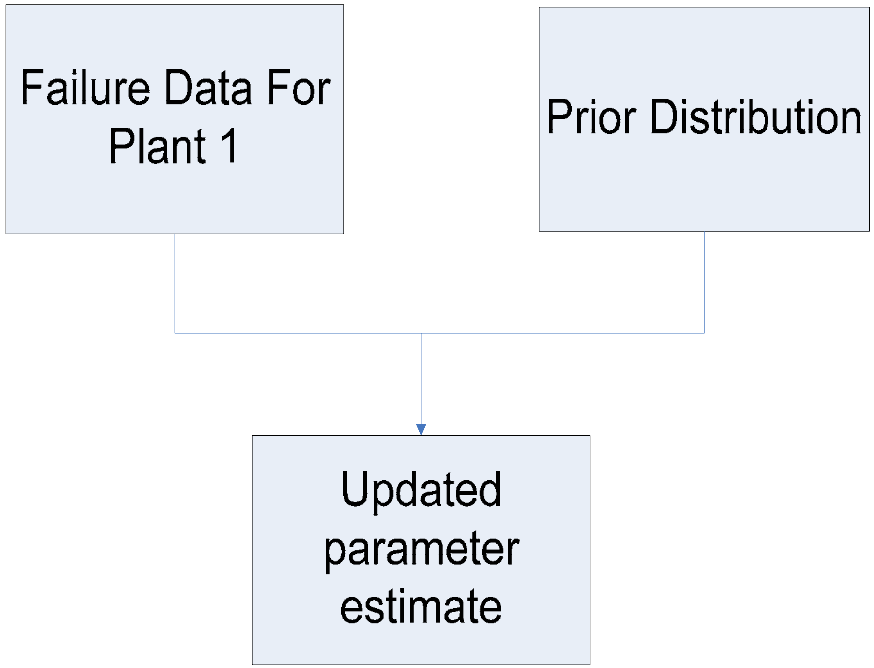
$P(B) = \Sigma\, P(B|\, A_i)\, P(A_i)$ is the probability of the data observations

Homogeneous and Non-Homogeneous Bayesian Analysis

- **Different proposed Bayesian methods**
- **Homogeneous analysis assumes equivalent sources**
- **Non-Homogeneous analysis assumes diverse sources**

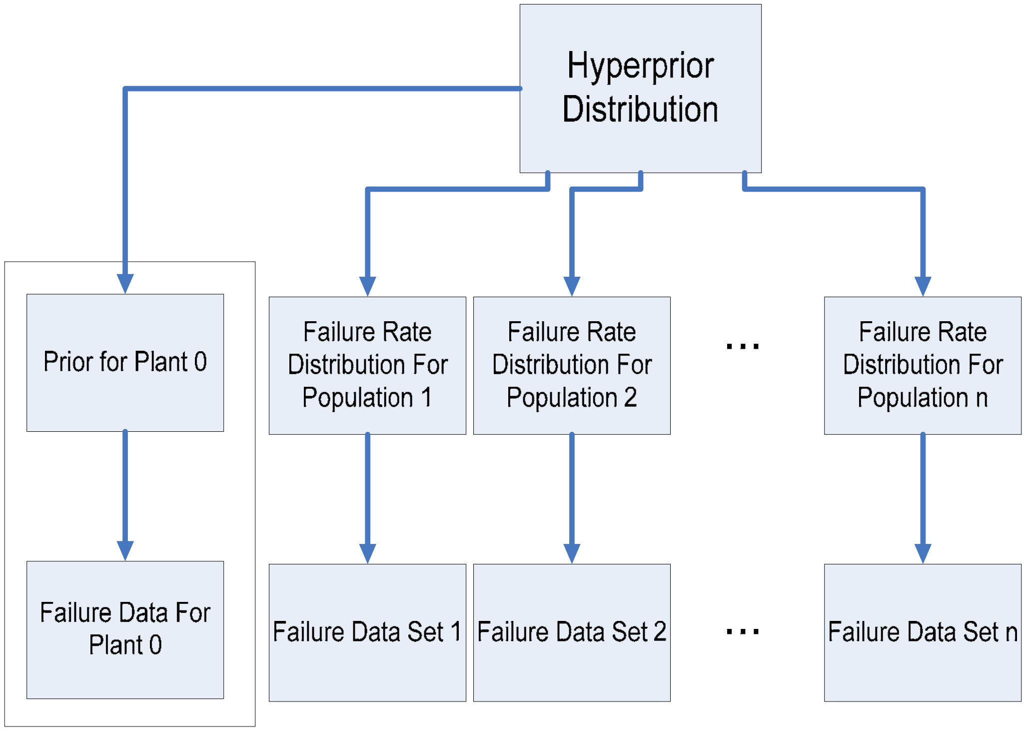
Homogeneous Analysis Structure

- **Homogeneous analysis combines observed data with prior belief**
- **Prior and observed data required**

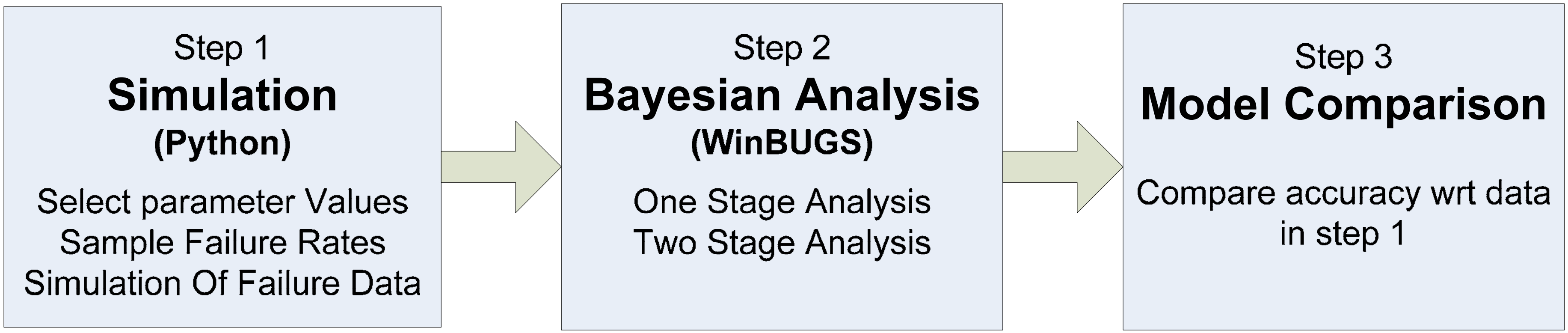


Non-Homogeneous Analysis Structure

- **Non-homogeneous has additional conceptual layer to homogeneous analysis**
- **Additional layer of uncertainty for data observation sources**
- **Additional uncertainty introduced using a hyperprior**



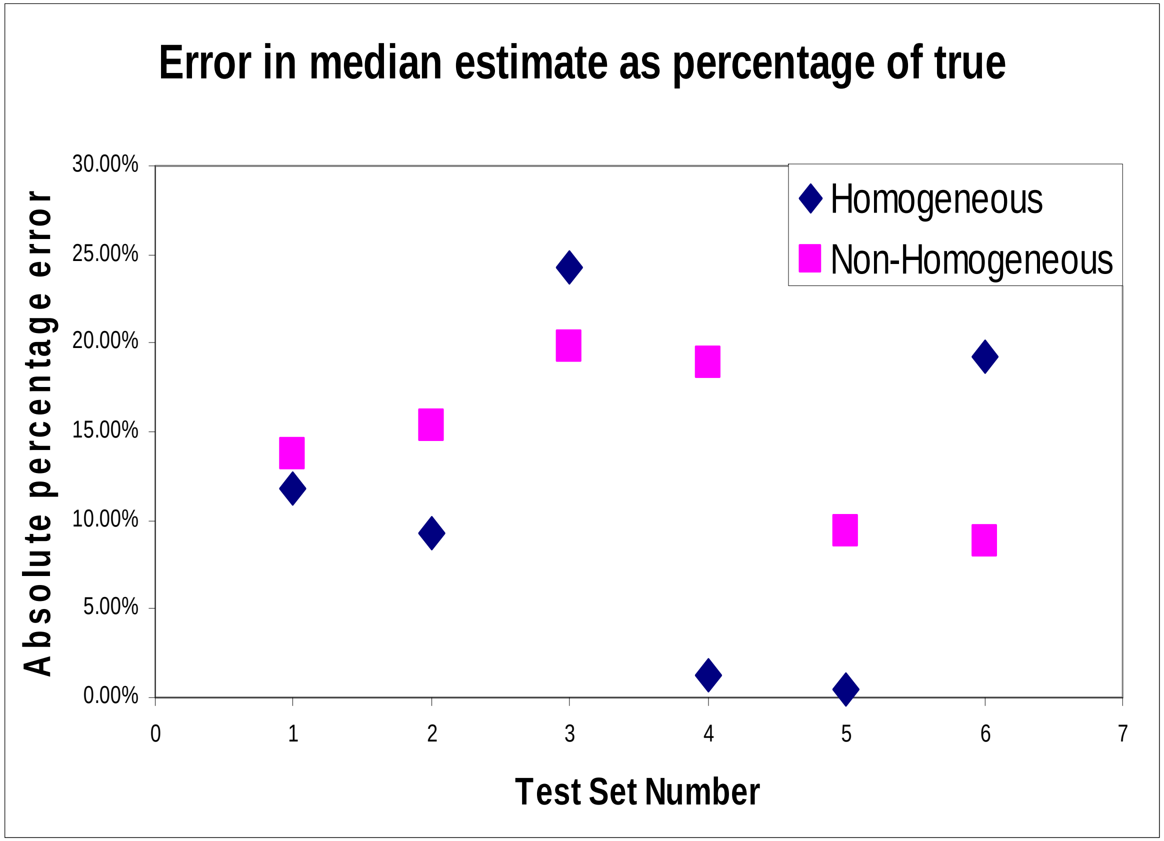
Model Accuracy Comparison



- **Simulate the failure process**
- **Estimate the failure rate using Bayesian models**
- **Accuracy comparison**

Results

- **Minimal difference observed**
- **Stochastic variability has a large effect**
- **The "an extra failure occurring by chance" effect is important**



Conclusions

- **It is difficult to discern whether homogeneous or non-homogeneous analysis is more "accurate"**
- **Homogeneous analysis may be preferred due to its simpler structure**
- **Non-homogeneous analysis provides conceptual consistency if diverse sources are used**
- **Stochastic effects cause high uncertainty in parameter estimates**

Thanks For Listening

Any questions?