Statistical Discovery.™ From SAS.

RELIABILITY ANALYSIS USING JMP®

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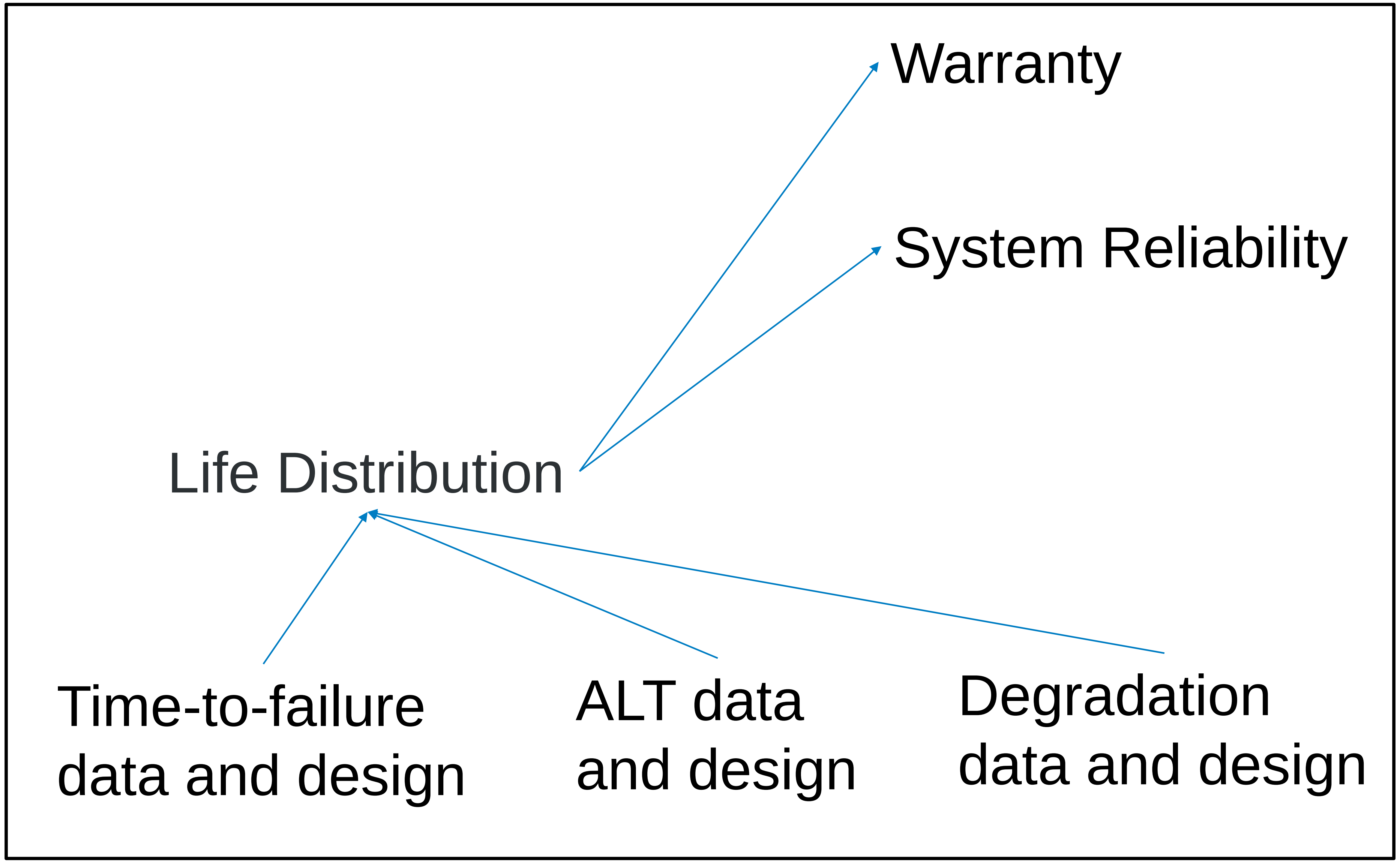
JMP FOR THE NON-REPAIRABLE

- Life Distribution
- Survival
- Reliability Forecast
- Fit Life by X
- Parametric Survival
- Cumulative Damage
- Degradation
- Test Plan (DOE)
- Demonstration Plan (DOE)
- ALT Design (DOE)
- Reliability Block Diagram



JMP FOR THE REPAIRABLE

Poisson Process

- Recurrence Analysis
- Reliability Growth
- Repairable Systems Simulation

Life Distribution

Reliability Block Diagram

Event Action Sub-diagram

THIS PRESENTATION

- Life Distribution
- Reliability Forecast
- Repairable Systems Simulation
- Degradation

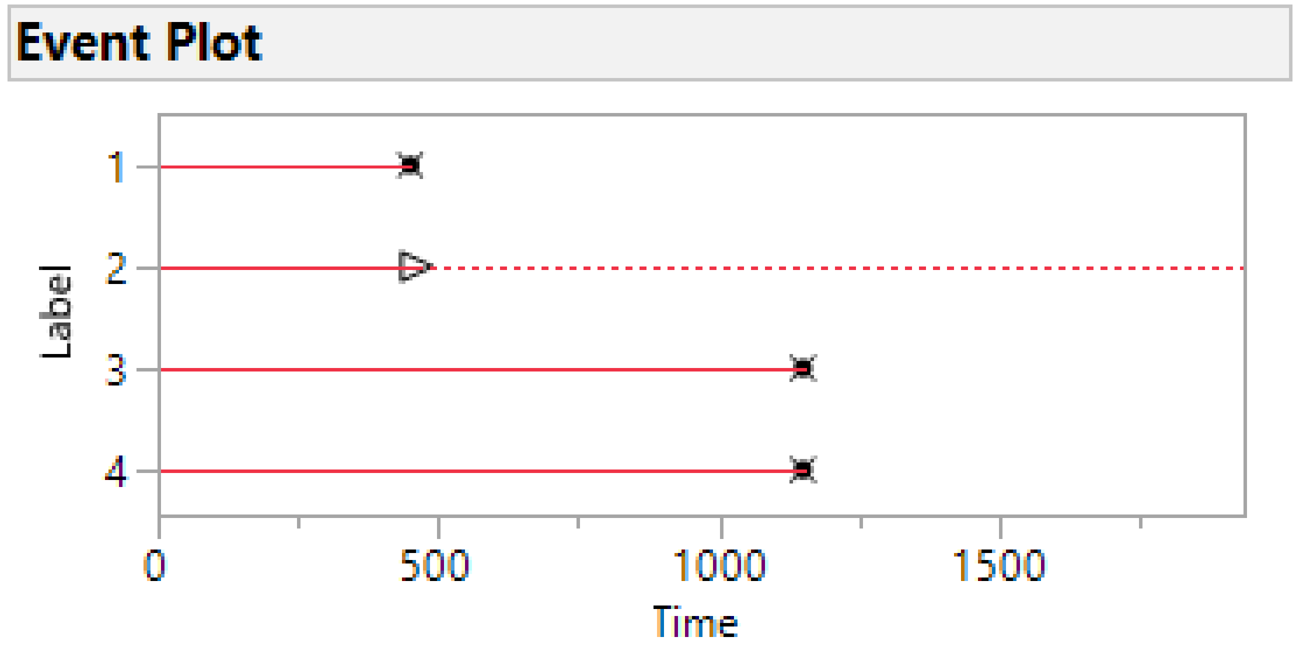
LIFE DISTRIBUTION

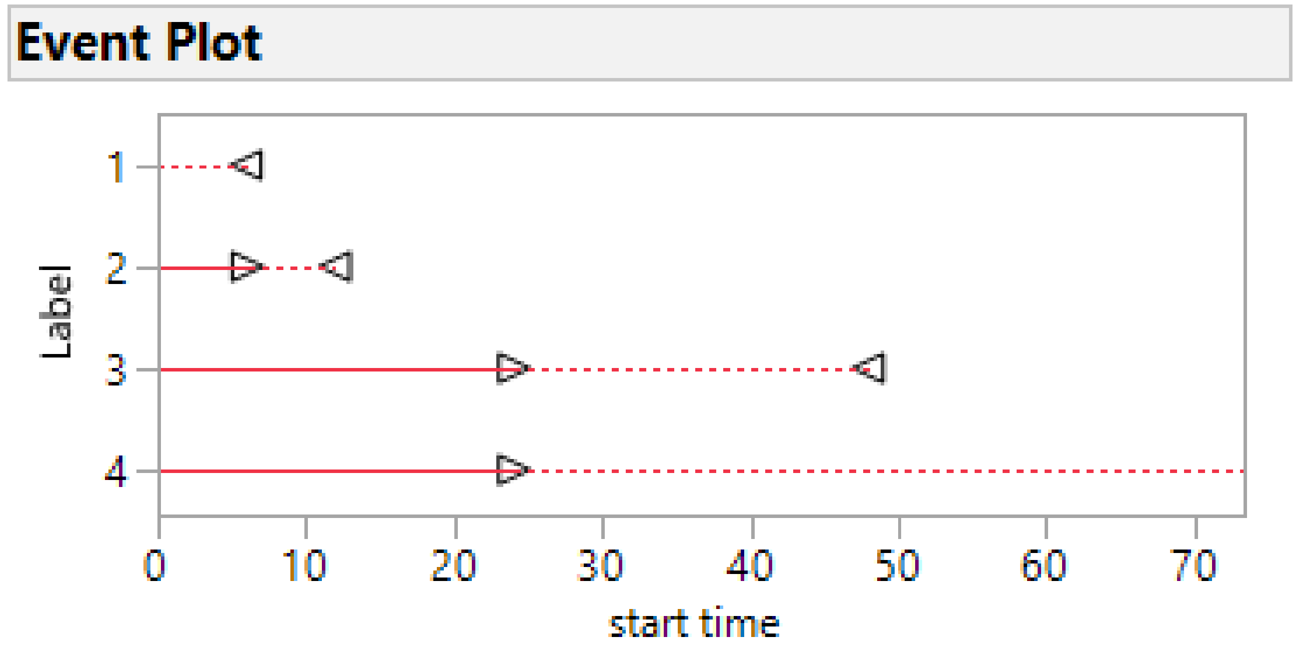
- Purpose of the Analysis:
  - Predict probabilities, percentiles, etc.
- Design Goal of the Software :
  - Fit distributions
  - Compare models
  - Calculate predictions
- Data: Regular data, Censored data, Competing cause
- Distributions:
  - Regular: Weibull, Lognormal, Normal, Logistic, etc.
  - Exotic: Zero inflated, Threshold, Defective subpopulation, Mixture, Latent Cause
- Method: Maximum Likelihood, Bayesian, Weibayes
- Intervals: Wald Intervals, Likelihood Intervals

LIFE DISTRIBUTION CENSORED DATA

Time	Censor
450	Failed
460	Censored
1150	Failed
1150	Failed

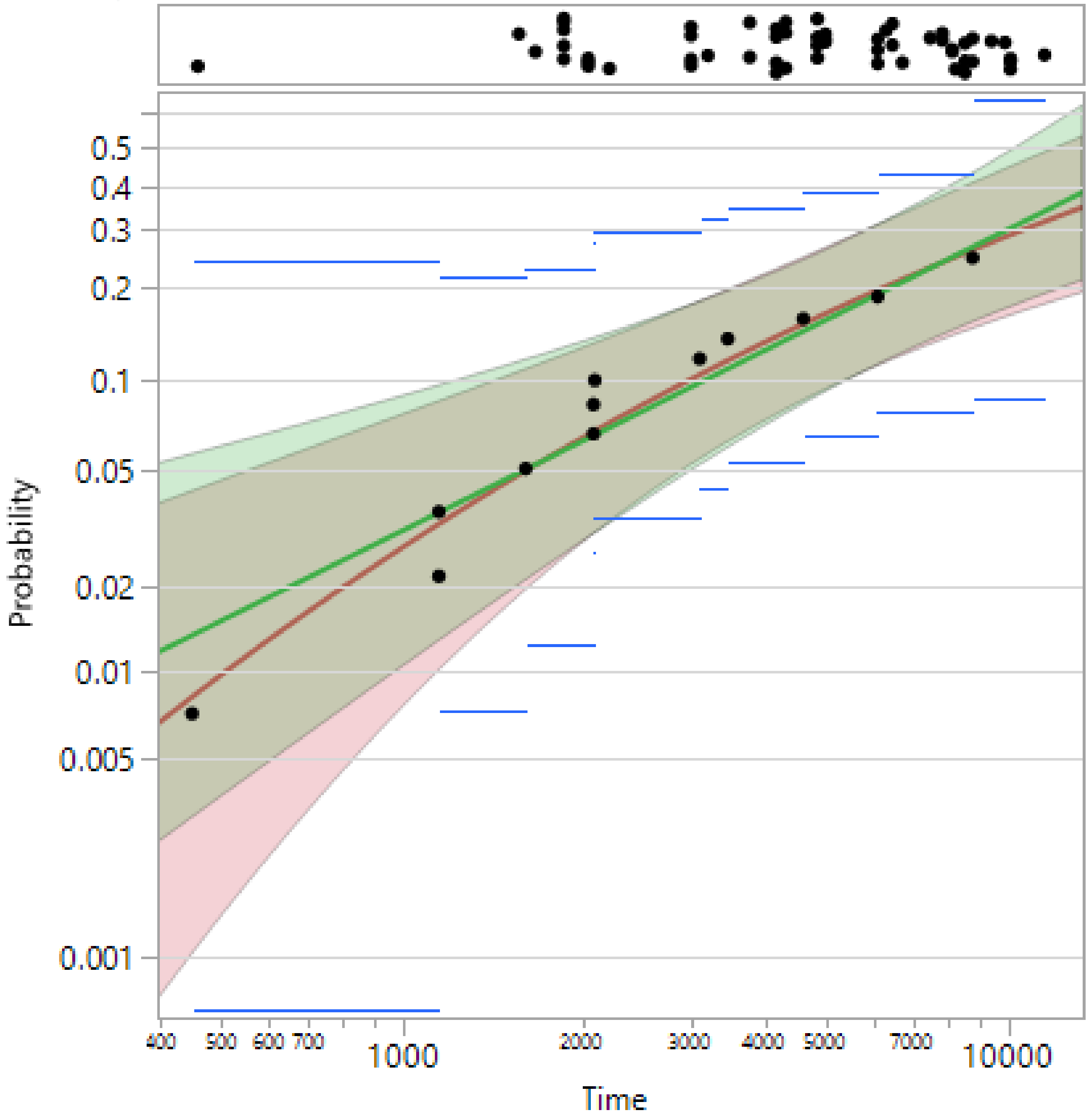
start time	end time
•	6
6	12
24	48
24	•

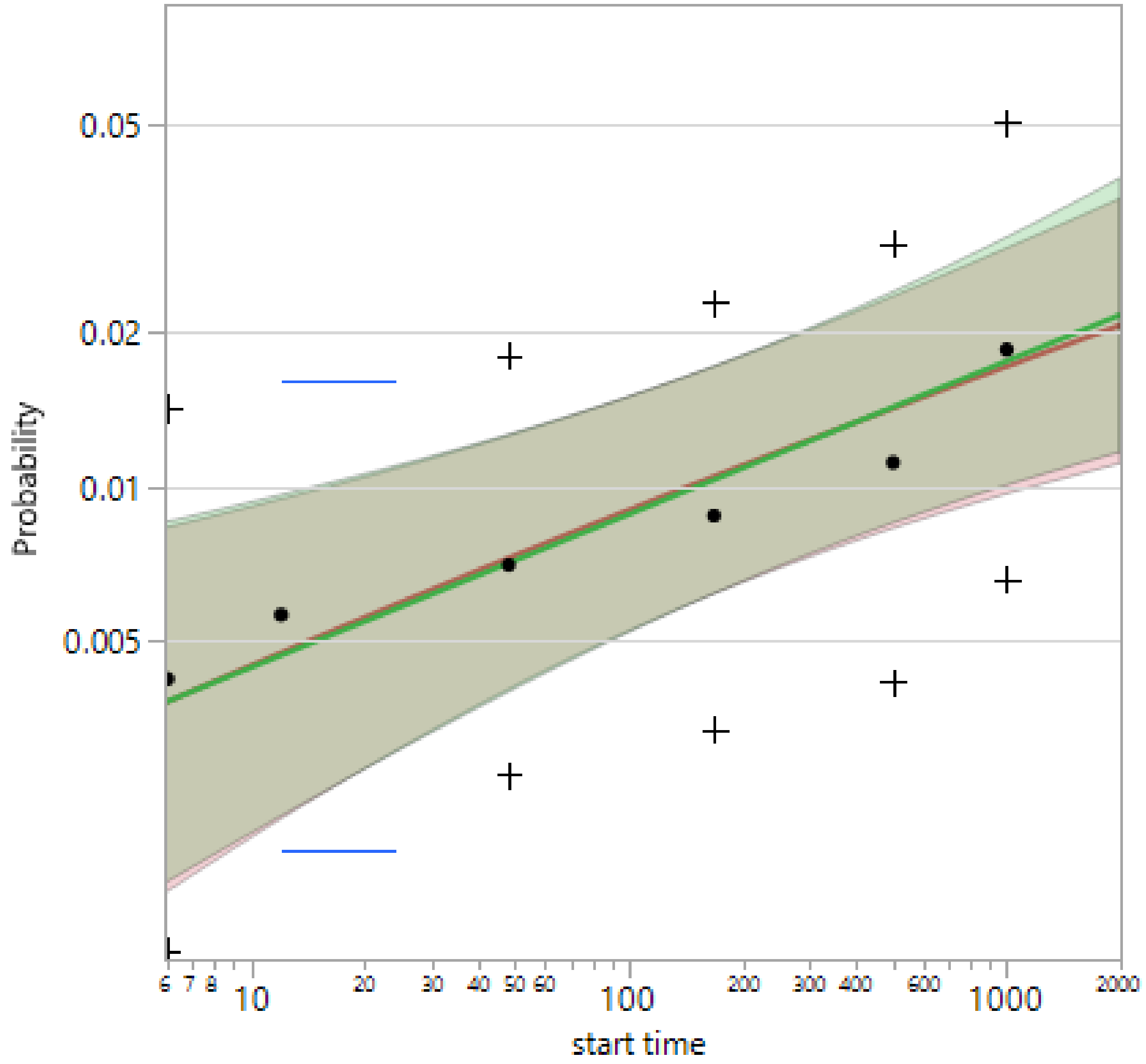




LIFE DISTRIBUTION FIND A GOOD FIT (FIT)

Distribution	Scale
☑ Nonparametric	○
☐ Lognormal	○
☑ Weibull	◉
☐ Loglogistic	○
☐ Frechet	○
☐ Normal	○
☐ SEV	○
☐ Logistic	○
☐ LEV	○
☐ Exponential	○
☐ LogGenGamma	
☐ GenGamma	
☐ TH Lognormal	
☐ TH Weibull	
☐ TH Loglogistic	
☐ TH Frechet	
☐ DS Lognormal	
☐ DS Weibull	
☐ DS Loglogistic	
☐ DS Frechet	





Time	Censor
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•	6
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24	•

LIFE DISTRIBUTION FIND A GOOD FIT (COMPARE & SELECT)

Compare Distributions

Distribution	Scale
☑ Nonparametric	○
☑ Lognormal	○
☑ Weibull	◉
☐ Loglogistic	○
☐ Frechet	○
☐ Normal	○
☐ SEV	○
☐ Logistic	○
☐ LEV	○
☐ Exponential	○
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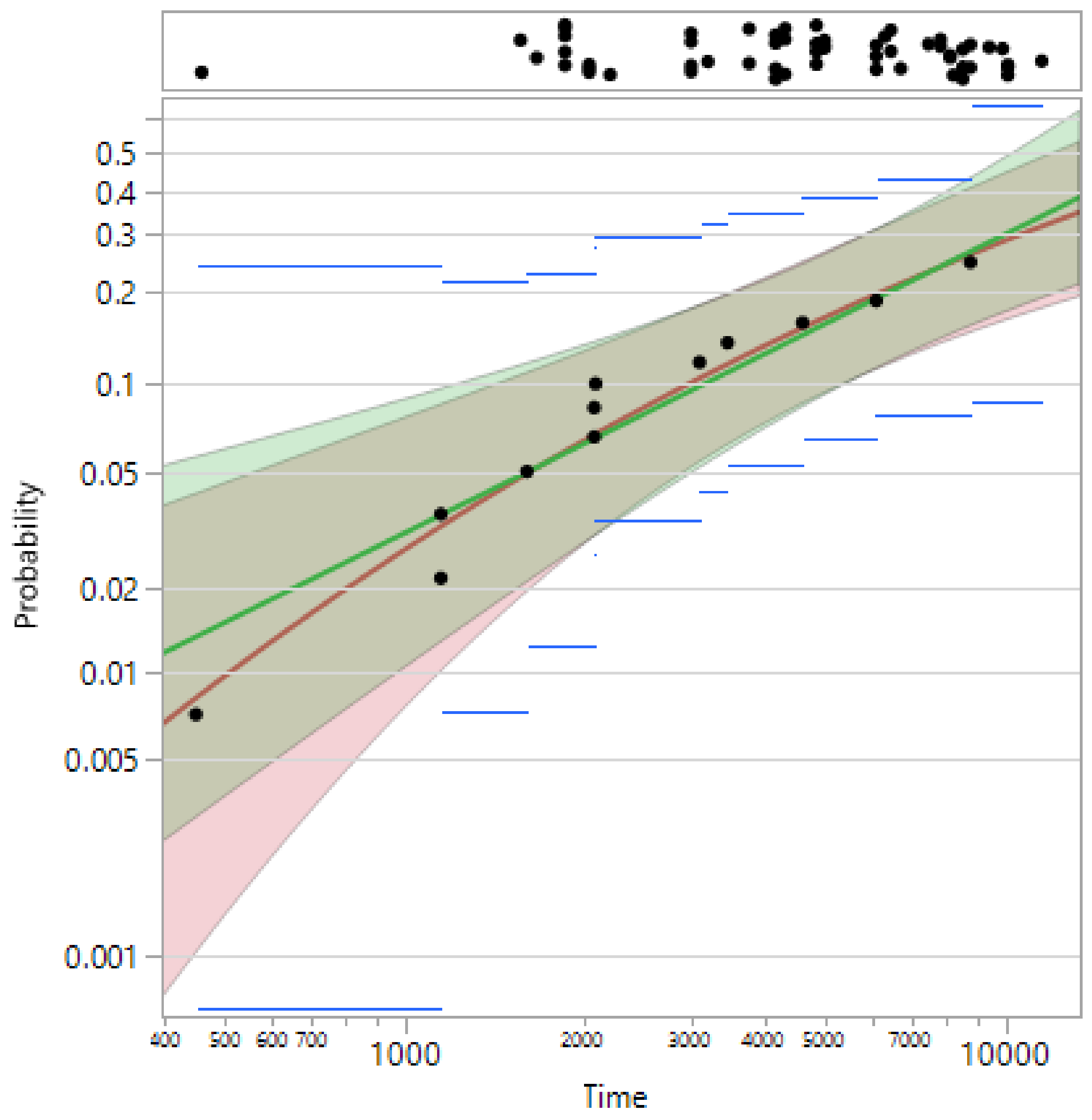
☐ TH Loglogistic	
☐ TH Frechet	
☐ DS Lognormal	
☐ DS Weibull	
☐ DS Loglogistic	
☐ DS Frechet	



Model Comparisons

Distribution	AICc	-2Loglikelihood	BIC
Exponential	272.41327	270.35444	274.60294
Frechet	272.70929	268.53019	277.02718
Lognormal	273.27840	269.09930	277.59629
Loglogistic	274.19585	270.01675	278.51374
Weibull	274.48454	270.30544	278.80243

Compare Distributions

Distribution	Scale
☑ Nonparametric	○
☑ Lognormal	○
☑ Weibull	◉
☐ Loglogistic	○
☐ Frechet	○
☐ Normal	○
☐ SEV	○
☐ Logistic	○
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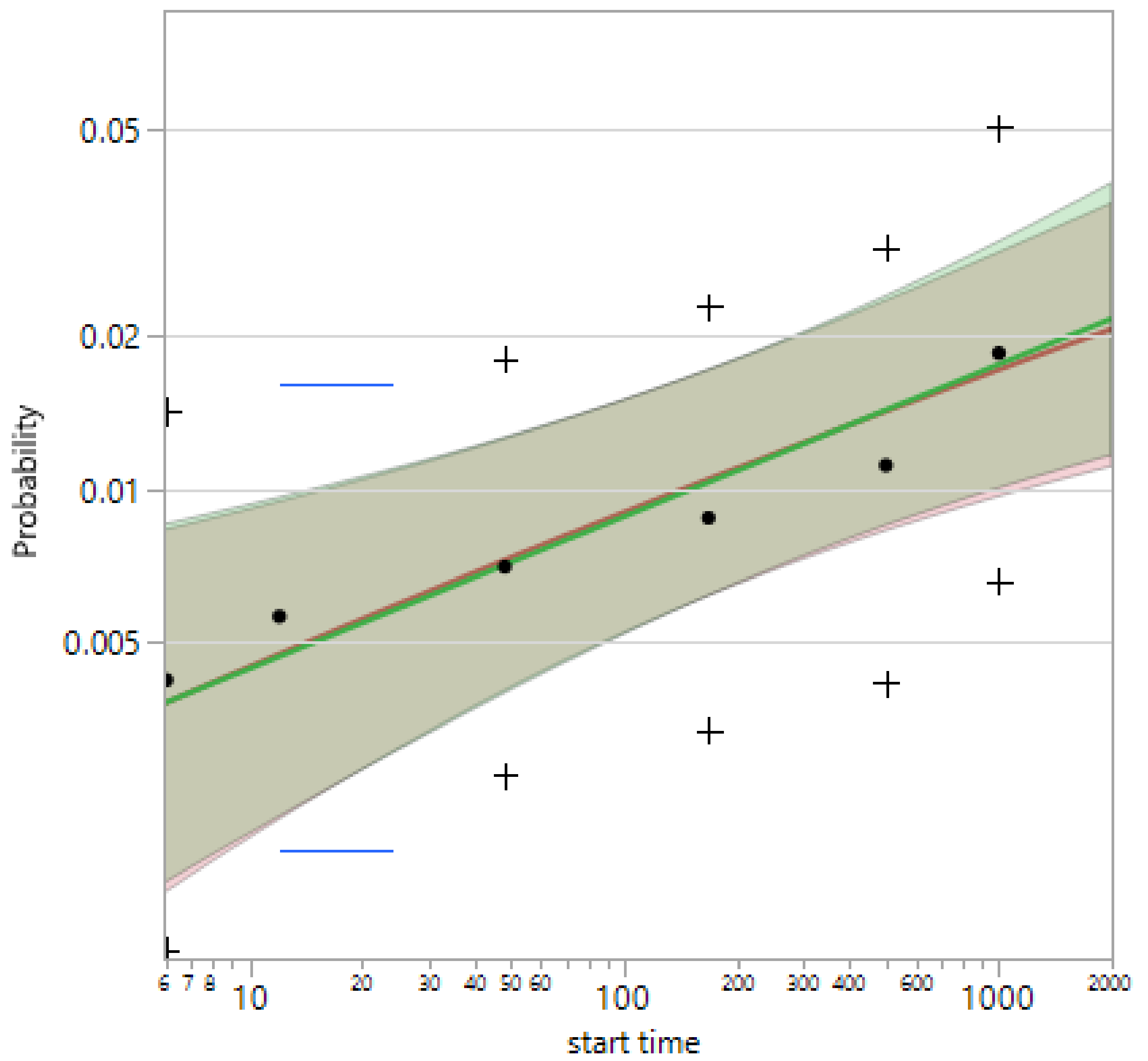
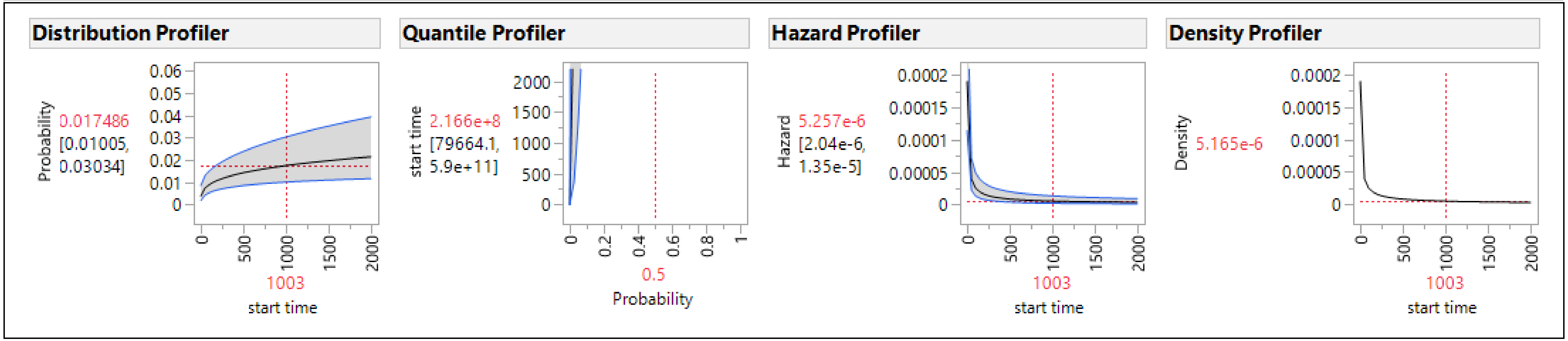


Model Comparisons

Distribution	AICc	-2Loglikelihood	BIC
Weibull	211.84567	207.83722	222.35827
Loglogistic	211.86332	207.85487	222.37591
Lognormal	212.25011	208.24166	222.76270
Frechet	212.56611	208.55766	223.07870
Exponential	245.19683	243.19402	250.45454

LIFE DISTRIBUTION PREDICT



Estimate Probability

start time	Failure Probability	Failure Probability Lower 95% (Wald)	Failure Probability Upper 95% (Wald)	Failure Probability Lower 95% (Likelihood)	Failure Probability Upper 95% (Likelihood)
1000.0000	0.01747044	0.01004375	0.03030396	0.00966549	0.02933600
2000.0000	0.02144855	0.01164662	0.03933412	0.01133987	0.03847784

Estimate Quantile

Failure Probability	Life Time Quantile	Life Time Quantile Lower 95% (Wald)	Life Time Quantile Upper 95% (Wald)	Life Time Quantile Lower 95% (Likelihood)	Life Time Quantile Upper 95% (Likelihood)
0.10000000	396456.93	4433.3901	35453253	18598.694	682815289
0.20000000	4882210.85	14310.6118	1665615916	92149.984	7.7069e+10

LIFE DISTRIBUTION STATISTICAL DETAILS

Methods:

- Maximum Likelihood (default)
- Bayesian (available for regular distributions)
- Weibayes (when there are no failures; available in Weibull reports)

Interval Types:

- Wald (when there are sufficient failures)
- Likelihood (otherwise)

Note: Intervals for parameter estimates and intervals for other predictions.

LIFE DISTRIBUTION EXAMPLE

RELIABILITY FORECAST

- Purpose of the Analysis:
  - Predict failure counts in the future: $N_t = \sum n_{t,i}$
  - Make a statement about the uncertainty in the prediction: $(\underline{N_t}, \overline{N_t})$
- Design Goal of the Software:
  - Explore raw data, by batch, group, and time.
  - Fit life distributions and compare
  - Arrange risk sets, produce forecast
- Data:
  - Nevada format, Dates format, Time-to-Event format
- Forecasting Types: Incremental; Cumulative
- Forecasting Intervals: Plug-in intervals; Prediction intervals

RELIABILITY FORECASTING

Sold Quantity	Sold Month	8/09	9/09	10/09	11/09	12/09	1/10	2/10	At Risk	3/10	4/10	…	
2550	7/09	11	13	25	24	33	18	55	2371	$p_{1,1}$	$p_{1,2}$		
2600	8/09		8	19	30	30	29	29	2455	$p_{2,1}$	$p_{2,2}$		
2650	9/09			14	18	25	26	27	2540	$p_{3,1}$	$p_{3,2}$		
2700	10/09				13	17	34	33	2603	$p_{4,1}$	$p_{4,2}$		
2750	11/09					12	21	29	2688	$p_{5,1}$	$p_{5,2}$		
2800	12/09						6	16	2778	$p_{6,1}$	$p_{6,2}$		
2850	1/10							17	2833	$p_{7,1}$	$p_{7,2}$		

$$N_t = \sum_{batch} N_{\text{batch},\, t}$$

?	?	?	?	Incre. Total
?	??	???	????	Cumu. Total

UNCERTAINTIES IN FORECASTING

Uncertainty Sources

- Knowing outcome probability, the outcome is still random, e.g. toss a coin.
- Probabilities might be estimated. Themselves involve uncertainties.

Solutions

- Uncertainties can be quantified using intervals.

Option Chart

	No Intervals	Plugin Intervals	Prediction Intervals
Incremental Counts		Ignore parameter uncertainty	Consider parameter uncertainty
Cumulative Counts		Ignore parameter uncertainty	Consider parameter uncertainty
		☑ Approximate Binomial by Poisson	

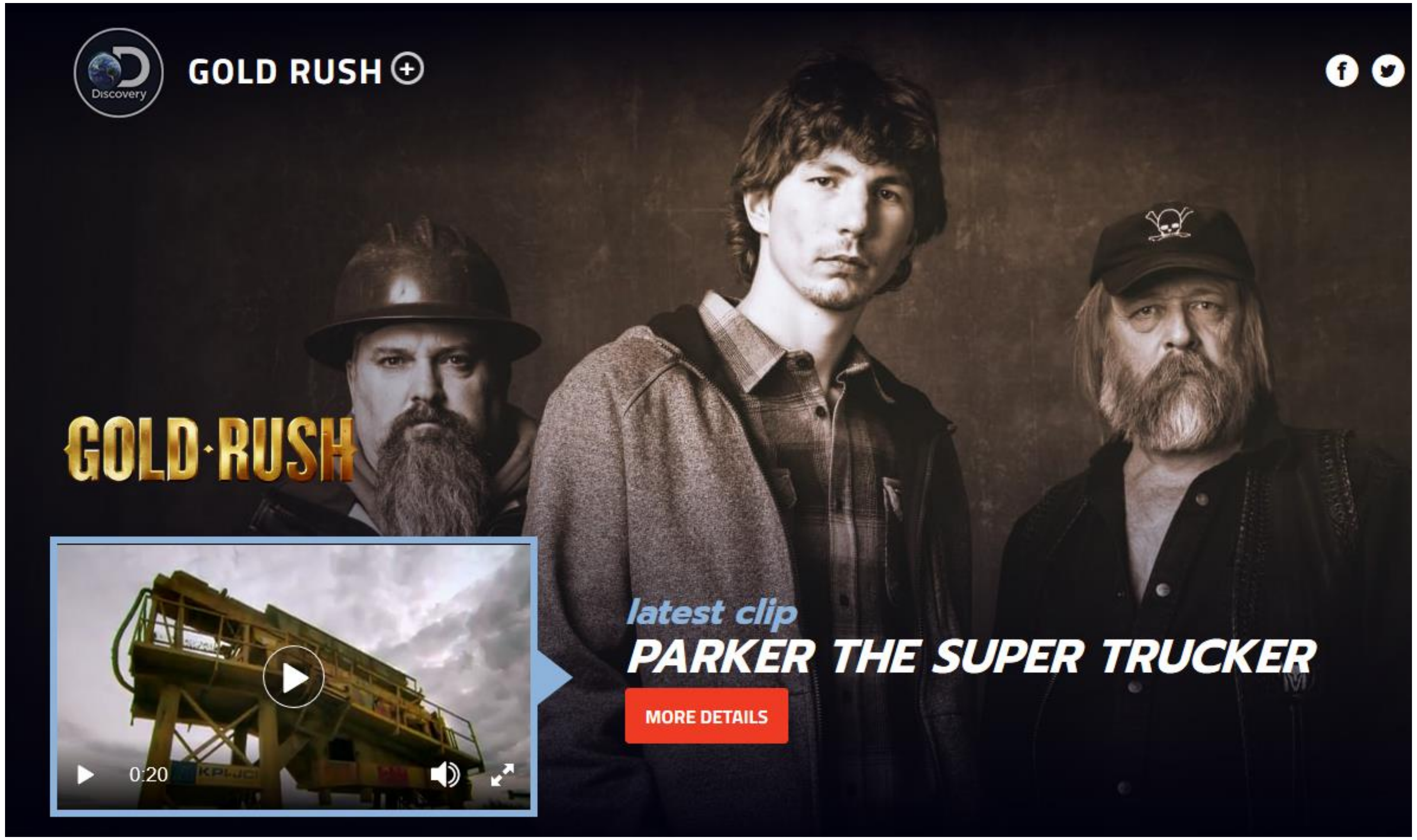
RELIABILITY FORECASTING | EXAMPLE

REPAIRABLE SYSTEMS SIMULATION

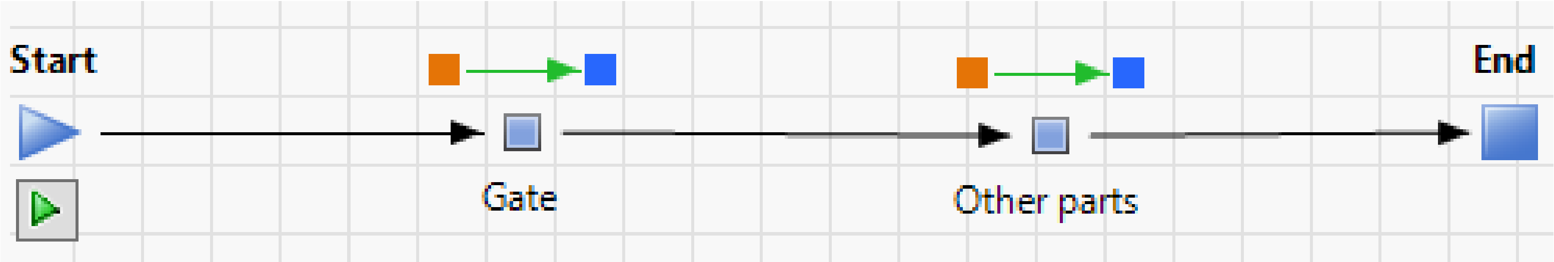
- For studying:
  - System reliability
  - When and how to repair
- Design Goals of the Software:
  - Expressive
  - Customizable
- System representation: Reliability Block Diagram
- Repair representation: Event-Action Sub-diagram
- Simulate: Events and changes of failure probabilities
- Collect: Events (times and consequences)

REPAIRABLE SYSTEMS SIMULATION

WHAT DOES IT SIMULATE?



7/2/2017 screenshot

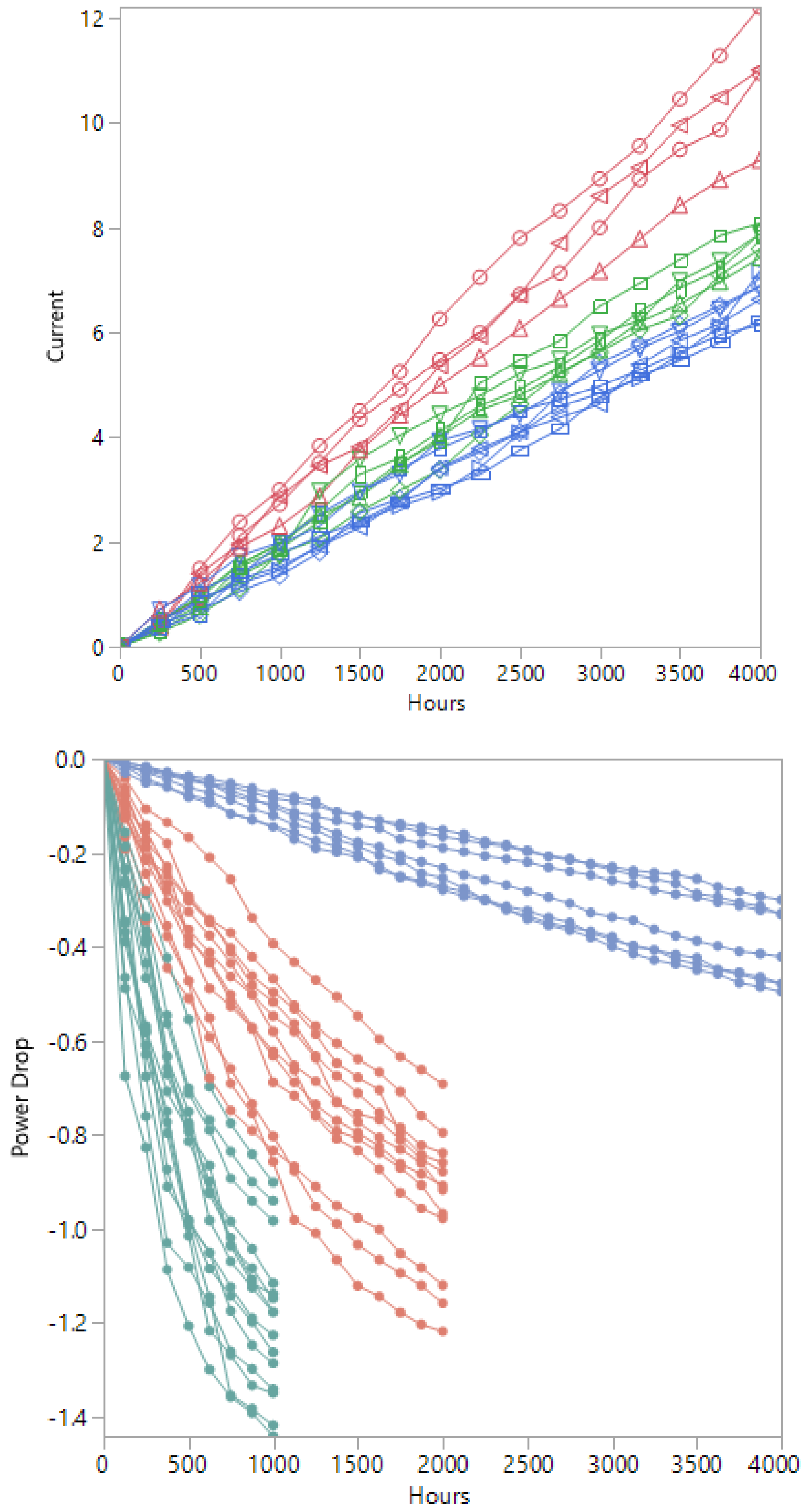


EXAMPLE: COST - CHEMICAL PLANT PLANNING

Conditions: 4 identical pumps, 1 different pump
Alternative 1: Replace the old with new
Alternative 2: Add one new pump

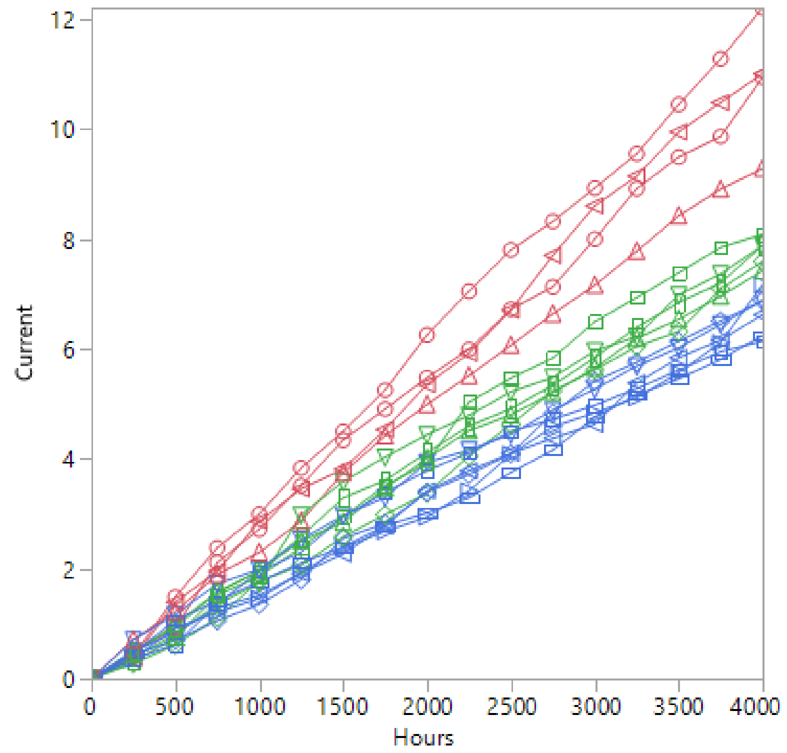
DEGRADATION

- Purposes of the Analysis:
  - Find pseudo failure times
  - Study kinetics
- Design Goals of the Software:
  - Fit built-in models automatically
  - Provide a user interface for fitting custom models
- Method: Least squares
- Path Types: Linear; Nonlinear
- Built-in Models
- Custom Models
  - Model building round trips



DEGRADATION BUILT-IN LINEAR MODELS

- Linear path models: $f(Y) \sim N(\mu = \beta_0 + \beta_1 g(t), \sigma)$
- f and g are transform functions, e.g. ln, exp, $sqrt$, etc.



	$\mu =$	**Intercept**: Zero	**Intercept**: Common	**Intercept**: Common in Group	**Intercept**: Different
Slope	Common	$\beta_1 g(t)$	$\beta_0 + \beta_1 g(t)$	$\beta_{0,k} + \beta_1 g(t)$	$\beta_{0,b} + \beta_1 g(t)$
Slope	Common in Group	$\beta_{1,k} g(t)$	$\beta_0 + \beta_{1,k} g(t)$	$\beta_{0,k} + \beta_{1,k} g(t)$	$\beta_{0,b} + \beta_{1,k} g(t)$
Slope	Different	$\beta_{1,b} g(t)$	$\beta_0 + \beta_{1,b} g(t)$	$\beta_{0,k} + \beta_{1,b} g(t)$	$\beta_{0,b} + \beta_{1,b} g(t)$

Subscript k denotes the group ID; b denotes batch ID.

DEGRADATION BUILT-IN NONLINEAR MODELS

- Nonlinear path models: $Y \sim N(\mu = h(t, \theta, X), \sigma)$
- h is specified via a JSL `parameter` function.

- Reaction Rate: $\mu = D_{\infty}(1 - e^{-R_U \times AF(Temp) \times t})$
- Reaction Rate Type I: $\mu = D_{\infty} e^{-R_U \times AF(Temp) \times t}$
- Constant Rate: $\mu = m(\beta_0 + g(X) \times f(t))$
  - Path transformation: m can be Identity, exp, log
  - Rate transformation: g can be Arrhenius, Power, or exp
  - Time transformation f can be Identity, $sqrt$

DEGRADATION EXAMPLE

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