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Title: Modeling the Reliability of Complex Systems with Multiple Data Sources: A Statistical Engineering Case Study

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Los Alamos
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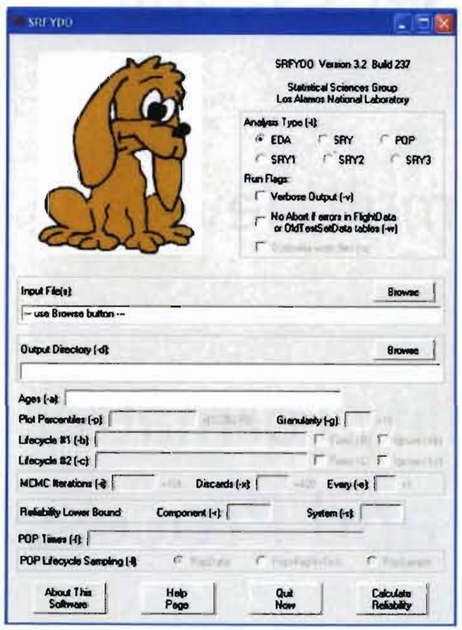
Title: Modeling the Reliability of Complex Systems with Multiple Data Sources: A Statistical Engineering Case Study

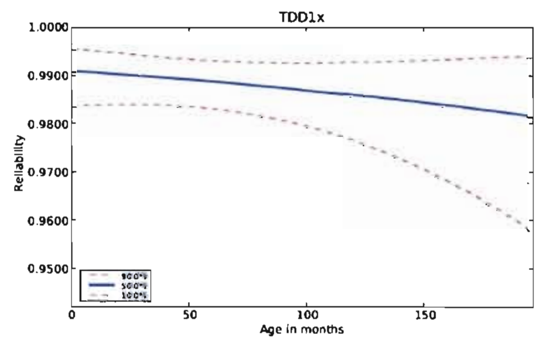
Abstract Text:
Estimating the reliability of complex systems with many parts and components often involves using multiple data sources, including expensive full system tests, as well as less expensive subsystem and component level tests. Using statistical methodology developed by the Statistical Sciences Group at Los Alamos National Laboratory, a process for estimating and predicting future reliability was developed. A multi-phase software tool, SRFYDO, was developed to make this process accessible and understandable to the system engineers who need to perform these analyses. In this talk, we present a short overview of the method, but focus on how the software was developed to incorporate multiple statistical tools with the goal of guiding engineers through an analysis.
Keywords: Full-system data, component data, software development, SRFYDO

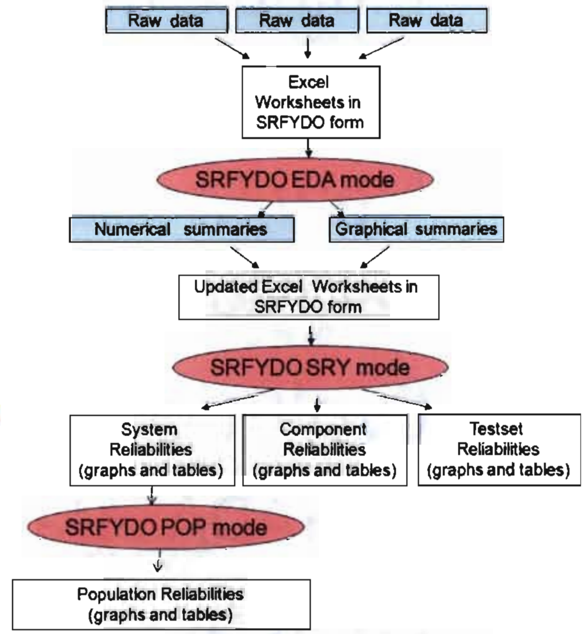
1: Anderson-Cook, Christine - Los Alamos National Laboratory (presenting)

Modeling the Reliability of Complex Systems with Multiple Data Sources:

A Statistical Engineering Case Study







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February 2012

Outline

- What is Statistical Engineering? - Background
- Motivation for System Reliability Approach – multiple data sources available with expensive full system tests
- New Statistical Method – Bayesian multi-level data combination
- Evolution of SRFYDO (System Reliability Formatter for YADAS Data and Output) Software and Process
- Final Product and Process
- Lessons Learned

Statistical Engineering –
What is it? and Why is it important?

- Definition: Statistical Engineering is the collaborative study and application of the tactical links between statistical thinking and statistical and discipline-specific tools with the objective of guiding better understanding of uncertainty in knowledge and decision-making to generate improved results to benefit the organization and/or society.

ASQ Statistic Division Resource Page:

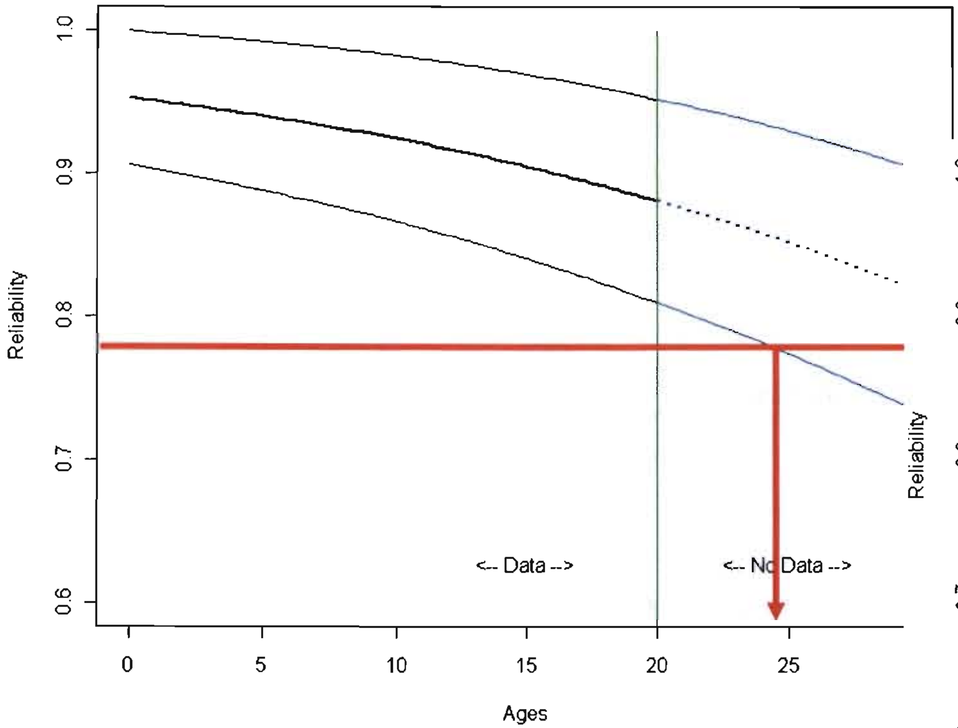
http://asq.org/statistics/quality-information/statistical-engineering

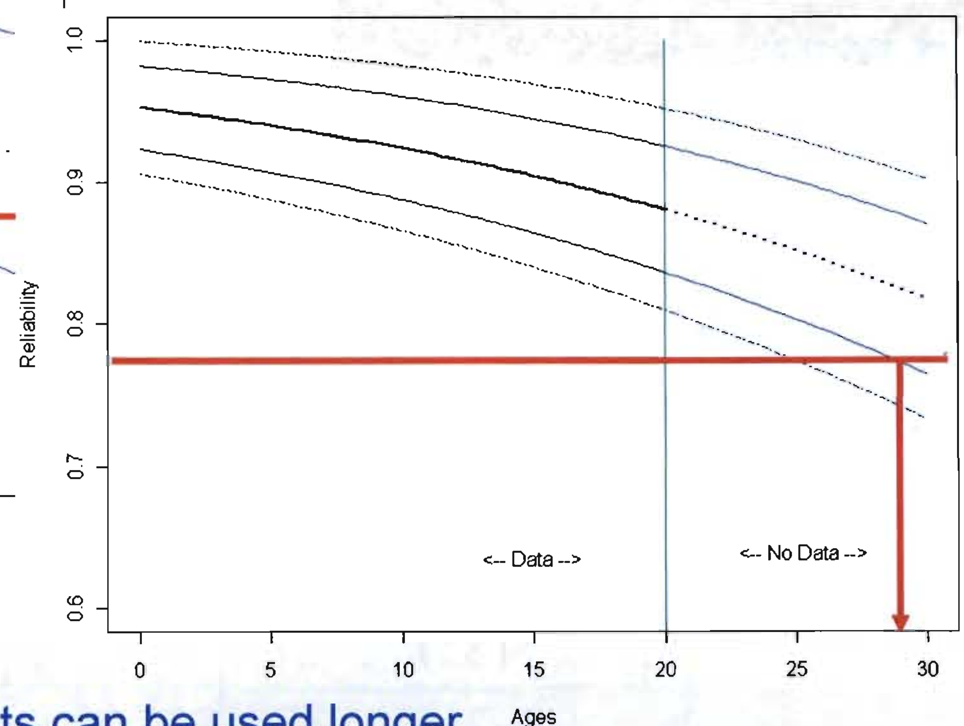
Characteristics of a Statistical Engineering Solution

- Satisfies a high-level need of the organization.
- No known solution to the problem.
- High degree of complexity involving both technical and non-technical challenges.
- More than one statistical technique required for solution.
- Long-term success requires imbedding solutions into work processes.
- The whole is greater than the sum of the parts.
- A solid theoretical foundation is required to guide development of a solution.
- The solution can be leverage to similar problems elsewhere

Motivation for New System Reliability Approach

- **Problem:** Insufficient system level data to estimate system reliability to the required precision

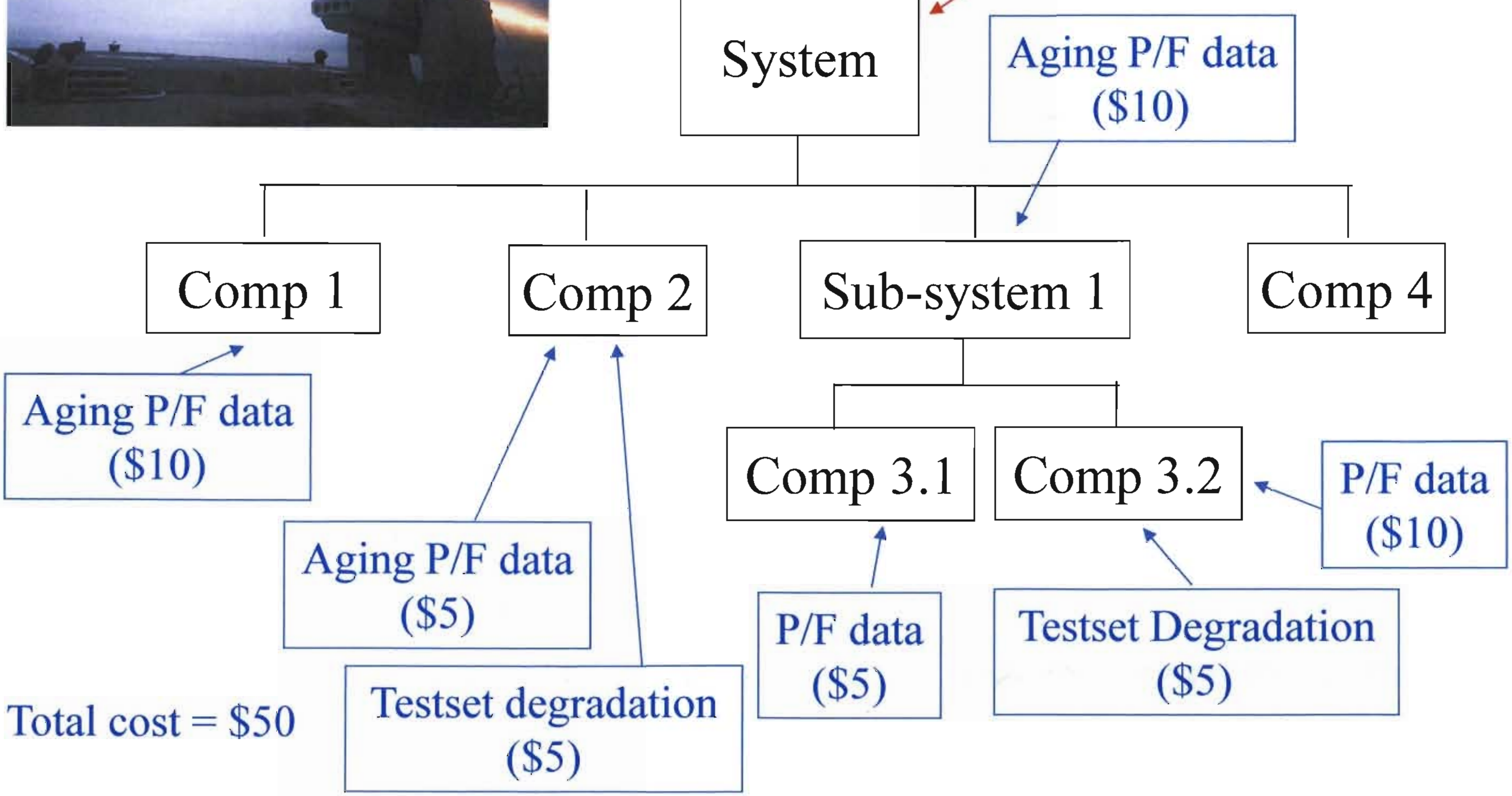




Better analysis increases precision → units can be used longer

Solution requires engineering knowledge of system structure and components

Motivation (continued)

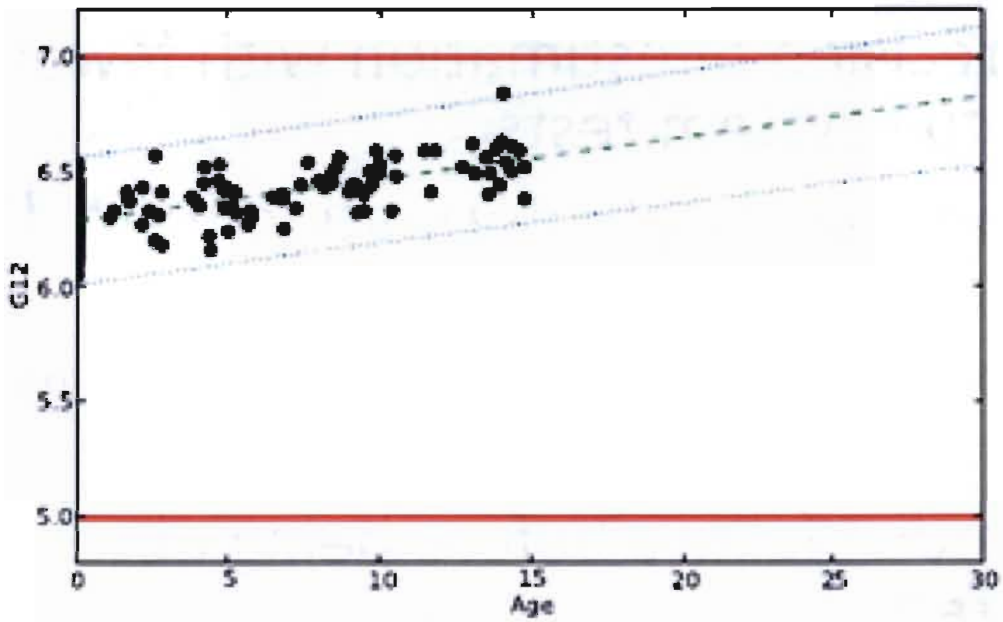


Advantages of SRFYDO Approach

- Uses data already available and thought to be relevant to predict reliability
- Improves precision of estimation with fewer destructive full-system tests
- Check on consistency of information from different data sources
- Flexibility to incorporate partial information into model
- Ability to predict failure before being observed in full-system test
- Component level reliabilities – leverage from different versions of system + better understanding

Disadvantage: More complex statistical method requiring more engineering knowledge to obtain results

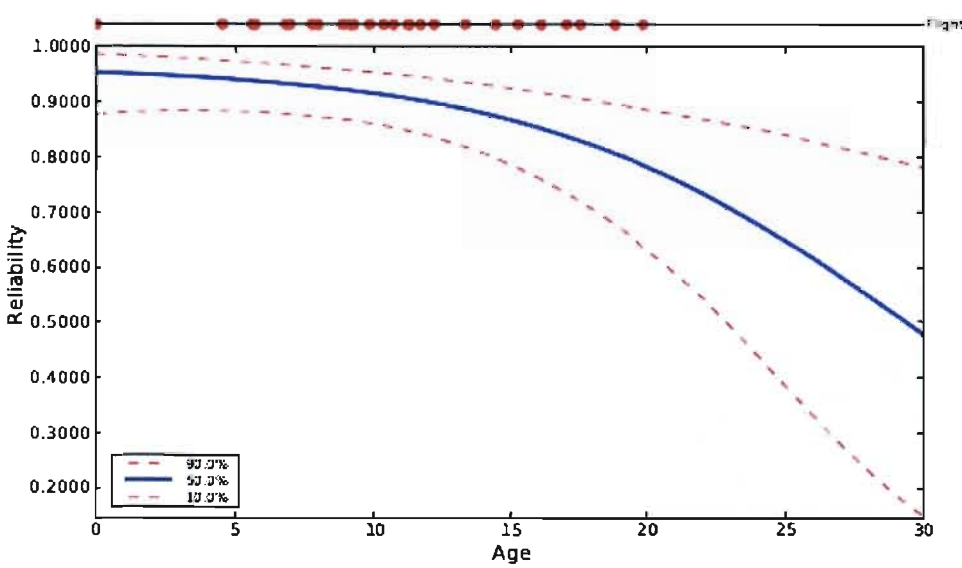
Advantage: Ability to predict failure before being observed in full-system test

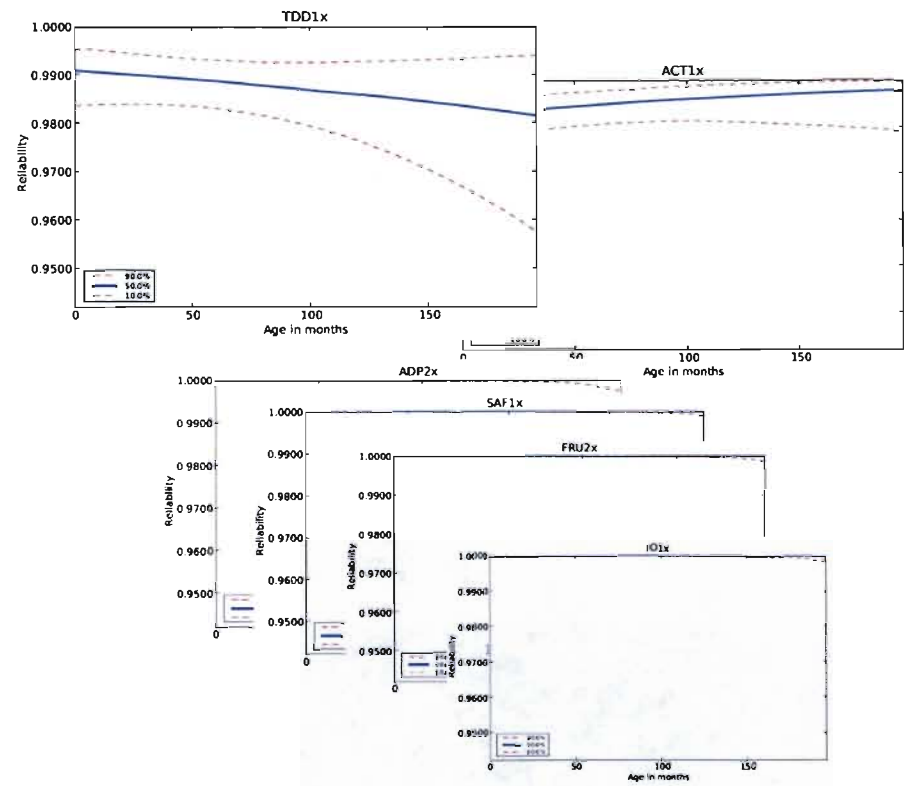


- Because we can track a trend in some of the continuous measurements, we can anticipate when failures might start to occur, before they actually have been observed

Advantage: Component Level Summaries

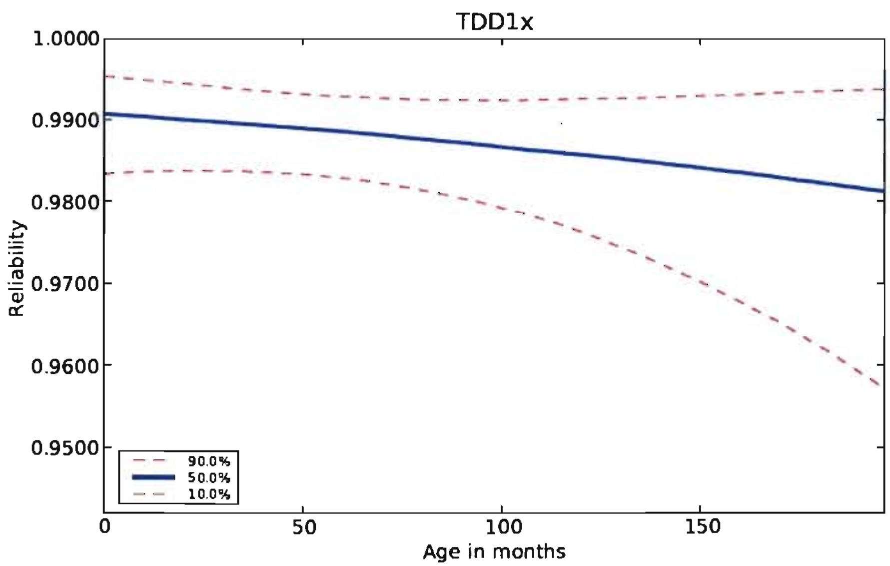
- Better understanding of system and important drivers of system reliability
- Ability to identify critical components and critical specs to implement corrective action

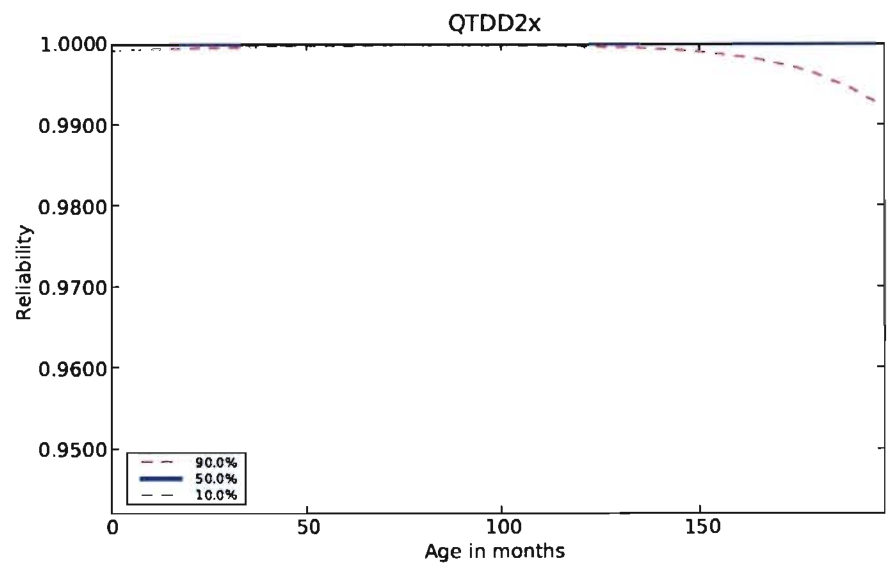




Advantage: Component Level Summaries (cont'd)

- Ability to compare different versions of the same component





Advantage: Component Level Summaries (cont'd)

- Ability to leverage data across different variants with common components
- Data used to estimate reliability:
  - SAF2x + 21 others → 75+47 = 122
  - ADP1x + 6 others → 75
  - ADP2x + 6 others → 47

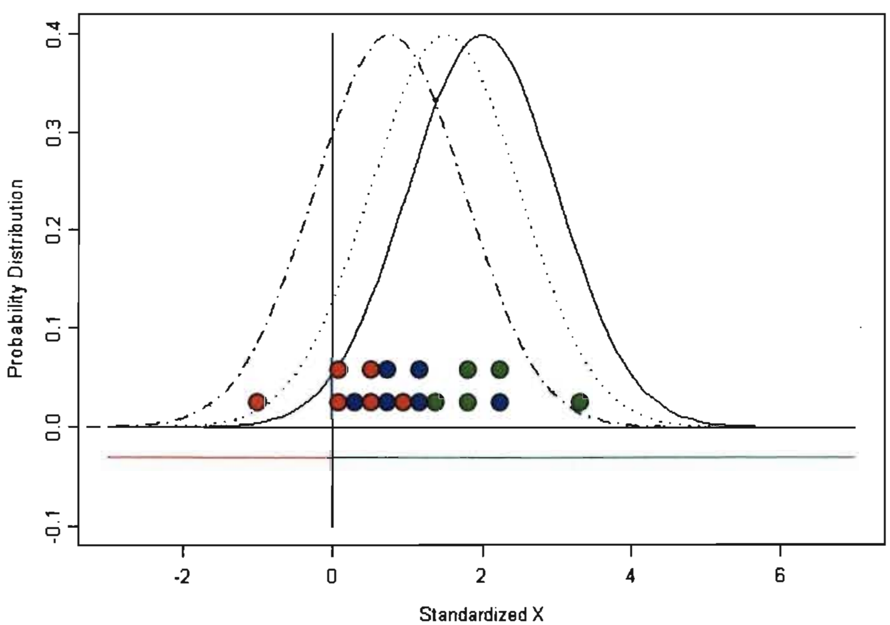
%VariantDef

Version	Component	Version	Component
Lot4_5	SAF1x	Lot6_7	SAF1x
	WH1x		WH1x
	ACT1x		ACT1x
	BPS1x_Rear		BPS1x_Rear
	RDL1x		RDL1x
	FinSquib1x		FinSquib1x
	MBC1x		MBC1x
	ECU2x		ECU2x
	ADP1x		ADP2x
	Harness1x		Harness1x
	FP1x		FP2x
	FRU1x		FRU2x
75	HH1x	47	HH1x
	IFR1x		IFR2x
	IO1x		IO2x
	LS1x		LS2x
	PM1x		PM1x
	RC1x		RC2x
	RT2x		RT2x
	IRU2x		IRU2x
	TDD1x		TDD1x
	BPS1x_Front		BPS1x_Front
	SS1x		SS1x
	XMTR2x		XMTR2x
	AFD1x		AFD1x
	RocketMotor1x		RocketMotor1x
	RFA1x		RFA1x
	TIVs1x		TIVs1x
	RFP1x		RFP1x

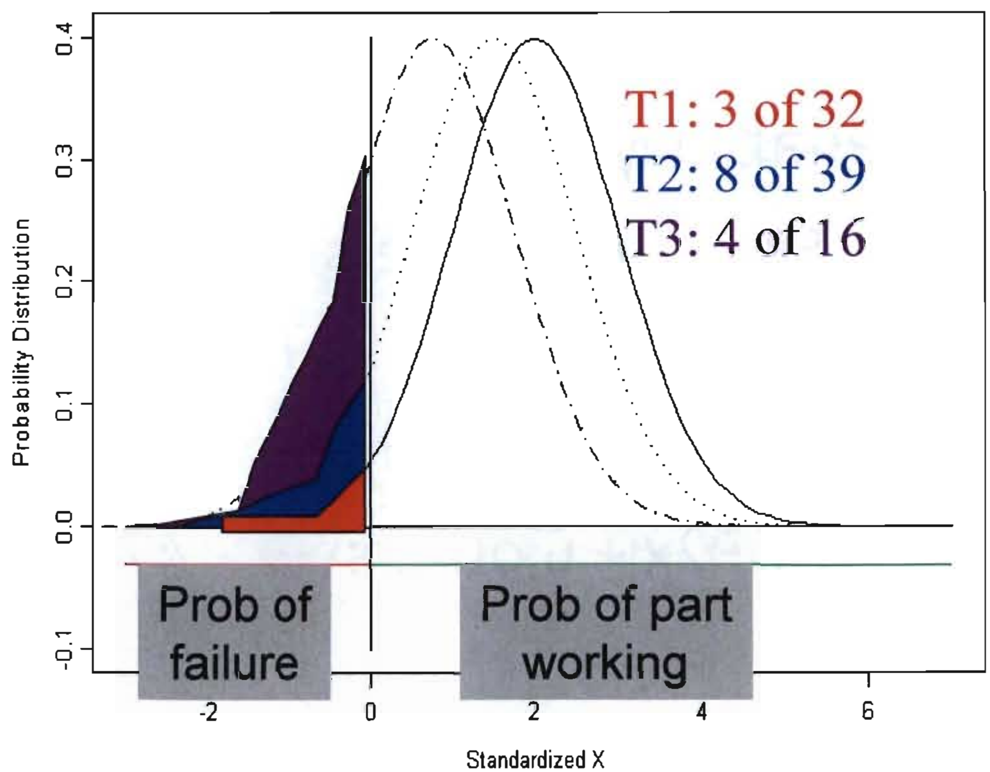
Basic Building Block

- Here we have two potential sources of information about this component:

From testset data, we obtain the mean of the characteristic at each time



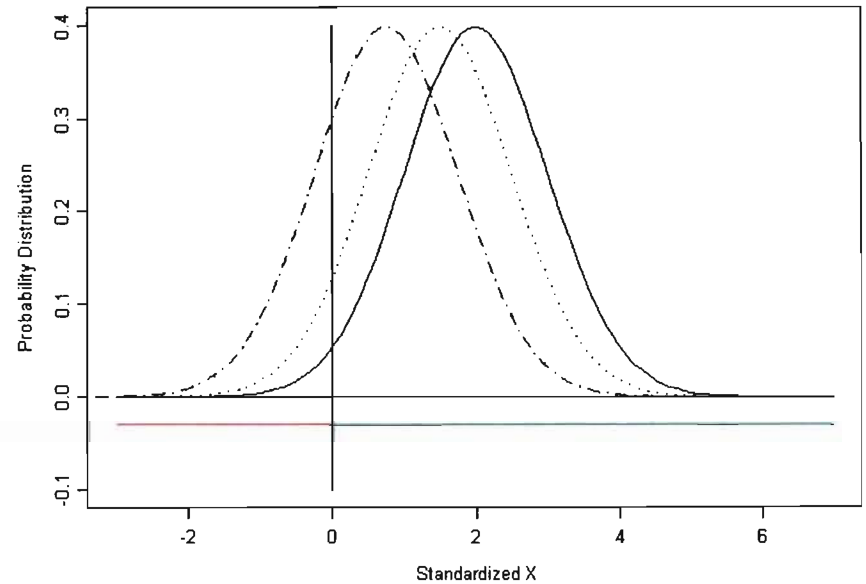
From the full system data, we obtain a proportion of success/failure at each time



Statistical Formulation

- For the probability that a particular component, say component with spec 1, will function correctly

$$p_1(x) = \Phi\left(\frac{\beta_{0,1} + \beta_{1,1}x - \theta_1}{\sqrt{\gamma_1^{\,2} + \sigma_1^{\,2}}}\right)$$



Φ = cdf of Normal distribution

$\beta_{0,1}$ – initial mean of testset distribution

$\beta_{1,1}$ – rate of shift of testset distribution

$\gamma_1^{\,2}$ – variance of testset distribution

θ_1 – discrepancy between means of spec and full system

$\sigma_1^{\,2}$ – additional variance from full system distribution

Background of Users

- Subject Matter Experts (SME) on particular system
  - System Engineers
  - Data Analysts
- Little or no formal statistical training

- Customers
- Department of Defense
  - NSWC Corona (RAM, ESSM, SeaSPARROW)
  - NSWC Yorktown / Indian Head (AMRAAM)
  - AMCOM/AMRDEC (Hellfire, Stinger)
  - MCPD Fallbrook (TOW)
- Department of Energy
  - LANL Enhanced and Core Surveillance Campaign

Evolution of SRFYDO

1. Development of methods

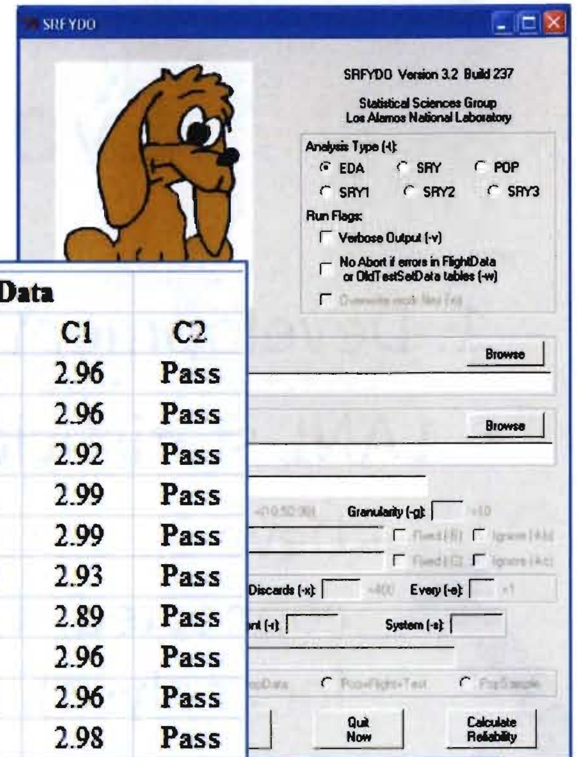
- LANL statisticians sat down with team of SMEs
  - Develop system model (identify components and how connected, map available data to components, obtain priors for analysis)
  - Statisticians did analysis
  - Sat down with SMEs to interpret results, fine-tune model

Characteristics:
- Helpful for development of new methodology – key problems identified
- Long lag for engineers until methods available
- New data added to analysis as it became available
- Methodology implemented with unfriendly code (usable only be creators)
- Very time intensive – not scalable to many systems

Evolution (continued)

2. Development of prototype of SRFYDO

- Formal analysis from GUI
- EXCEL spreadsheet



%NewTestSetData

Age	M1	C1	C2
0	3.01	2.96	Pass
0	3.02	2.96	Pass
0	3.06	2.92	Pass
0	3.08	2.99	Pass
0	3.84	2.99	Pass
0	3.10	2.93	Pass
0	3.11	2.89	Pass
0	3.11	2.96	Pass
0	3.09	2.96	Pass
0	3.11	2.98	Pass
2	3.16	2.62	Pass
2			Pass
2	3.19	2.64	Pass
2			Pass
2		2.6	Pass
2.06	3.23		Pass

%VariantDef

Variant
Block1

%ComponentDef

Component	SpecName	SpecType	LowerSpec	UpperSpe
Control				
Guidance1				
Guidance2				
Propulsion1				
Propulsion2				
TargetDetection				
Armament				

%FlightKey

Result	Variant	Co
Success	Block1	
Success	Block2	
Success	Block3	
Dud	Block1	
Dud	Block2	
Dud	Block3	
Crash	Block1	
Crash	Block2	
Crash	Block3	
MissTarget	Block1	
MissTarget	Block2	
MissTarget	Block3	
NoExplosion	Block1	
NoExplosion	Block2	
NoExplosion	Block3	
Undiagnosed	Block1	
Undiagnosed	Block2	
Undiagnosed	Block3	

%FlightData

Missile	Age	NumTrans	Variant			n	Armament
891230	3.26	9	Block 1				1
891060	3.3	15	Block 1				1
891064	4.51	17	Block 1				1
891001	4.65	15	Block 1				2
							2
891044	12.18	37	Block 1	Success		3	3
891004	12.38	42	Block 1	Success		3	3

%PriorSystem

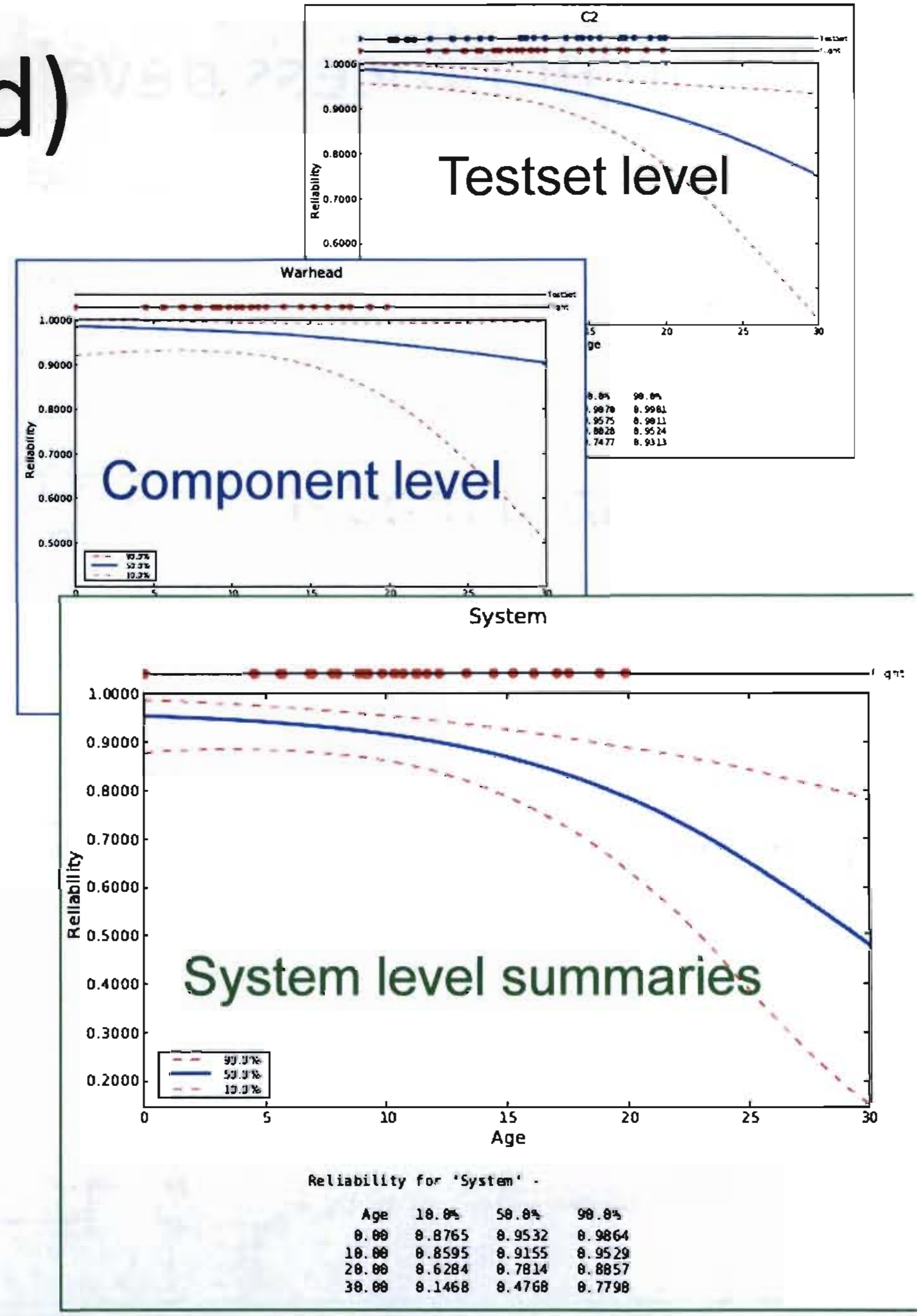
Age	NumTrans	Variant	WorstRel	LikelyRel	BestRel
0	0	Block1	0.9	0.97	1
0	0	Block2	0.9	0.97	1
0	0	Block3	0.9	0.97	1
20	49	Block1	0.7	0.85	0.9
20	49	Block2	0.65	0.8	0.9
20	49	Block3	0.65	0.8	0.9
%end					

Evolution (cont'd)

- Output as PDF and flat text

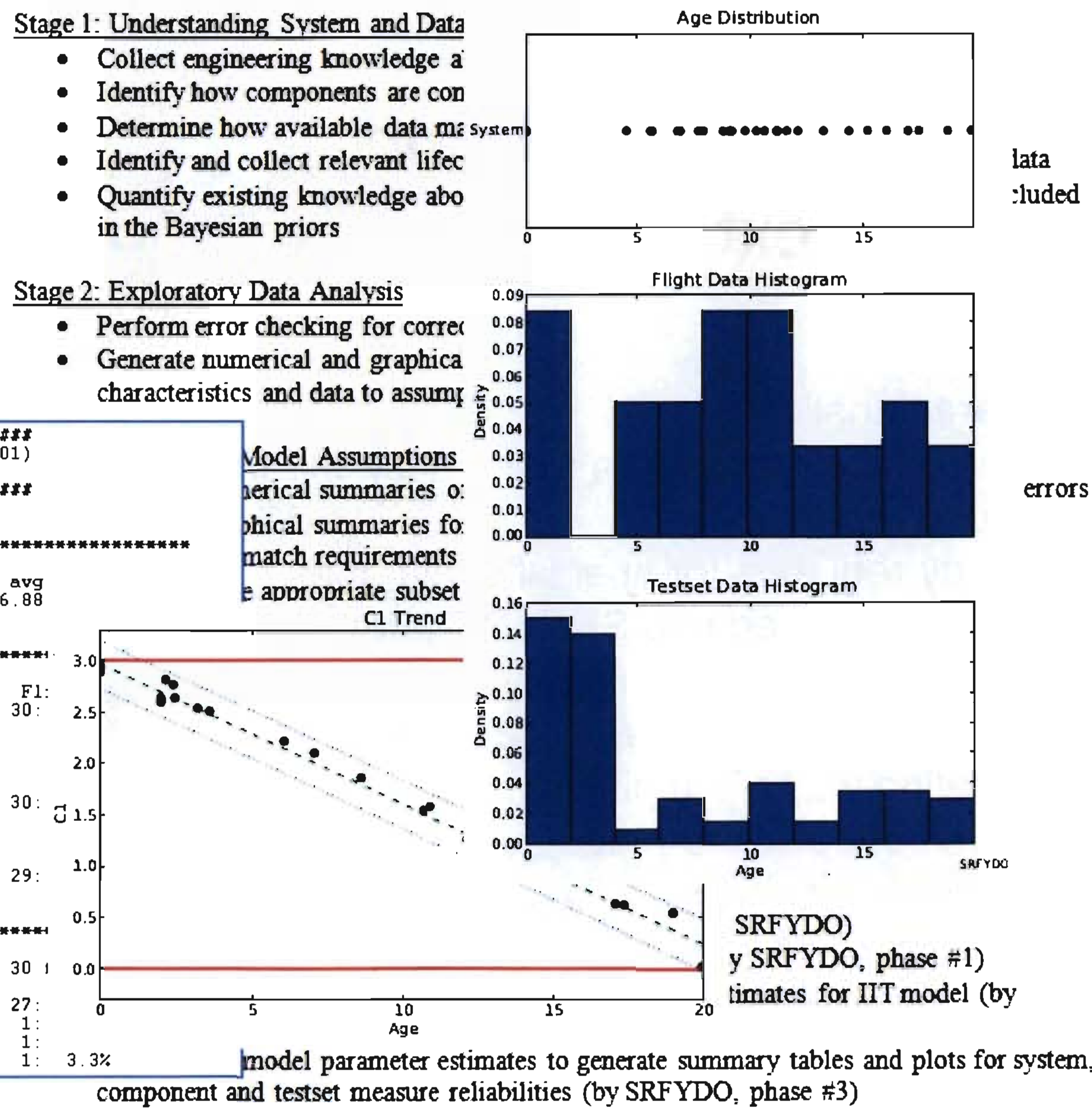
Characteristics:
- SMEs able to function more independently
- Much more timely
- Many requests for special summaries (often integrated into SRFYDO later)

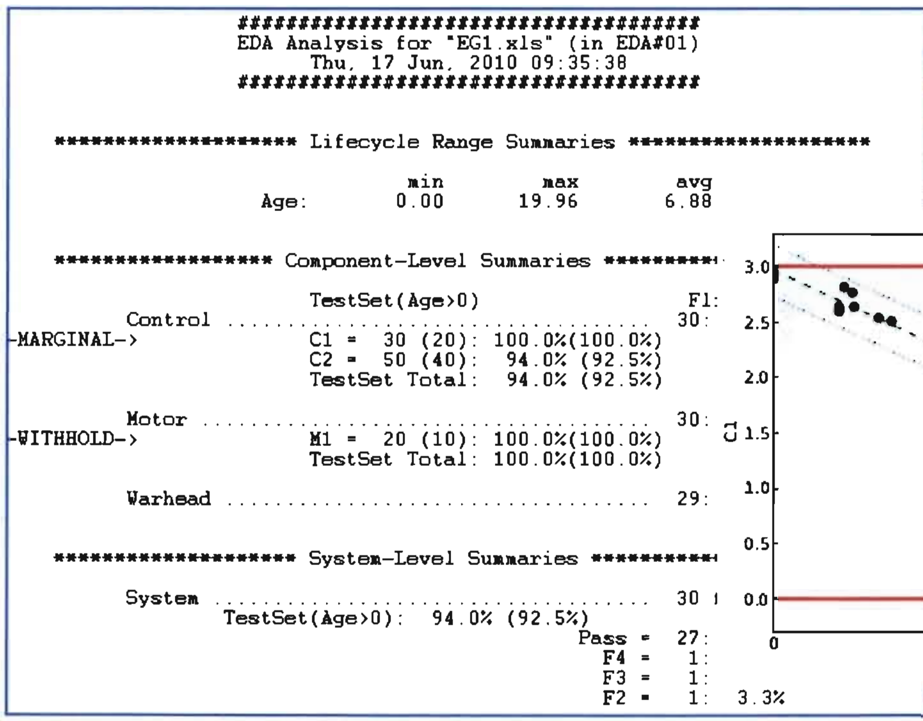
- When applied to new systems, system modeling was often difficult
- Much of data and model assumption checking that LANL did in early stages was not happening (constructing summaries in own software was easy to skip)



3. Larger process developed with EDA stage in SRFYDO

- EDA graphics
- Sanity checks
- Itemized model





The assumptions of the model are listed below:

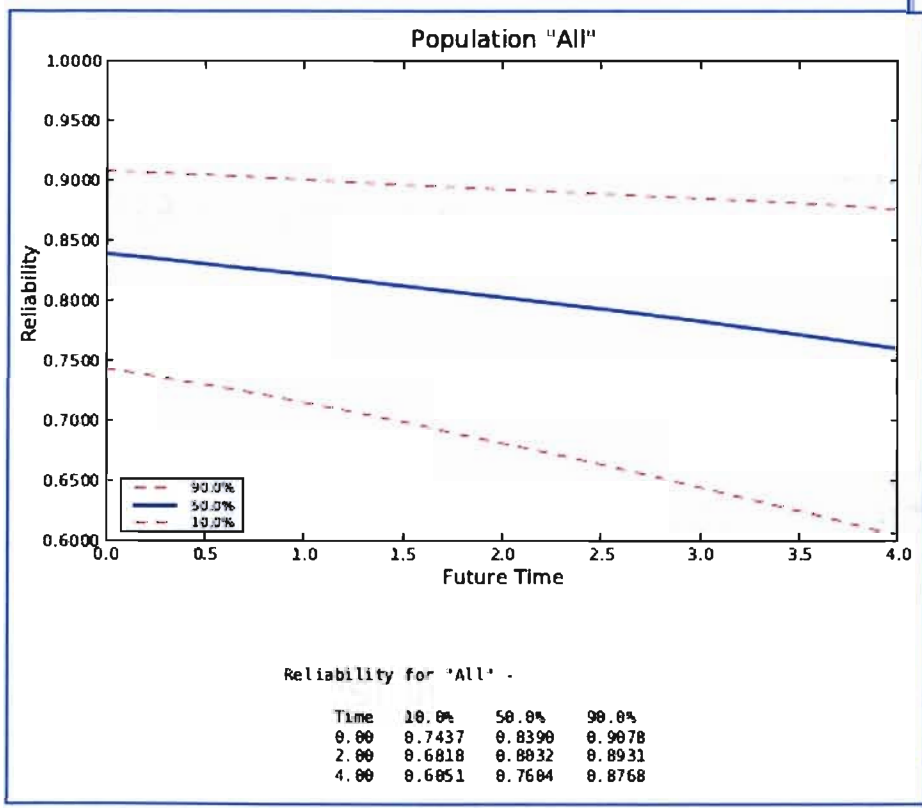
- System Structure
  1. System is a series system.
  2. Only critical testset measures are included in the analysis.
  3. Stockpile of systems is a homogeneous population (or we have lifecycle measures to distinguish between sub-populations.
- Matching Data Types
  4. Full system (flight) tests are considered the most accurate assessment of system reliability.
  5. Surrogacy assumption (systems selected for flight and testset tests have similar lifecycle properties and can be sensibly combined into a single analysis).
  6. Testset data limits correspond to operational limits for what is required of component during a full-system test.
- Testset data:
  7. Linear shift as component ages.
  8. Data at a given time are approximately normally di symmetric, non-extreme outliers).
  9. Only a single operational limit is important for failu
- Lifecycle covariates
  10. Lifecycle covariates not highly correlated.

Process for verifying assumptions:
- Engineering knowledge
- Examining summaries from EDA
- Both

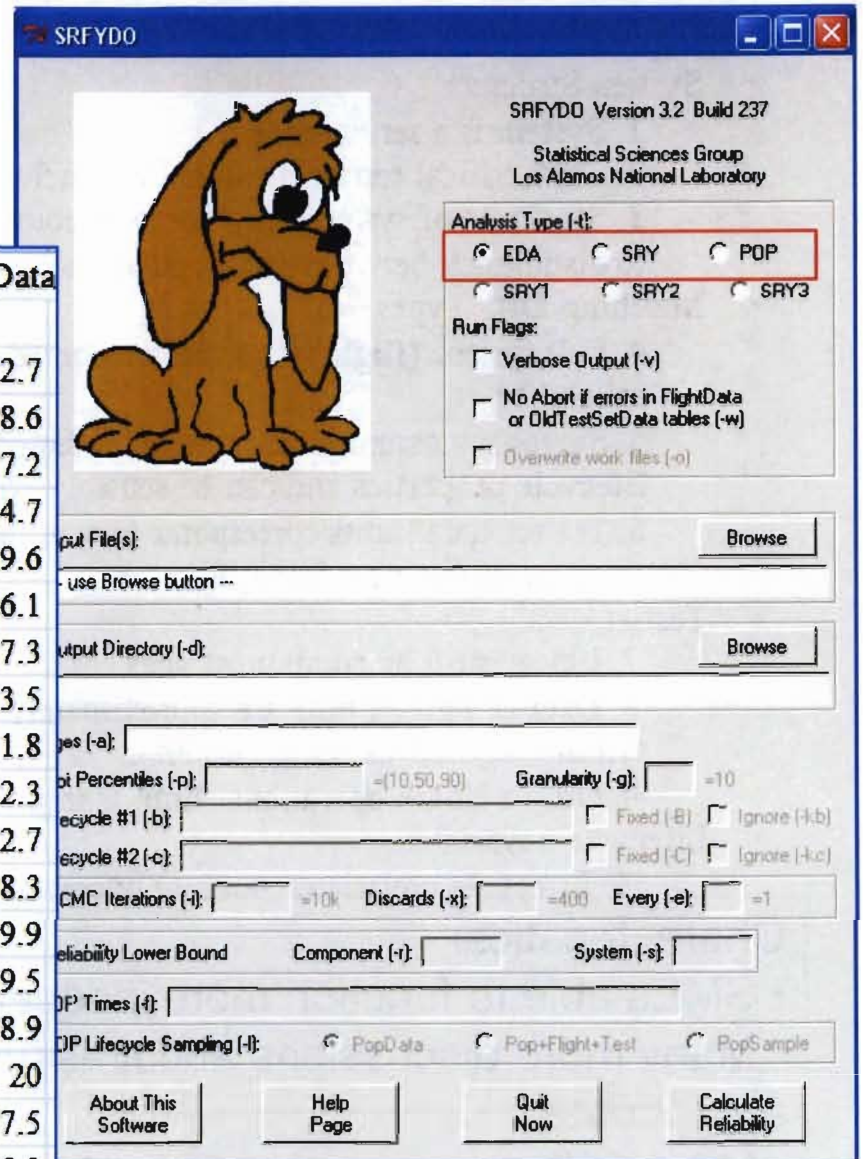
Characteristics:
- SMEs able to function more independently
- Many more discussions about assumptions and boundaries of where model appropriate
- Many fewer re-analyses (huge time-saving)
- More scalable – getting a new system ready for analysis more timely
- SME gaining confidence and expertise with method

4. New methodology added

- Population reliability for group of systems added (POP stage)

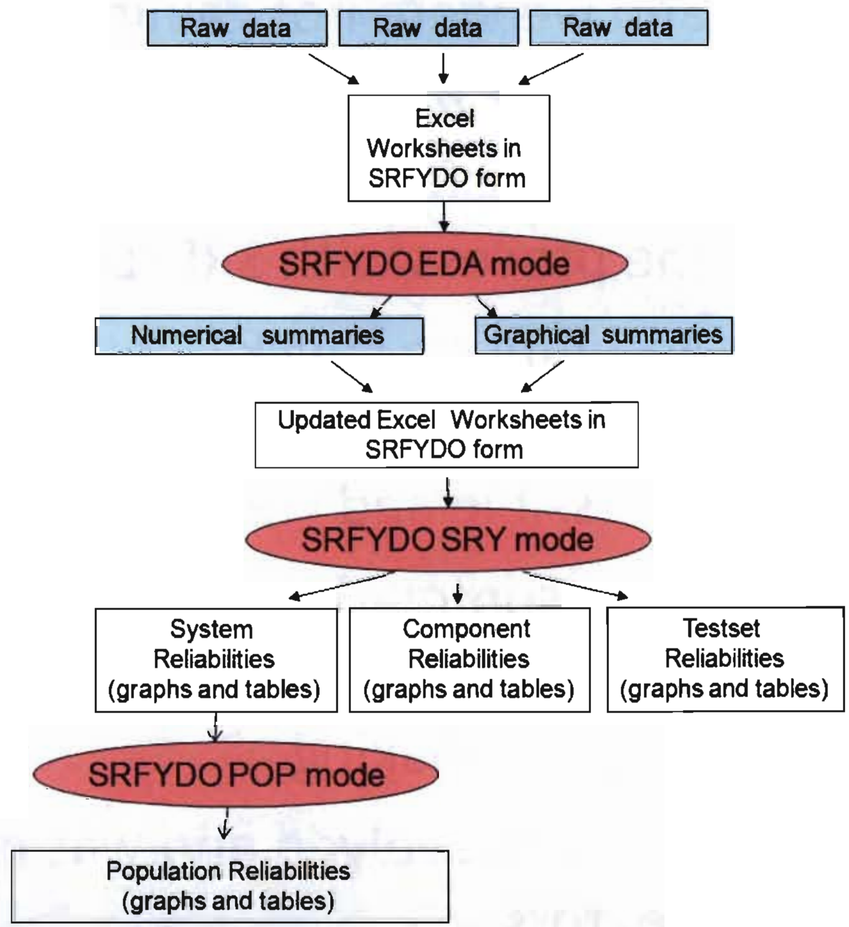


%PopData
Age
12.7
18.6
17.2
14.7
19.6
16.1
17.3
13.5
11.8
12.3
12.7
18.3
19.9
19.5
18.9
20
17.5
15.3
12.2
11.9



Final Product and Process

- SRFYDO is the computational engine to guide a process
- EDA mode uses common statistical summaries and graphics which builds in assumptions checking



- Systems analyzed range from:
  - 5 components with one variant
  - 35 components with 8 variants (60+ total components)

Users functioning relatively independently
LANL offers annual training and consulting support

Lessons Learned

- When the focus was on software, our scope was too limited and we were not gaining much traction
- The shift to a guided process (with built in tools for each step) was transformational to our success – the training focuses on the process with SRFYDO being its support
- Assumption check is intuitive for many statisticians, but is built on a foundation of statistical training – making this concrete, accessible and well defined for our customers was essential
- If the summaries / tools needed to perform an analysis are easily available, then the focus shifts to interpretation and decision-making
- The plan evolved and was driven by both the users and the creators

System Reliability - Conclusions

- The process for obtaining system reliability estimates using multiple sources of data using SRFYDO offers a way of incorporating relevant sub-system and component level data to supplement full-system data, which leads to better understanding and potential improvements to estimation and prediction precision
- It allows SMEs to use a sophisticated statistical approach without having to master all of the details of the analysis, but depends of engineering judgment to make sure we have answered the right question

SRFYDO runs on a PC (requires Python, JAVA and Excel) and is available to any US Government agency free of charge srfydo@lanl.gov

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Statistical Engineering - Conclusions

- Characteristics:
  - Satisfies a high-level need of the organization.
  - No known solution to the problem.
  - High degree of complexity involving both technical and non-technical challenges.
  - More than one statistical technique required for solution.
  - Long-term success requires imbedding solutions into work processes.
  - The whole is greater than the sum of the parts.
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Quality Engineering Special Issue on Statistical Engineering (March 2012): 17 papers – 2 panel papers, 3 general, 3 on SE education, 9 case studies

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