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Form 836 (7/06)

"Modeling the Reliability of Complex Systems with Multiple Data Sources: A Case Study on Making Statistical Tools Accessible to Engineers"

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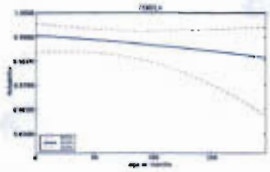
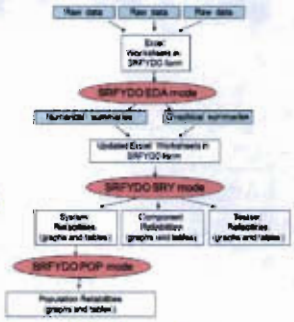
LANL

Estimating the reliability of complex systems, such as Department of Defense weapons, often involves using multiple data sources, including expensive and destructive full system tests, as well as non-destructive 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 with the goal of assisting the engineers with their analyses.

Modeling the Reliability of Complex Systems with Multiple Data Sources: A Case Study on Making Statistical Tools Accessible to Engineers





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May 2011

Outline

- 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

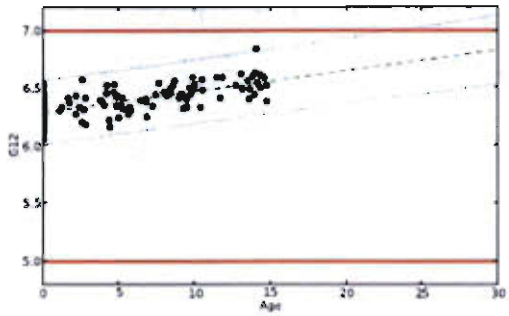
Motivation for New System Reliability Approach

Advantages of MSRA 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 and process to obtain results

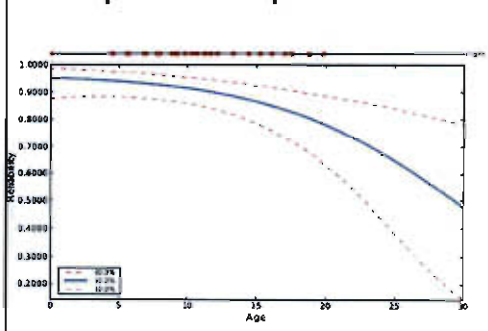
Advantage: Ability to predict failure before being observed in full-system test

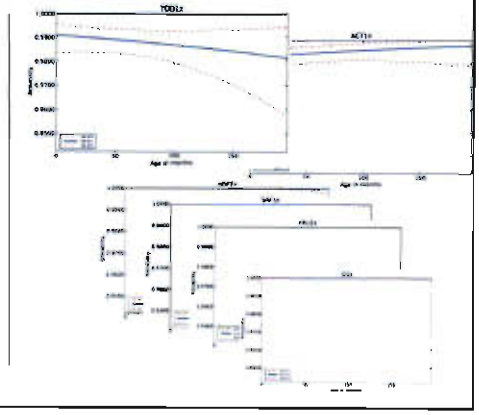


- Because we can track a trend in some of the continuous measurements, we can anticipate when failures might start to occur, before they actually have been observed

Advantage: Component Level Summaries

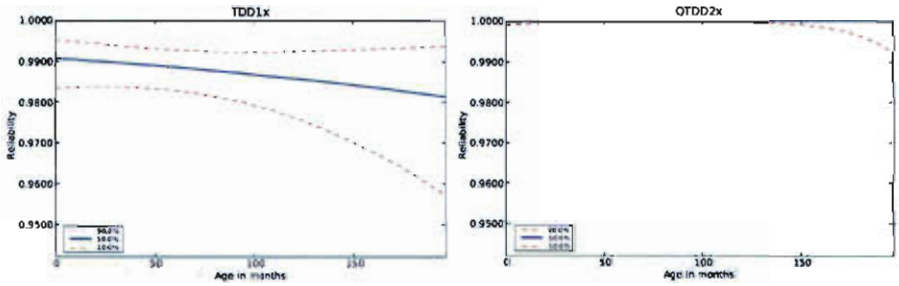
- Better understanding of system and important drivers of system reliability
- Ability to identify critical components and critical specs to implement corrective action





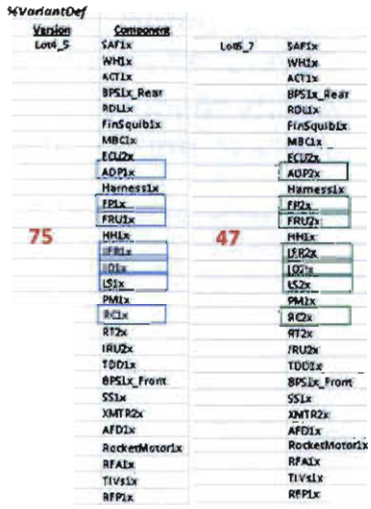
Advantage: Component Level Summaries (cont'd)

- 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

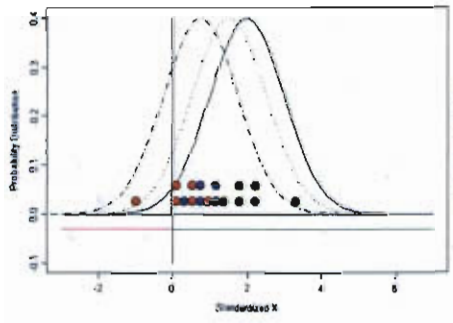


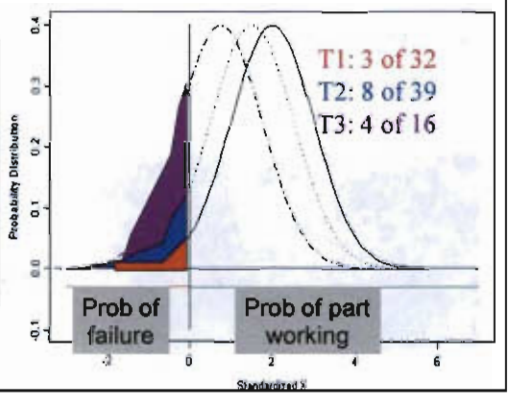
Basic Building Block

- 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

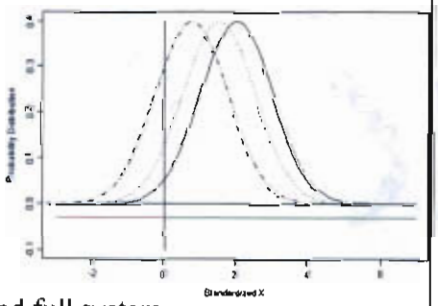




Statistical Formulation

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

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



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

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

γ_1^2 – variance of testset distribution

θ_1 – discrepancy between means of spec and full system

σ_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	Armament
2	3.19	2.64	Pass	1
2			Pass	1
2		2.6	Pass	1
2.06	3.23		Pass	2

%VariantDef

Variant
Block1

%ComponentDef

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

%FlightKey

Result	Variant
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

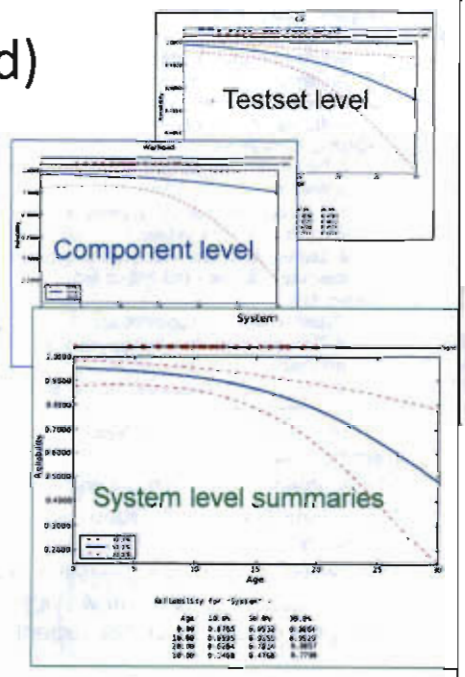
Missile	Age		NumTrans	Variant
891239		3.26	9	Block 1
891060		3.3	16	Block 1
891064		4.51	17	Block 1
891091		4.65	15	Block 1
891044		12.18	37	Block 1
891004		12.38	42	Block 1

%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



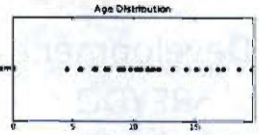
Characteristics:
- SMEs able to function more independently
- Much more timely
- Many requests for special summaries (often later integrated into SRFYDO)

- 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

Stage 1: Understanding System and Data
- Collect engineering knowledge a
- Identify how components are con
- Determine how available data ma
- Identify and collect relevant lifec
- Quantify existing knowledge abo in the Bayesian priors



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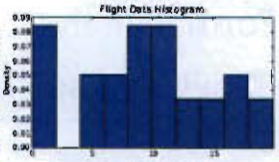
Stage 2: Exploratory Data Analysis
- Perform error checking for corre
- Generate numerical and graphica characteristics and data to assum



errors

Model Assumptions
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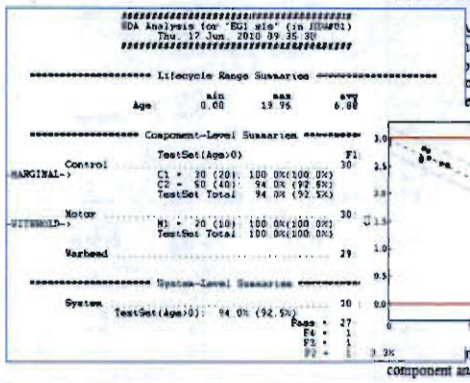
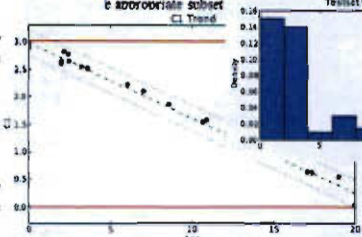
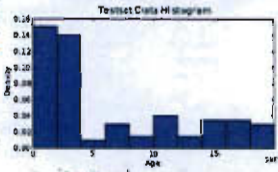
match requirements
e appropriate subset







SRFYDO)
y SRFYDO, phase #4)
timates for IIT model (by

model parameter estimates to generate summary tables and plots for system, component and testset measure reliabilities (by SRFYDO, phase #3)

The assumptions of the model are listed below:

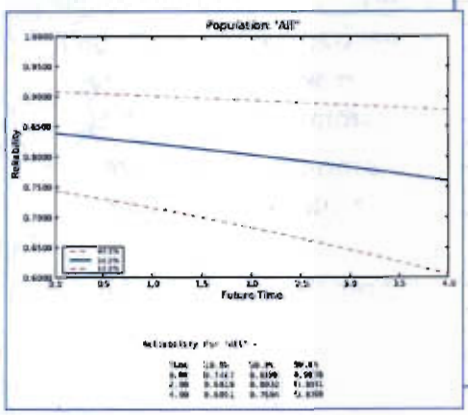
- System Structure
  1. System is a series system.
  2. Only critical testset measures are included in the analysis.
  3. Stockpile of systems is a homogeneous population (or we have lifecycle measures to distinguish between sub-populations.
- Matching Data Types
  4. Full system (flight) tests are considered 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 failt
- 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

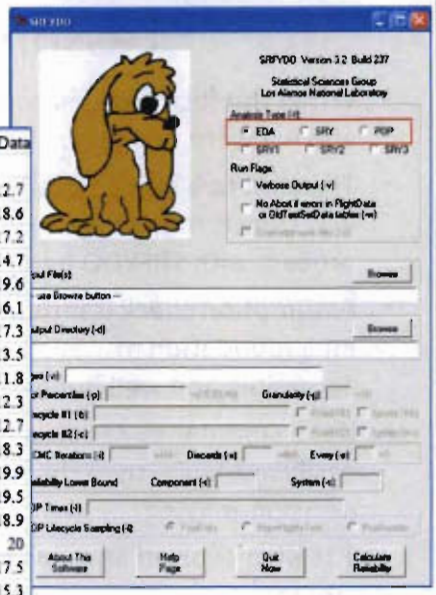
4. New methodology added

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



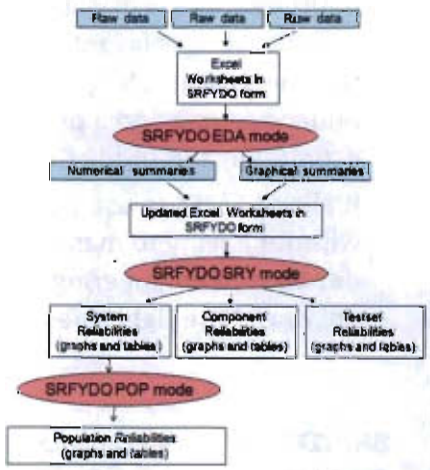
%PopData

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 transforming 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

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 a potential improvement to the precision of estimation and prediction
- 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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