LA-UR- 11-06252

Approved for public release; distribution is unlimited.

Title:	TCG-XIV Complex System Health Assessment Research: Improving Reliability Estimates with Environmental Data and Pareto Fronts for Multiple Objective Resource Allocation Optimization
Author(s):	Christine Anderson-Cook
Intended for:	Joint Munitions Program All TCG Meeting November 2011

Form 836 (7/06)

TCG-XIV Complex System Health Assessment Research: Improving Reliability Estimates with Environmental Data and Pareto Fronts for Multiple Objective Resource Allocation Optimization

Christine Anderson-Cook

Abstract

In this presentation intended for the general Joint Munitions Program audience, an overview of the project will be given. In addition, technical highlights from the past year will be discussed. Two case studies are presented which consider improving reliability for complex systems by incorporating environmental summaries, as well as selecting a best new set of data to collect to maximally improve prediction at the system and sub-system levels.

UNCLASSIFIED

LA-UR 11-

TCG-XIV Complex System Health Assessment Research: Improving Reliability Estimates with Environmental Data and Pareto Fronts for Multiple Objective Resource Allocation Optimization

Christine Anderson-Cook, Ph.D.
LANL
candcook@lanl.gov

November 2011

Los Alamos NATIONAL LABORATORY EST. 1943

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

UNCLASSIFIED

NNSA

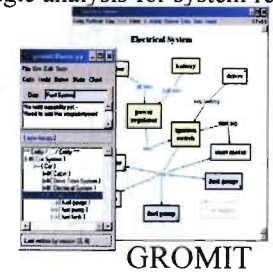
UNCLASSIFIED

History of LANL Projects in TCG-XIV

MSRA

2003

Developing statistical tools to combine multiple data sources into a single analysis for system reliability estimation



GROMIT

SRFYDO

2010

CSHA

2015

- Expand statistical methodology and tools to incorporate more data types (Environmental and handling)
- Broaden definition from reliability to system health
- Provide tools to directly assist with decision-making for management of stockpiles

Los Alamos NATIONAL LABORATORY EST. 1943

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

UNCLASSIFIED

Slide 1

NNSA

Complex System Health Assessment (TCG XIV)

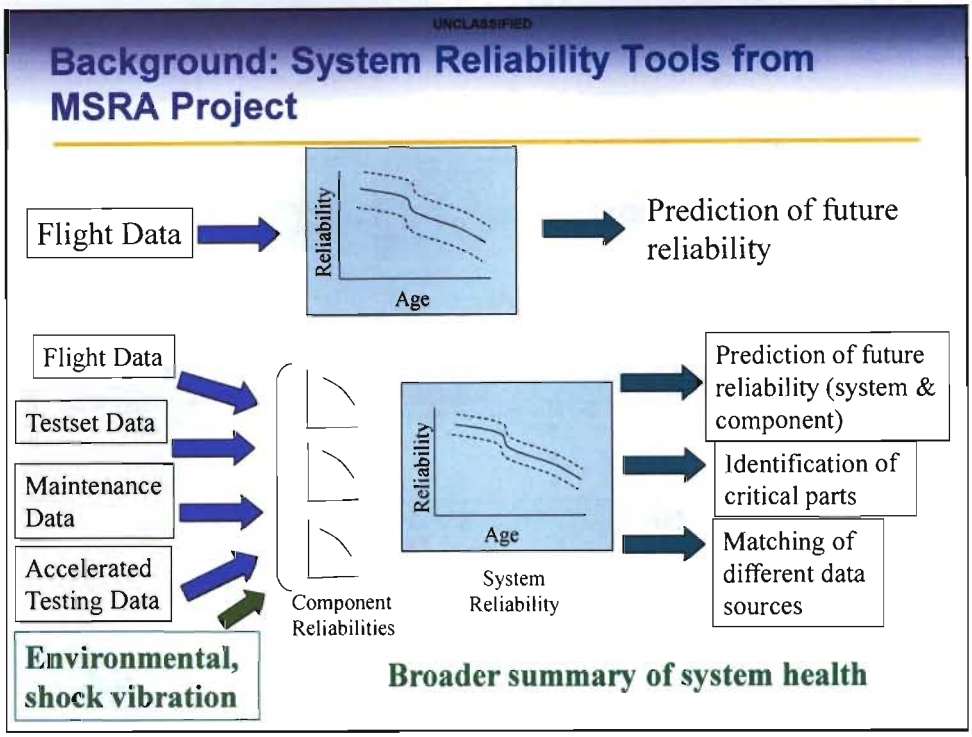
- Goal/Objective: Provide a suite of methods and tools for assessing and managing the health of complex systems using a variety of different data types.
- Approach:
  1. Combining environmental and condition-based measures with engineering mechanisms for individual components to help manage stockpiles of complex system using a cost-benefit framework.
  2. Enhance and expand the methods and tools developed as part of the Reliability Assessment methods (developed in Munitions Stockpile Reliability Assessment project 2003-2010) for system modeling and statistical health assessment.
  3. Incorporate newly developed Prognostics and Health Management (PHM) methodology into system reliability modeling and analysis methods and tools.
  4. Transition methods and tools to DoD and DOE systems.
- Project timeline: Started 2010, projected ending 2015

Outline

- Background
- Case study 1 – incorporating environmental data to improve reliability estimate
- Case study 2 – selecting a best resource allocation strategy based on multiple objectives
- Plan for remainder of FY12

UNCLASSIFIED

Background: System Reliability Tools from MSRA Project



UNCLASSIFIED

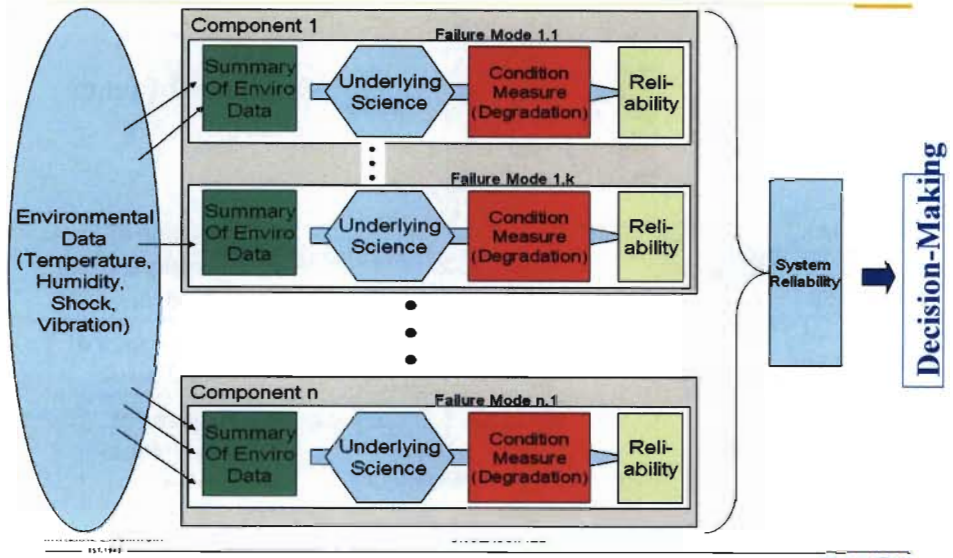
CSHA: 2 Tasks

- Prognostics and Health Management
  - Using individual system exposures (temperature, humidity, shock, vibration) to improve precision and accuracy of prediction of system health or reliability*
  - Leverages new technology to monitor storage conditions
- System Assessment
  - Statistical methods to assess and compare data collection alternatives (resource allocation)*
  - Statistical methods to quantify benefits of different usage stratgies
  - Better models to accommodate discrepancies between data types
  - Better models for extrapolating usage patterns

* More details with case study

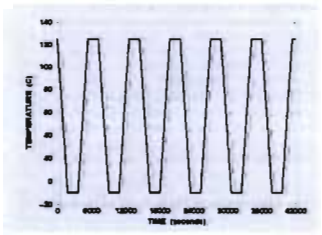
PHM – Details

Connection of Environmental Data to Reliability

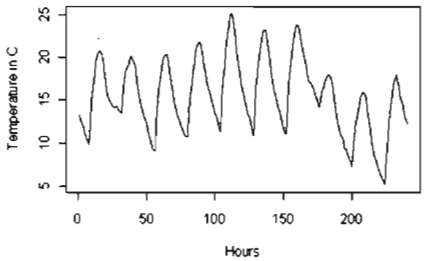


PHM Case Study: Single Failure Mode (Component Level)

- Solder Joint Failures (leveraging model from SNL project)
  - Modeling λ, **microstructural coarsening percentage (**MCP), as a function of age and temperature
  - Failure thought to occur when $\lambda \geq \lambda_{fail}$



Lab cycling

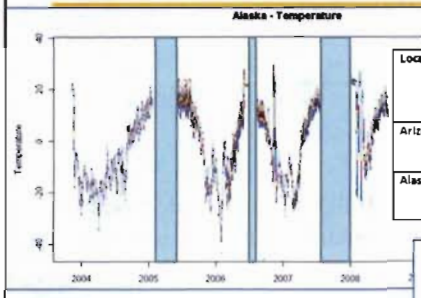


Sample Field observations (SNL Yuma, AZ storage data)

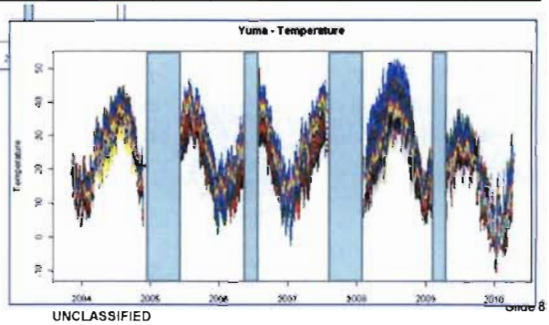
Los Alamos NATIONAL LABORATORY

UNCLASSIFIED

SNL Storage Data (Alaska and Arizona)



Location	#Days	% Missing	Ave Temp	Ave Temp Amp	Ave Daily Min/Max Temp	Ave RH	Ave RH Amp	Ave Daily Min/Max RH
Arizona	2353	19.3	23.18	12.5	16.73 / 29.22	33.37	4.58	31.13 / 37.65
Alaska	2353	14.8	3.25	5.37	-0.36 / 5.01	54.43	2.89	53.10 / 56.00



Used as basis for generating 400 sets of environmental data with characteristics between these extremes

Los Alamos NATIONAL LABORATORY EST.1943

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

UNCLASSIFIED

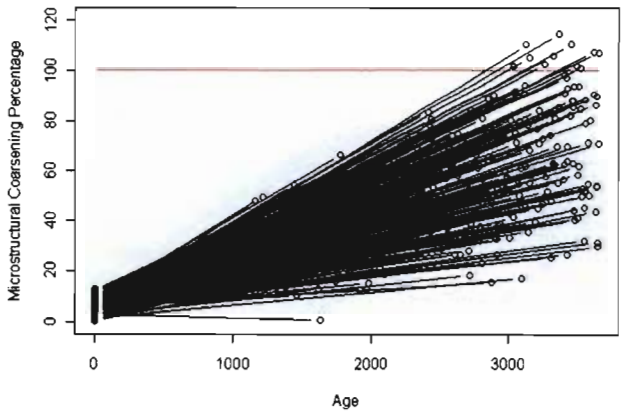
NNSA

Joint DoD/DOE Munitions Technology Development Program

Slide 8

UNCLASSIFIED

MCP over Aging



2 observations of MCP (age = 0, age in [3,10] years)

Failure assumed when MCP ≥ 100%

Variability of measures at age 0 is [0%,15%]

Goal: improve quality of prediction over using just age alone

Los Alamos NATIONAL LABORATORY EST.1943

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

UNCLASSIFIED

NNSA

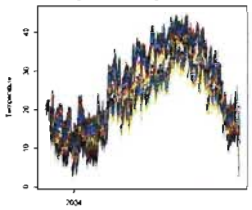
Joint DoD/DOE Munitions Technology Development Program

Slide 9

UNCLASSIFIED

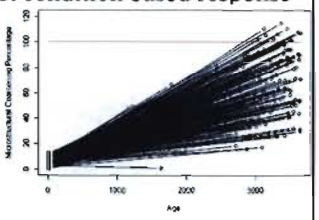
Statistical Approach

Daily / Hourly Data



Numerical Summaries

Build many possible models to predict condition based response



Model selection (based on good prediction)

Prediction model:
-Time to failure
- condition value

Rank	BIC Value	Posterior Probability	Model Terms
1	1725.98	0.1186	Age + "Age x DTMean" + "Age x DTAmp"
2	1726.01	0.1172	Age + "Age x TMean" + "Age x DTAmp"
3	1729.35	0.0220	Age + Corr + "Age x DTMean" + "Age x DTAmp"
4	1729.37	0.0217	Age + Corr + "Age x TMean" + "Age x DTAmp"
5	1729.40	0.0213	Age + "Age x DTMean" + "Age x DTAmp" + "Age x DR-Mean"
6	1729.40	0.0213	Age + "Age x DTMean" + "Age x DTAmp" + "Age x RHMean"
7	1729.42	0.0211	Age + "Age x TMean" + "Age x DTAmp" + "Age x DRMean"
8	1729.42	0.0211	Age + "Age x TMean" + "Age x DTAmp" + "Age x RHMean"

Los Alamos NATIONAL LABORATORY EST. 1943

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

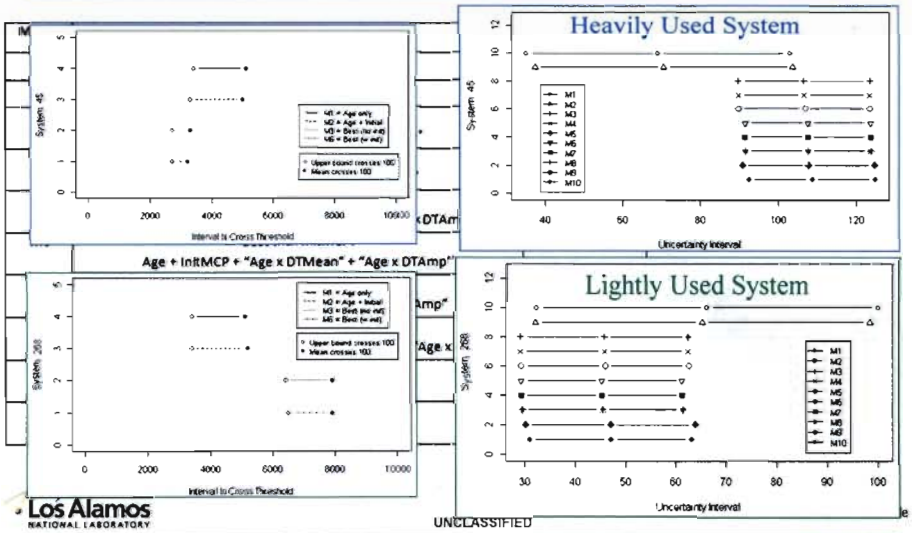
Slide 10

NNSA

Joint DoD/DOE Munitions Technology Development Program

UNCLASSIFIED

Comparison to Non-Environmental Data



Los Alamos NATIONAL LABORATORY EST. 1943

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

UNCLASSIFIED

NNSA

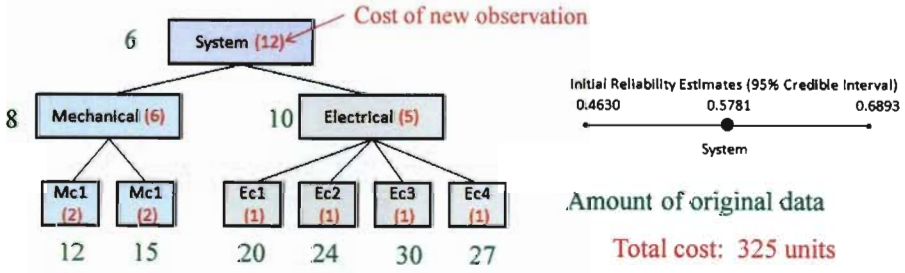
Joint DoD/DOE Munitions Technology Development Program

Summary of Results

- Underlying degradation model guided choice of summaries of environmental data to explore
- When compared to just age alone, including temperature average and amplitude summaries led to a reduction in uncertainty for predicting
  - MCP value
  - Time until anticipated failure
- Long term goal:
  - Improve precision of reliability estimate with environmental data based model of component failure modes
  - Make data collection / storage efficient for individual monitors (eg. If failure mode model only uses "age", "average temperature", "average temperature amplitude" then data stored is minimal)

System Reliability Case Study: What new data to collect?

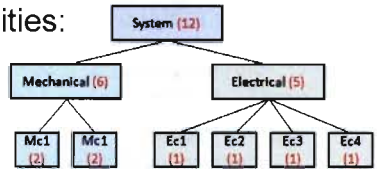
- Given the results of an existing reliability analysis based on multiple sources of data, what new data should we collect to **maximally improve** our estimation?



- What new data should we collect?
- What basis should we use for choosing?
- How do we justify what is best for our goals?

Goal of New Data Collection for our Example

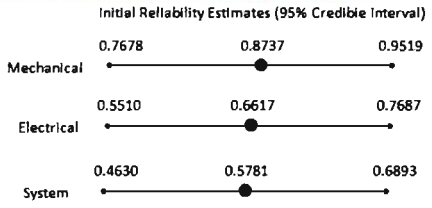
- Engineers would like to improve the precision of estimation for the following 3 quantities:
  - System reliability estimate
  - Mechanical Sub-system
  - Electrical Sub-system



- Focus on the width of the credible interval:

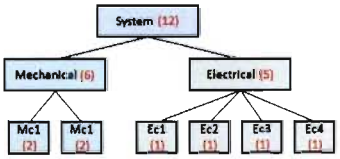
Goal: Reduce the width of each of these 3 intervals as much as possible

Baseline:



Allocations Possible

25 possible allocations:
-All have same total cost
- Good variety of where data are collected



Results									
Mc1	Mc2	Ec1	Ec2	Ec3	Ec4	Mechanical	Electronic	System	Alloc. #
0	0	0	0	0	0	0	0	10	1
0	0	0	0	0	0	20	0	0	2
0	0	0	0	0	0	0	24	0	3
0	0	0	0	0	0	10	0	5	4
0	0	0	0	0	0	0	12	5	5
0	0	0	0	0	0	10	12	0	6
15	15	0	0	0	0	0	0	5	7
0	0	15	15	15	15	0	0	5	8
8	7	0	0	0	0	5	0	5	9
0	0	9	8	6	7	5	0	5	10
0	0	9	8	6	7	0	6	5	11
8	7	0	0	0	0	0	6	5	12
8	7	9	8	6	7	0	0	5	13
16	14	0	0	0	0	10	0	0	14
8	7	9	8	6	7	10	0	0	15
0	0	18	16	12	14	0	12	0	16
8	7	9	8	6	7	0	12	0	17
8	7	0	0	0	0	5	12	0	18
0	0	9	8	6	7	5	12	0	19
0	0	9	8	6	7	10	6	0	20
8	7	0	0	0	0	10	6	0	21
30	30	0	0	0	0	0	0	0	22
0	0	30	30	30	30	0	0	0	23
15	15	15	15	15	15	0	0	0	24
17	13	18	16	12	14	0	0	0	25

Initial:
0.1841 0.2177 0.2263

Results of Analysis for 25 Allocations

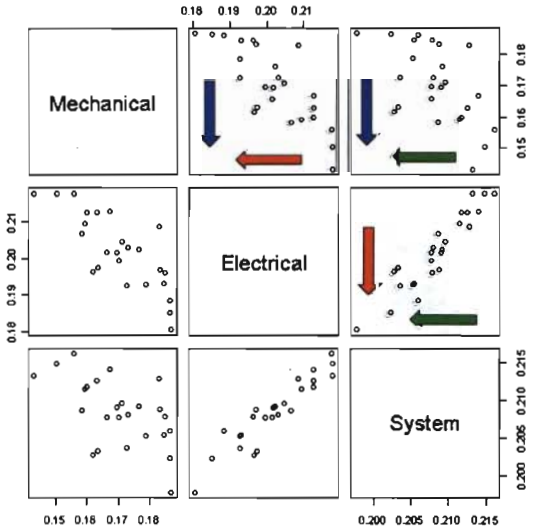
Mc1	Mc2	Ec1	Ec2	Ec3	Ec4	Mechanical	Electronic	System	Alloc. #	Mechanical	Electrical	System
0	0	0	0	0	0	0	0	10	1	0.182896	0.208562	0.212798
0	0	0	0	0	0	20	0	0	2	0.155939	0.217593	0.216135
0	0	0	0	0	0	0	24	0	3	0.186184	0.188425	0.205978
0	0	0	0	0	0	10	0	5	4	0.167084	0.212652	0.213953
0	0	0	0	0	0	0	12	5	5	0.183102	0.196996	0.208728
0	0	0	0	0	0	10	12	0	6	0.169521	0.201595	0.208982
15	15	0	0	0	0	0	0	5	7	0.160029	0.212583	0.211654
0	0	15	15	15	15	0	0	5	8	0.184335	0.193014	0.20547
8	7	0	0	0	0	5	0	5	9	0.163004	0.212495	0.212505
0	0	9	8	6	7	5	0	5	10	0.176321	0.202387	0.209188
0	0	9	8	6	7	0	6	5	11	0.184579	0.196233	0.207769
8	7	0	0	0	0	0	6	5	12	0.171135	0.204599	0.20955
8	7	9	8	6	7	0	0	5	13	0.172838	0.202965	0.208023
16	14	0	0	0	0	10	0	0	14	0.150264	0.217789	0.214795
8	7	9	8	6	7	10	0	0	15	0.158434	0.206712	0.20864
0	0	18	16	12	14	0	12	0	16	0.186341	0.185205	0.202329
8	7	9	8	6	7	0	12	0	17	0.17274	0.192642	0.203601
8	7	0	0	0	0	5	12	0	18	0.166135	0.201575	0.207661
0	0	9	8	6	7	5	12	0	19	0.178806	0.19274	0.205274
0	0	9	8	6	7	10	6	0	20	0.169961	0.199462	0.207632
8	7	0	0	0	0	10	6	0	21	0.159256	0.209364	0.211409
30	30	0	0	0	0	0	0	0	22	0.143072	0.217661	0.213209
0	0	30	30	30	30	0	0	0	23	0.186722	0.18047	0.19775
15	15	15	15	15	15	0	0	0	24	0.163415	0.197407	0.203219
17	13	18	16	12	14	0	0	0	25	0.161928	0.196507	0.20274

Slide 16

Credible Interval Results for 25 allocations

Recall: Goal is to minimize the width of the credible interval for each of:

- System
- Mechanical
- Electrical



Los Alamos NATIONAL LABORATORY EST. 1943

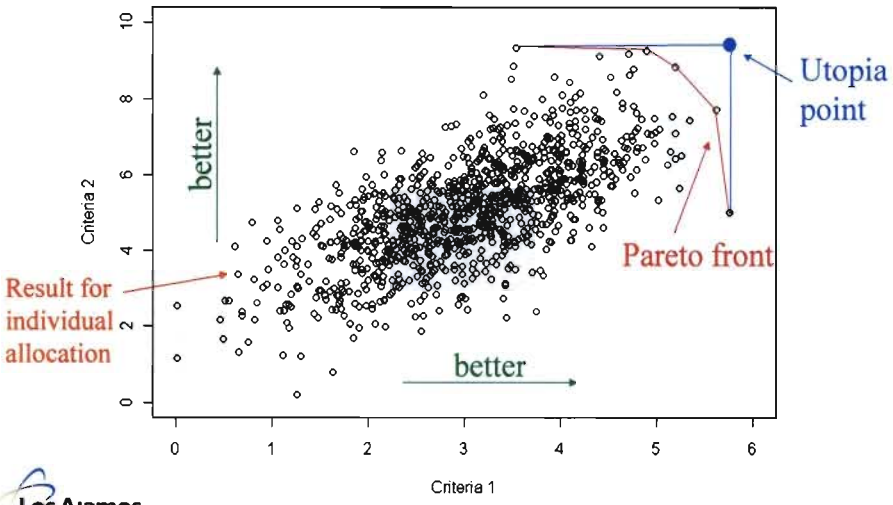
Operated by the Los Alamos National Security, LLC for the DOE/NNSA

NNSA

Joint DoD/DOE Munitions Technology Development Program

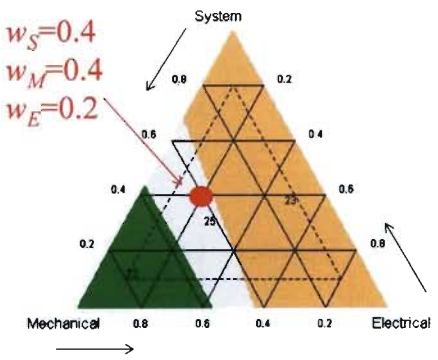
7

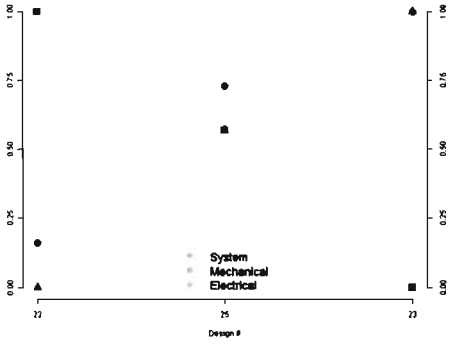
The Pareto Frontier Approach



Finding Best Allocation for All Weightings of Criteria (Additive)

$$Desirability = w_S CW_S + w_M CW_M + w_E CW_E$$





Mc1	Mc2	Ec1	Ec2	Ec3	Ec4	Mechanical	Electronic	System	Alloc. #
30	30	0	0	0	0	0	0	0	22
0	0	30	30	30	30	0	0	0	23
15	15	15	15	15	15	0	0	0	24
17	13	18	16	12	14	0	0	0	25

Summary of Results

- Uses methodology to evaluate anticipated improvement in prediction before data are collected
- Pareto method can divide allocations into 2 categories
  - Eliminate from further consideration – not ideal under any scenario
  - Candidates for further study – best for some scenario
- Graphical summaries allow for choice of best allocation to suit decision-maker's priorities
- Can expand to do a search for best allocation possible

Update & Plan Forward – PHM & SA

- Prognostics and Health Management
  - Currently working on EXCEL tool to take raw data from individual systems and convert into system level summaries to be used as input to statistical analysis
  - Develop generalized methodology for incorporating environmental data to model general component level failure modes
  - REAL DATA WANTED (candcook@lanl.gov)
- System Assessment
  - Case study to demonstrate Pareto front optimization for management of stockpile (order of which units to use when)

References

- **Anderson-Cook, C.M. (2011) "Using Individual System Temperature and Humidity Storage Data to Improve Precision and Accuracy of Solder Joint Condition-Based Reliability Estimates – A Case Study" LANL Tech Report, LAUR 11-05046 (34 pages)**
- **Anderson-Cook, C.M., Chapman, J., Lu, L. (2011) "Selecting a Best Allocation of New Data for Improving Estimation Precision of System and Sub-System Reliability using Pareto Fronts: A Demonstration" LANL Technical Report, LAUR 11-05479 (25 pages)**
- Anderson-Cook, C.M., Huzurbazar, A.V., Graves, T.L., Hamada, M.S., Kelly, E., Klamann, R., Lawrence, E., Morzinski, J., Vander Wiel, S., Wilson, A. (2011) "Summary of Statistical Reliability Methods and Tools Development as part of the Enhanced Surveillance Campaign (ESC) and Joint Munitions Program (JMP)" LANL Technical Report, LAUR 11-01703 (376 pages)
- Chapman, J., Morris, M., Anderson-Cook, C.M. (2011) "A Computationally Efficient Strategy for Evaluating the Estimation Improvement for Candidates in a Resource Allocation Study" LANL Technical Report LA-UR 10-04501
- Pintar, A., Anderson-Cook, C.M., Wu, H. (2011a) "Model Selection for Good Estimation and Prediction Over a User-Specified Covariate Distribution for Linear Models Under the Frequentist Paradigm" LANL Technical Report LA-UR 11-04729
- Pintar, A., Anderson-Cook, C.M., Wu, H. (2011b) "Prediction-Based Model Selection for Bayesian Multiple Regression Models" LANL Technical Report LA-UR 11-04735