



# 712CD

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# Operational Forecasting Capabilities Supporting Preparatory Sustainment Battle Command



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# Overview

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- **Problem Statement**
- **Defining Sustainment Battle Command**
- **The Future Force**
- **The Model**
- **Nearly Orthogonal Latin Hypercube (NOLH)**
- **The Design of Experiments**
- **Results**
- **The Way Ahead**
- **Conclusion**

# Problem Statement

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- **Combatant Commander's Future Force:**
  - Technologically advanced, Net-centric, Dynamically distributed, Rapidly generated.
- **Control Through Sustainment Battle Command (SBC):**
  - Provides a conduit for:
    - Technologically enhanced information centralization / distribution.
    - Building/sustaining combat power
    - Identifying, mobilizing, and delivering:
      - the right requirements,
      - to the right locations,
      - in the right quantities,
      - at the right time.
  - **Absolutely critical to build and sustain the necessary combat power during all phases of combat operations.**

# What is Sustainment Battle Command?

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***“The application of leadership and decision making to the planning and execution of sustainment operations in support of combat.”***

- **Demonstrates the proficiency of Logistics Commanders to support the combat mission.**
- **Characterized by leadership and decision making.**
- **Emphasizes choices have substantial impact upon the available capabilities of the combatant commanders.**

# The Future Force

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- **Future Combat System Brigade Combat Team (FCS BCT):**
  - 4 Combined Arms Battalions (CAB).
  - 8 FCS Manned Combat Systems.
  - 2 FCS Unmanned Combat Systems.
  - 5 Contemporary Combat Systems.
  - 1094 Total Vehicles.
- **FCS Operational Mode Summary/Mission Profile (OMS/MP) (2006):**
  - Maintenance/Reliability Data collected from Vector in Command:
    - Generic 72 hour Caspian Sea scenario.
    - Three sets of missions for three Major Combat Operations (MCO).
  - TRAC-LEE converted Mean Miles Between Failure (MMBF) to Mean Time Between Failure (MTBF) Reliability Data.

# The Model

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- **Dynamic Sustainment/Logistics Battle Command:**

Developer	TRADOC Analysis Center- Monterey
Development Collaborators	TRAC-LEE, TRAC-WSMR, AMSAA, TRAC-FLVN, CASCOM
Primary User	TRAC-LEE Sustainment Analysts
Primary Use	FCS FY07 OSD Review

- **Command-line run Java program.**
- **Simkit implementation with complete event graph diagram.**
- **Simulates Class IX material consumption throughout the course of a scenario.**

# NOLH

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- **Nearly Orthogonal Latin Hypercube (NOLH):**
  - **Efficient, “space-filling”, all-purpose design generating a wide variety of factor level combinations.**
  - **Flexibility of Design and Analysis:**
    - **Many fewer design points required compared to traditional designs such as factorials.**
    - **Few limits on # of factors, # levels, sampling budget.**
    - **Allows broad exploration of the dynamic solution space.**
    - **Facilitates mathematical modeling of multiple MOE’s .**
  - **Effective screening tool for identifying threshold settings, non-linear results, and multiple higher-order interactions.**

# The Design of Experiments (DOE)

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- **Meta-Modeling: Build a statistical model of the simulation model.**
- **Nearly Orthogonal Latin Hypercube (NOLH) and Critical Factors:**
  - **Design NOLH DOE encompassing current DS input parameters.**
  - **Perform influence analysis, based upon results of baseline scenario and NOLH design.**
  - **Identify critical input factors.**
  - **Develop relationship between input factors and forecasting methodology.**
  - **Identify critical MOE's / MOP's.**

# DOE Factor Development

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- **Over 150 Model Input Parameters.**
- **Screened to 10 Input Factors:**
  - **Failure Dist Scaling:**
    - The rate at which any type of failure occurs onboard any vehicle in the BCT.
  - **Consumable Dist Scaling:**
    - The rate at which parts arrive to fill material requirements.  
“Velocity of parts.”
  - **Auto/Comm Parameter Scaling:**
    - The number of automotive and communication mechanics assigned to the two major groupings of repair teams- (1,2,3 CRT) and (Rear CRT).
  - **Work Rule Limits:**
    - Maximum number of hours a mechanic can work per day.
  - **Prob Crew Repair Damage:**
    - The probability the vehicle crew can repair damage to the vehicle.
  - **Prob Crew Repair Reliability**
    - The probability the vehicle crew can repair reliability failures to the vehicle.
  - **Prob Correct Diagnosis:**
    - The probability the repair team correctly diagnoses the problem.

# DOE Factor Settings

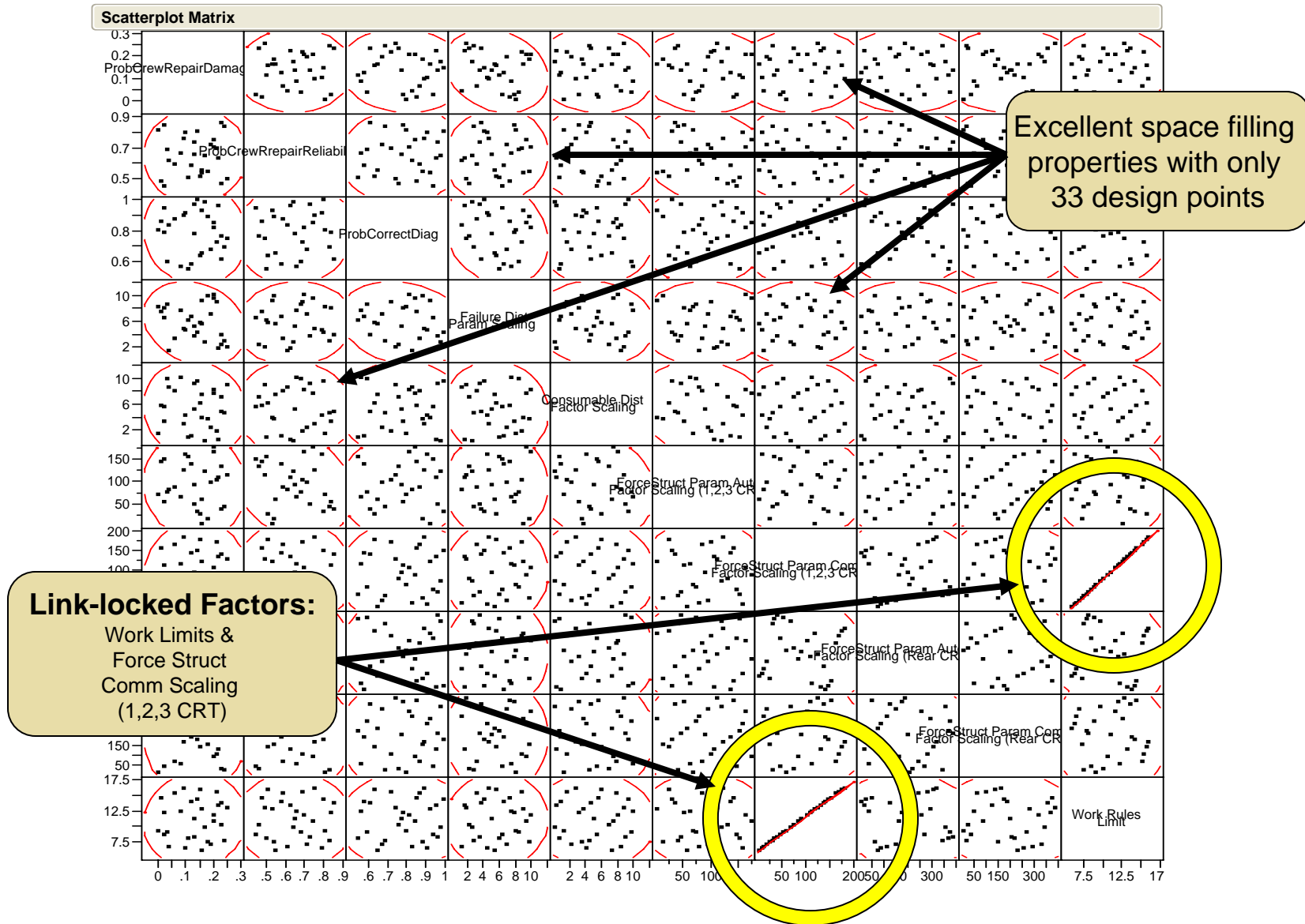
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- **Factors Set to 33 Levels.**
- **Factor Range Settings:**
  - **Failure Dist Scaling- 1/10x to 10x of Baseline**
  - **Consumable Dist Scaling- 1/10x to 10x of Baseline**
  - **Auto/Comm Parameter Scaling- 1/10x to 10x of Baseline (4 Sets)**
  - **Work Rule Limits- 6 hrs to 16 hrs**
  - **Prob Crew Repair Damage- 0.0 to 0.4**
  - **Prob Crew Repair Reliability- 0.4 to 0.8**
  - **Prob Correct Diagnosis- 0.65 to 0.99**
- **MOE Focus: Force Operational Availability (Ao).**
- **Future work will include a broader set of MOE.**

# DOE Correlation

	ProbCrew RepDmg	ProbCrew RepReliab	ProbCorrect Diag	FailureDist ParamScale	ConsumDist ParamScale	ForceStruct AutoScale (1,2,3 CRT)	ForceStruct CommScale (1,2,3 CRT)	ForceStruct AutoScale (Rear CRT)	ForceStruct CommScale (Rear CRT)	Work Rules Limit
ProbCrew RepDmg	1									
ProbCrew RepReliab	0.009223	1								
ProbCorrect Diag	0.000924	0.004606	1							
FailureDist ParamScale	0.011228	0.002649	-0.004974	1						
ConsumDist ParamScale	-0.029114	0.008934	-0.027099	0.001149	1					
ForceStruct AutoScale (1,2,3 CRT)	-0.005127	0.001771	-0.016154	-0.001386	0.005126	1				
ForceStruct CommScale (1,2,3 CRT)	0.029021	0.000282	0.006633	-0.008075	-0.003287	0.006641	1			
ForceStruct AutoScale (Rear CRT)	-0.008467	0.000285	-0.002233	-0.001034	-0.016339	0.009335	-0.001664	1		
ForceStruct CommScale (Rear CRT)	0.020147	-0.006441	-0.001670	0.001898	0.014490	0.001798	0.015876	-0.006718	1	
Work Rules Limit	0.030000	-0.002055	0.005395	-0.007321	-0.001437	0.007967	0.999985	-0.001846	0.015084	1

# DOE Space-Filling



# Results: *A<sub>o</sub> Alpha Meta-Model*

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## Summary of Fit

RSquare	0.996738
RSquare Adj	0.996521
Root Mean Square Error	0.005608
Mean of Response	0.94959
Observations (or Sum Wgts)	33

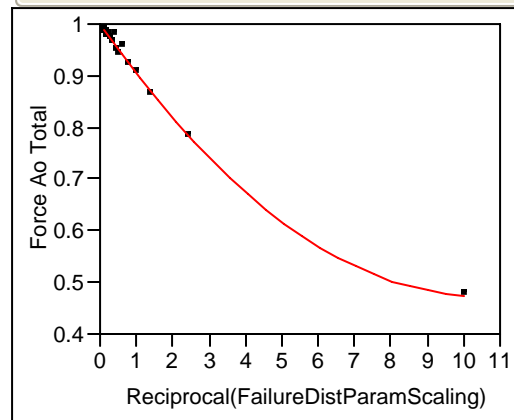
## Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	0.28835419	0.144177	4584.062
Error	30	0.00094355	0.000031	Prob > F
C. Total	32	0.28929774		<.0001*

## Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	0.997622	0.001264	789.35	<.0001*
Reciprocal(FailureDistParamScaling)	-0.094552	0.002352	-40.20	<.0001*
(Reciprocal(FailureDistParamScaling)-0.65865)*(Reciprocal(FailureDistParamScaling)-0.65865)	0.0048511	0.00027	17.95	<.0001*

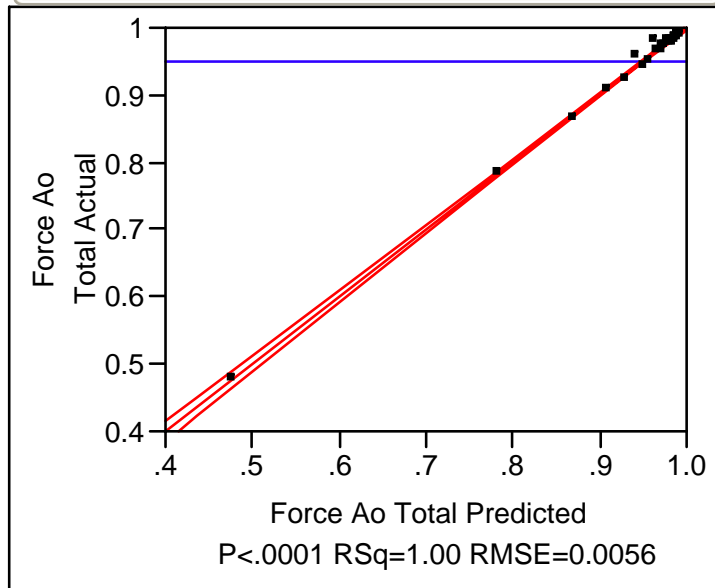
## Regression Plot



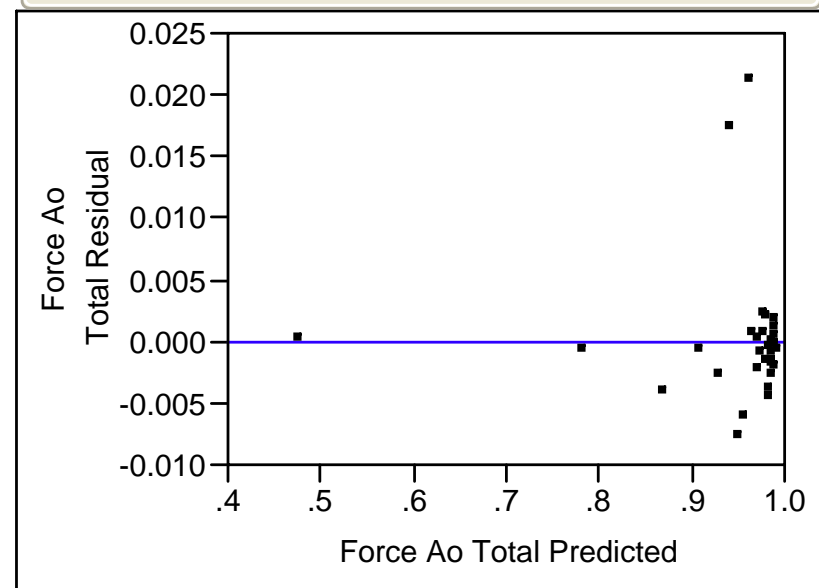
# Results: *A<sub>o</sub> Alpha Meta-Model*

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Actual by Predicted Plot



Residual by Predicted Plot



# Initial Meta-Model

## Scaled Estimates

Continuous factors centered by mean, scaled by range/2

Term	Scaled Estimate	Std Error	t Ratio	Prob> t
Intercept	0.9353452	0.001258	743.54	<.0001*
Reciprocal(FailureDistParamScaling)	-0.468031	0.011641	-40.20	<.0001*
(Reciprocal(FailureDistParamScaling)-0.65865)*(Reciprocal(FailureDistParamScaling)-0.65865)	0.1188636	0.00662	17.95	<.0001*

Mean of the Failure Rate overwhelmingly dominates Ao.

## Results: *A<sub>o</sub> Alpha Meta-Model*

factor	Force Ao Total	Predicted Force Ao Total	Lower 95%	Upper 95%
1	0.94173557	0.94948828	0.93782525	0.96115131
2	0.97270838	0.97356676	0.96192773	0.98520579
3	0.95759706	0.9403314	0.92862467	0.95203812
4	0.97615154	0.97551184	0.96386873	0.98715495
5	0.94997376	0.95620011	0.94455731	0.96784291
6	0.9657853	0.96526209	0.95363017	0.97689401
7	0.9823947	0.98133051	0.97033017	0.99479
8	0.97138147	0.97128197	0.96033017	0.98739
9	0.97657664	0.98106293	0.97033017	0.99279
28	0.78174993	0.78238471	0.77133017	0.79295
29	0.86473149	0.86888704	0.85733017	0.881643
30	0.97932436	0.97718773	0.96554036	0.98883509
31	0.92439137	0.92709831	0.91529725	0.93889937
32	0.90554963	0.90629716	0.89427978	0.91831455
33	0.47549603	0.47541395	0.45921871	0.4916092

Very accurate predictive capabilities across a broad range of Ao.

# Results:

## *A<sub>o</sub> Beta Meta-Model*

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### Summary of Fit

RSquare	0.999291
RSquare Adj	0.999128
Root Mean Square Error	0.002808
Mean of Response	0.94959
Observations (or Sum Wgts)	33

### Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	0.28909273	0.048182	6110.547
Error	26	0.00020501	7.885e-6	Prob > F
C. Total	32	0.28929774		<.0001*

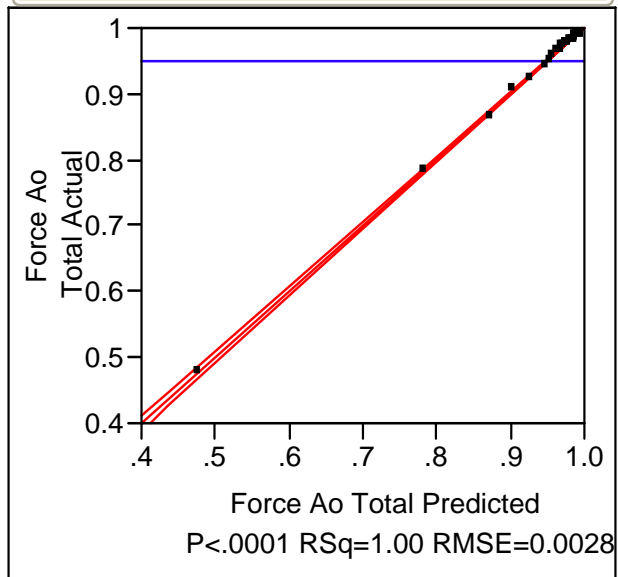
### Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	0.9857171	0.003237	304.52	<.0001 *
ProbCorrectDiag	0.0183867	0.003771	4.88	<.0001 *
Reciprocal(FailureDistParamScaling)	-0.093169	0.001202	-77.48	<.0001 *
(Reciprocal(FailureDistParamScaling)-0.65865)*(Reciprocal(FailureDistParamScaling)-0.65865)	0.0046751	0.000138	33.78	<.0001 *
Consumable Dist Factor Scaling	-0.000985	0.000169	-5.82	<.0001 *
(Consumable Dist Factor Scaling-5.0503)*(Consumable Dist Factor Scaling-5.0503)	0.0002627	6.431e-5	4.08	0.0004 *
(ProbCorrectDiag-0.77061)*(Consumable Dist Factor Scaling-5.0503)	-0.003749	0.001066	-3.52	0.0016 *

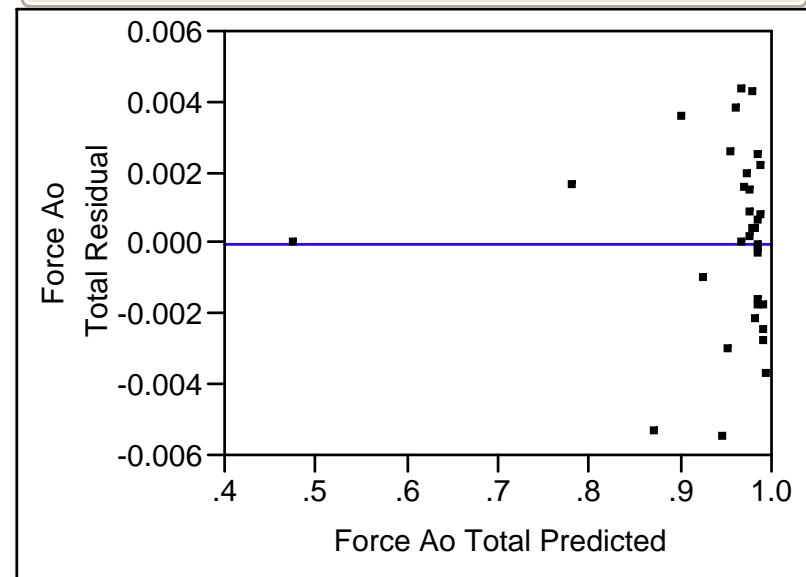
# Results: *A<sub>o</sub> Beta Meta-Model*

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Actual by Predicted Plot



Residual by Predicted Plot

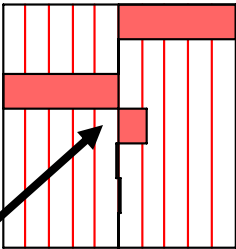


# Improved Meta-Model

## Scaled Estimates

Continuous factors centered by mean, scaled by range/2

Term	Scaled Estimate	Std Error	t Ratio	Prob> t
Intercept	0.9335442	0.000811	1150.63	<.0001*
ProbCorrectDiag	0.0040451	0.00083	4.88	<.0001*
Reciprocal(FailureDistParamScaling)	-0.461185	0.005952	-77.48	<.0001*
(Reciprocal(FailureDistParamScaling)-0.65865)*(Reciprocal(FailureDistParamScaling)-0.65865)	0.1145525	0.003392	33.78	<.0001*
Consumable Dist Factor Scaling	-0.004877	0.000838	-5.82	<.0001*
(Consumable Dist Factor Scaling-5.0503)*(Consumable Dist Factor Scaling-5.0503)	0.0054361	0.001576	4.08	0.0004*
(ProbCorrectDiag-0.77064)*(Consumable Dist Factor Scaling-5.0503)	-0.004082	0.001161	-3.52	0.0016*



Mean of the Failure Rate still overwhelmingly dominates Ao.

## Results: *A<sub>o</sub> Beta Meta-Model*

factor	Force Ao Total	Predicted Force Ao Total	Lower 95%	Upper 95%
1	0.94173557	0.94730071	0.94125295	0.95334848
2	0.97270838	0.96838136	0.96226359	0.97449912
3	0.95759706	0.955104	0.94840414	0.96180386
4	0.97615154	0.97423641	0.96741987	0.98105295
5	0.94997376	0.95304409	0.94710902	0.95897916
6	0.9657853	0.96205599	0.95605447	0.96805751
7	0.9823947	0.97819169	0.97127004	0.98511333
8	0.97138147	0.96985293	0.9630015	0.97669431
9	0.97657664	0.97643196	0.9700015	0.98286237
28	0.78174993	0.78020106	0.7732015	0.7872015
29	0.86473149	0.87008692	0.8630815	0.8770815
30	0.97932436	0.97894801	0.9729415	0.9849415
31	0.92439137	0.92543854	0.91931045	0.93156664
32	0.90554963	0.90202376	0.89582181	0.9082257
33	0.47549603	0.4755157	0.46735401	0.48367739

Superior predictive capabilities across a broad range of Ao.

## **Results:** *Observations*

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- **Lessons Learned from Meta-Model:**
  - Passes Common Sense test.
  - The overwhelming factor which drives Ao is the failure rate.
  - Low failure rate implies high system reliability as measured by high Ao.
  - Demonstrates that component reliability drives system reliability for this model, operating in this range of inputs.
  - Demonstrates value of understanding underlying relationships within model.
- **The resulting equation is a “quick and dirty” substitute for the simulation.**

# The Way Ahead

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- **Focused Range Model within likely parameter operating ranges:**
  - **Broad spectrum exploratory analysis defined how the model worked.**
  - **Future work will focus on more plausible parameter inputs.**
- **Time Series Analysis:**
  - **Meta-Model for MMH and Parts Fill Rate.**
  - **Determine appropriate COP “snap-shot” rate for determining time segments used in forecasting.**
- **Compete four basic forecasting methodologies:**
  - **Original stepwise regression model.**
  - **Exponential smoothing.**
  - **Part period (3-period) moving average.**
  - **Auto-Regressive Moving Average (ARMA) / Auto-Regressive Integrated Moving Average (ARIMA).**

# Questions...

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- **SEED Center Website:** <http://harvest.nps.edu/>
- **TRAC Monterey Website:** <http://www.trac.nps.navy.mil/home.htm>