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Customer Success Is Our Mission

Test Optimization using rdExpert Executive Overview

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The Test Optimization Challenge

"We are being challenged by our customers and by the marketplace to develop and deliver increasingly complex systems with smaller performance margins that meet the user's requirements in the shortest time, with high reliability, open and adaptable, and at the lowest cost."

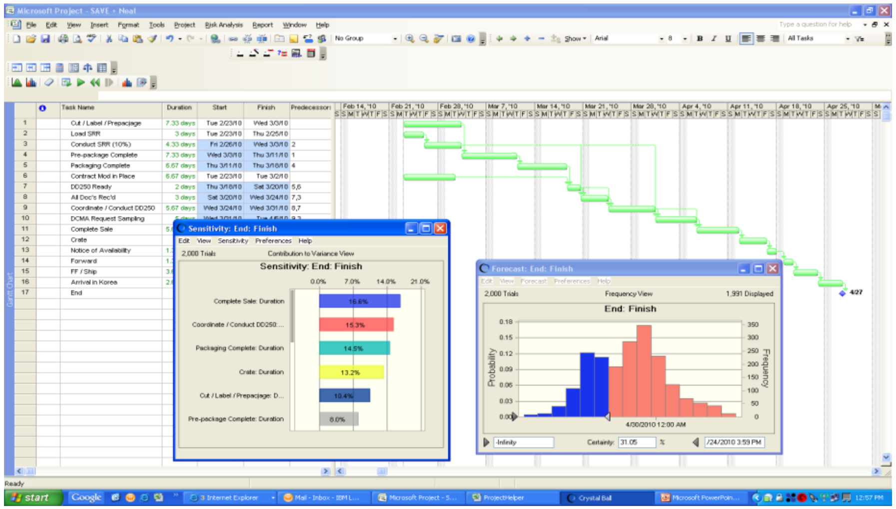
Given this challenge, there is more pressure than ever on Integration, Verification & Validation activities to deliver performance results on time and within budget.

Industry studies have estimated test and rework to represent between 30 and 50% of product development costs. Given this investment, test represents fertile ground for high maturity optimization techniques. Typical benefits of statistically-based test optimization include:

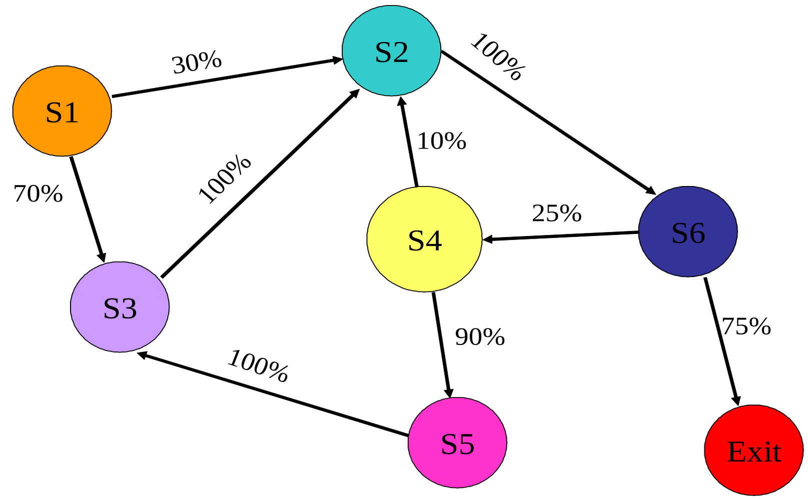
- Increased Mission Assurance
- Optimized performance
- Improved cycle time
- Increased Productivity
- Reduced cost

Statistically-Based Test Optimization

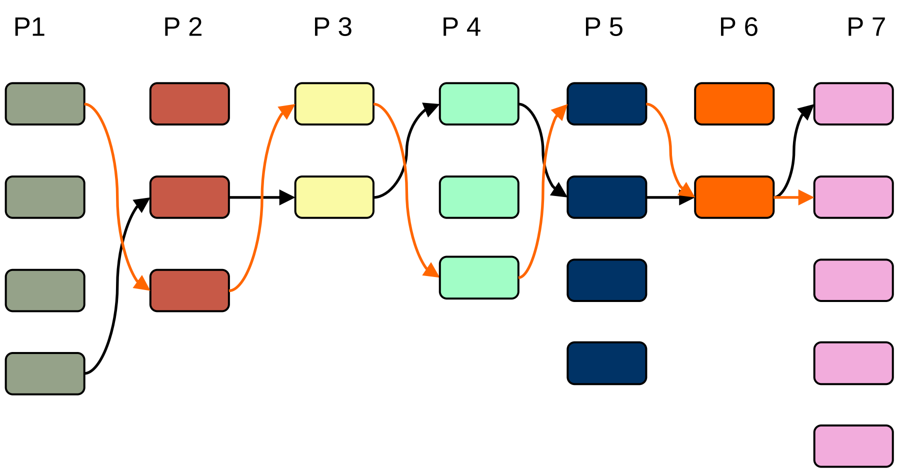
Scheduling Analysis of Variability Engine



Use-Case Stochastic Modeling



Design of Experiments (DOE) / Combinatorial Design Methods (CDM)



Statistically-based test optimization techniques have been deployed across all Raytheon IDS businesses, all major programs and new starts.

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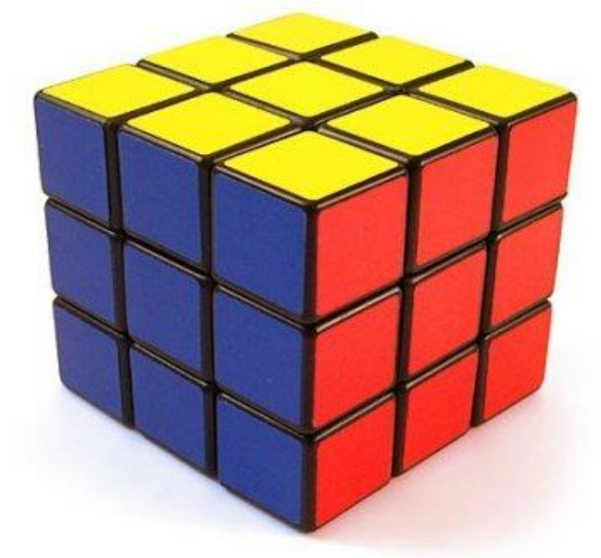
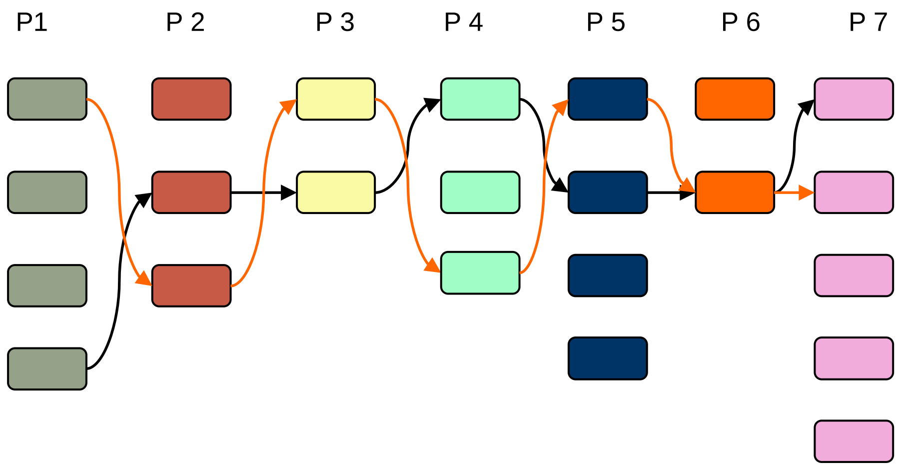
Statistically-Based Test Optimization

Testing all possible combinations may be infeasible!

- **When you must test a subset of all combinations– how to choose an appropriate subset?**
- **The integrated application of statistical methods, most notably Design of Experiments (DOE) & Combinatorial Design Methods (CDM), has been cited by the Department of Defense as an industry best practice in this space.**





Statistically-Based Test Optimization

- **Combinatorial Design Methods (CDM)** enable assessment of test plans for their requirements and critical interoperability test coverage (through n-way analysis) thereby providing key Mission Assurance and business risk & opportunity benefits.

- **Design of Experiments (DOE)** enable development of highly efficient test plans while ensuring full requirement and critical interoperability test coverage.
  – Because test is multi-factor, multi-level, orthogonal d-optimal experimental designs are utilized.
  – Since it is often the case for certain test factor level combinations to be infeasible, a constrained solution algorithm is utilized.

Outcome Predicted & Stakeholder Audience

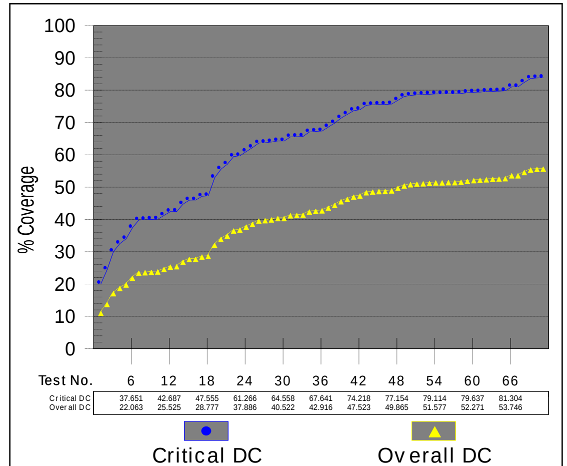
- **Outcome Prediction:** A quantitative assessment of existing test coverage and statistical generation / analysis of alternative highly efficient and effective test plans.

- **Key stakeholder audience and why the outcome prediction is of critical importance to them:**
  - **Systems / Software / Hardware Engineering / Operations:**
    - Enables efficient and effective development & optimization of test plans resulting in improved test productivity and defect containment while reducing cycle time
  - **Program / Project Management:**
    - Provides an objective quantitative assessment of test plan risk & opportunity from both a Mission Assurance and efficiency perspective.
  - **Customer**
    - Assurance of required test coverage
    - Cost value of test effort

Test Optimization using rdExpert

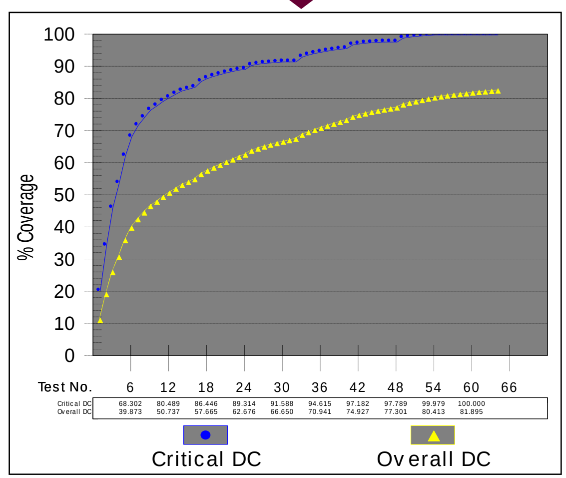
- **Utilizes Mathematical foundations of DOE & Applied Statistics**
- **Test & Evaluation Assessment**
  - **Analytically assesses existing test plan for its critical domain coverage utilizing Combinatorial Design Methods**
  - **Identifies specific test gaps**
- **Test & Evaluation Optimization**
  - **Generates balanced and optimized orthogonal test cases that reduce T&E cost, schedule and risk using d-optimal design algorithms**
  - **Prioritizes test cases for technical importance, cost, and/or schedule**
  - **Automatically generates test scripts/procedures ready for execution**
  - **Orthogonal array test design enables isolation of potential root causes of failure**

Weapons Fire Detection & Classification System Industry Case Study (courtesy of Phadke Associates)



T&E Assessment

- **Evaluated existing test plan for its test coverage**
- **Identified 750+ critical domain test coverage gaps**



T&E Optimization

- **Reduced test cases (10% less tests)**
- **Reduced T&E Risk: Eliminated all 750+ identified test gaps**
- **Review & optimization effort took less than 1 man- week**

Objective: Increased Critical Domain Test Coverage Effectiveness & Efficiency

Test Optimization using rdExpert

While the origins of this approach and enabling tool set are from the Commercial IT / Software Engineering application space, we have found this approach to generically apply within the Aerospace industry in Systems, Software and Hardware testing.

Attached to illustrate this perspective is a generic case study application and a summary listing of our deployment efforts to date.

Subsystem Testing- Radar Detection Case Study

Test Design Space:

- Speed (S1,S2,S3,S4)
- Target Size (Small, Medium, Large)
- Environment (Land, Water)
- Range (Close, Far)
- With other Targets (Yes, No)

Subsystem Testing- Radar Detection Case Study

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Original Mission Layout

		Mission 1	Mission 2	Mission 3	Mission 4	Mission 5	Mission 6
Speed	S1	1	0	1	1	1	1
	S2	1	0	1	1	1	1
	S3	0	1	0	1	1	0
	S4	0	1	0	0	0	0
Size	Small	1	1	0	1	1	0
	Med	0	1	1	1	1	1
	Large	0	0	0	0	0	0
Envir	Land	1	1	0	1	1	0
	Water	0	0	1	0	0	1
Range	Close	1	1	1	1	1	0
	Far	0	1	1	0	0	1
Other Targets	Yes	1	1	0	1	0	1

Subsystem Testing- Radar Detection Case Study

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Current Test Plan- Mission Breakout

Test	Speed	Size	Envir	Range	Other Targets
1	S1	Small	Land	Close	Yes
2	S2	Small	Land	Close	Yes
3	S3	Small	Land	Close	Yes
4	S3	Med	Land	Close	Yes
5	S3	Small	Land	Far	Yes
6	S3	Med	Land	Far	Yes
7	S4	Small	Land	Close	Yes
8	S4	Med	Land	Close	Yes
9	S4	Small	Land	Far	Yes
10	S4	Med	Land	Far	Yes
11	S1	Med	Water	Close	No
12	S1	Med	Water	Far	No
13	S2	Med	Water	Close	No
14	S2	Med	Water	Far	No

15	S1	Small	Land	Close	Yes
16	S2	Small	Land	Close	Yes
17	S3	Small	Land	Close	Yes
18	S1	Med	Land	Close	Yes
19	S2	Med	Land	Close	Yes
20	S3	Med	Land	Close	Yes
21	S1	Small	Land	Close	No
22	S2	Small	Land	Close	No
23	S3	Small	Land	Close	No
24	S1	Med	Land	Close	No
25	S2	Med	Land	Close	No
26	S3	Med	Land	Close	No
27	S1	Med	Water	Far	Yes
28	S2	Med	Water	Far	Yes

Subsystem Testing- Radar Detection Case Study

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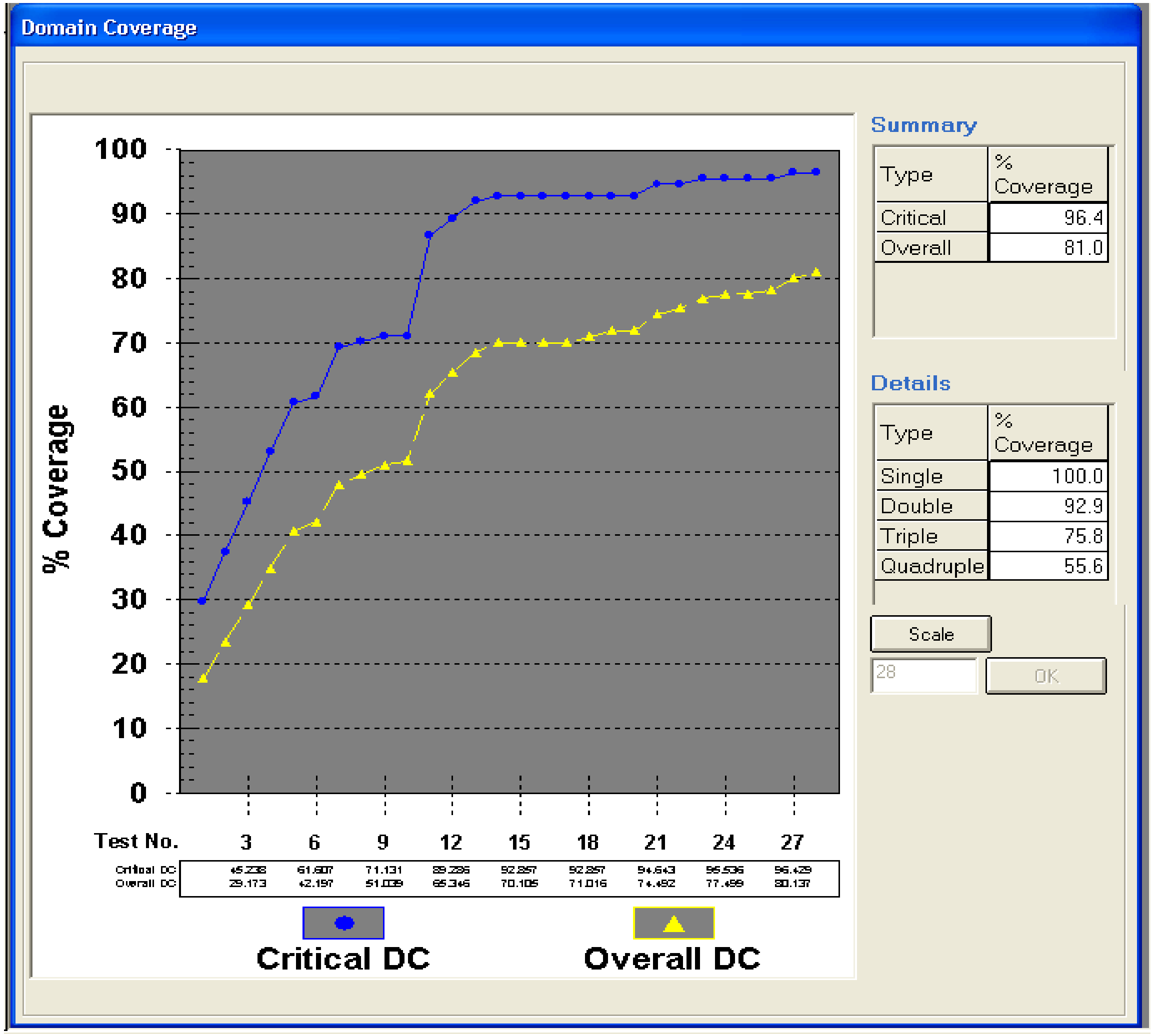
Test Coverage Analysis using rdExpert



Critical Coverage = average of single and double (2-way) coverage

Overall Coverage = average of Single though quad coverage

Single = Factor level (i.e., Speed = S1)

Double = combination of any two factor levels (i.e., Speed = S1 and Envir = Water)

Triple = combination of any three factor levels

Quad = combination of any four factor levels

Subsystem Testing- Radar Detection Case Study

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Risk Analysis – missing 2-way pairings

Risk Analysis

Select Analysis Type : Interoperability Risk

Number of Missing Inter-Operability Combinations = 4

Sr No	Combination	Description
1	1-3, 3-2	Speed = s3 is not tested with Envir = Water
2	1-4, 3-2	Speed = s4 is not tested with Envir = Water
3	1-4, 5-2	Speed = s4 is not tested with Other Targets = no
4	2-1, 3-2	Size = small is not tested with Envir = Water

Note: Analysis doesn't include "missing" condition of Large Target.

Subsystem Testing- Radar Detection Case Study

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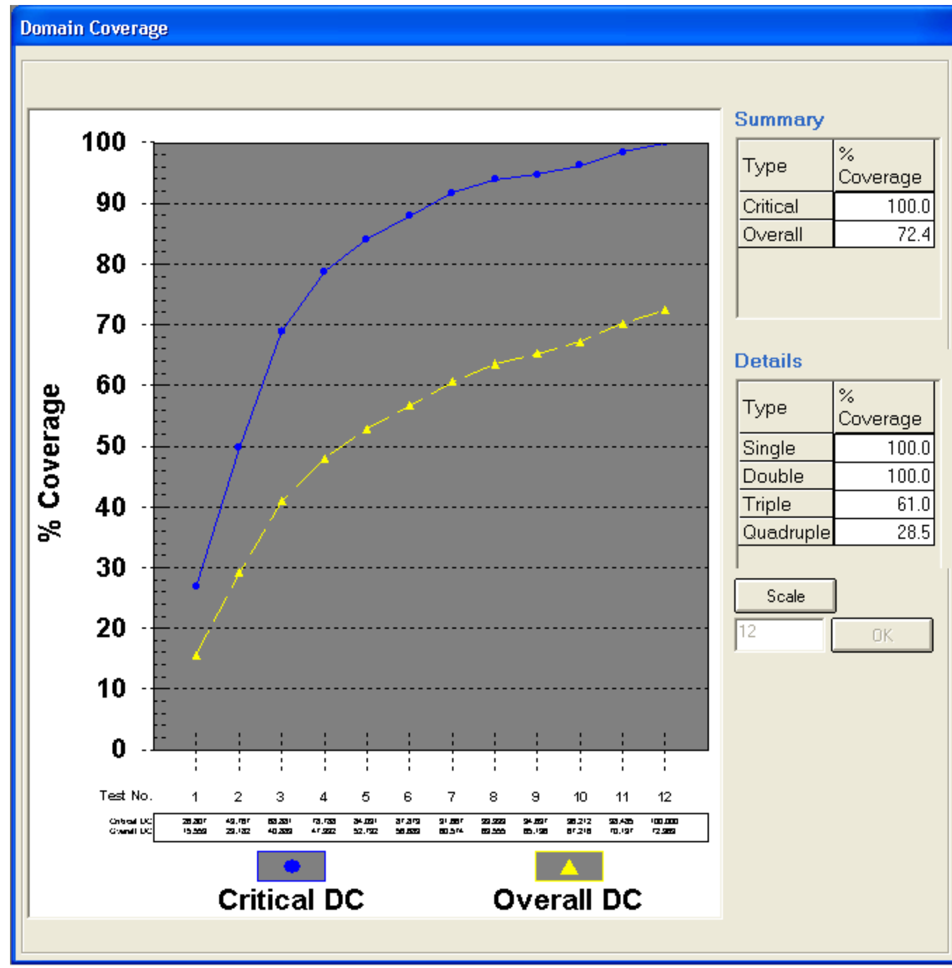
rdExpert / DOE generated alternative test plan

	Speed	Size	Envir	Range	Other Targets
1	S1	Medium	Water	Far	No
2	S2	Large	Land	Close	No
3	S3	Small	Water	Close	Yes
4	S4	Medium	Land	Close	Yes
5	S1	Large	Land	Far	Yes
6	S2	Small	Water	Far	Yes
7	S4	Large	Water	Far	No
8	S1	Small	Water	Close	No
9	S2	Medium	Water	Far	No
10	S4	Small	Land	Close	Yes
11	S3	Medium	Land	Close	No
12	S3	Large	Land	Far	Yes



Note: Test Plan includes Large Targets

Subsystem Testing- Radar Detection Case Study

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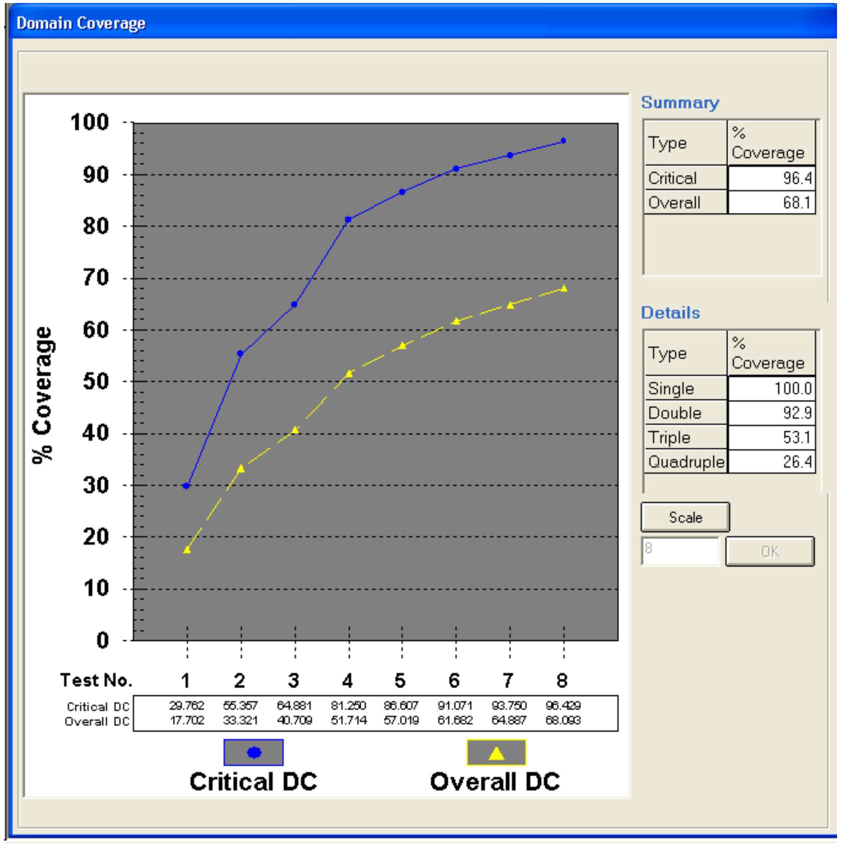
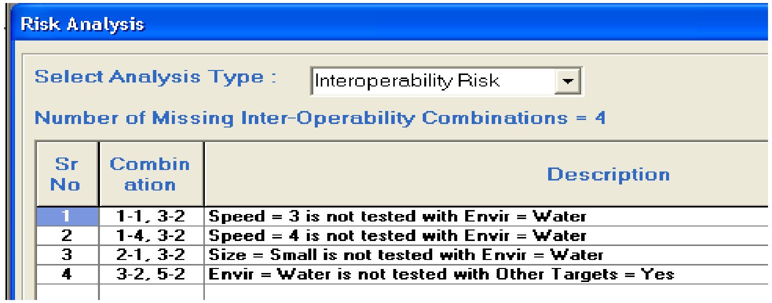
rdExpert / DOE generated alternative test plan with assumptions

	Speed	Size	Envir	Range	Other Targets
1	S3	Small	Land	Far	No
2	S1	Medium	Water	Close	No
3	S2	Medium	Water	Far	No
4	S4	Medium	Land	Close	Yes
5	S1	Small	Land	Far	Yes
6	S2	Small	Land	Close	Yes
7	S3	Medium	Land	Close	Yes
8	S4	Small	Land	Far	No



Assumptions:

- No Large Targets over Land
- No Small or Large Targets over Water
- No Speed 3 or 4 over Water
- No Other Targets over Water



Subsystem Testing- Radar Detection Case Study
Test Plan / Mission Comparison: Original vs. Optimized

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Test	Speed	Size	Envir	Range	Other Targets
1	S1	Small	Land	Close	Yes
2	S2	Small	Land	Close	Yes
3	S3	Small	Land	Close	Yes
4	S3	Med	Land	Close	Yes
5	S3	Small	Land	Far	Yes
6	S3	Med	Land	Far	Yes
7	S4	Small	Land	Close	Yes
8	S4	Med	Land	Close	Yes
9	S4	Small	Land	Far	Yes
10	S4	Med	Land	Far	Yes
11	S1	Med	Water	Close	No
12	S1	Med	Water	Far	No
13	S2	Med	Water	Close	No
14	S2	Med	Water	Far	No
15	S1	Small	Land	Close	Yes
16	S2	Small	Land	Close	Yes
17	S3	Small	Land	Close	Yes
18	S1	Med	Land	Close	Yes
19	S2	Med	Land	Close	Yes
20	S3	Med	Land	Close	Yes
21	S1	Small	Land	Close	No
22	S2	Small	Land	Close	No
23	S3	Small	Land	Close	No
24	S1	Med	Land	Close	No
25	S2	Med	Land	Close	No
26	S3	Med	Land	Close	No
27	S1	Med	Water	Far	Yes
28	S2	Med	Water	Far	Yes

	Speed	Size	Envir	Range	Other Targets
1	S3	Small	Land	Far	No
2	S4	Small	Land	Far	No
3	S1	Med	Water	Close	No
4	S2	Med	Water	Far	No
5	S4	Med	Land	Close	Yes
6	S3	Med	Land	Close	Yes
7	S2	Small	Land	Close	Yes
8	S1	Small	Land	Far	Yes

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Deployment Results Summary

Test	Original Test Plan	Optimized Test Plan
Subsystem Testing	28 Tests	8 Tests (71% reduction)
Systems Mission Testing	25 Missions	18 Missions (28% reduction)
Subsystem Simulation	100 Runs	40 Runs (60% reduction)
Range Testing	1036 Tests	632 Tests (39% reduction)
Software Subsystem Testing	90 Tests	63 Tests (30% reduction
System Scenario Generation	8 Missions	6 Missions (25% reduction)
System MOE Testing	1600 Tests	885 Tests (45% reduction)
System Testing	246 Tests	48 Tests (80% reduction)
Supplier Testing	90 Tests	49 Tests (45% reduction)

In each case, the reduction in number of test cases was achieved while maintaining or improving upon existing test coverage.

Results & Benefits

- Statistically-based test optimization has changed the way we think as a business about test development, coverage and risk & opportunity analysis.

- Side-by-side program comparisons vs. traditional methods across six programs has resulted in an overall average test case and cycle time reduction of 30+ % while maintaining or improving upon existing test coverage.

- Because of its delivered program results, Statistically-based Test Optimization is no longer being thought of as an alternative, new and exciting approach but rather as our standard practice.

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DoD Memorandum of Agreement (MOA)

Design of Experiments (DOE) in Test and Evaluation

At the request of the Service Operational Test Agency (OTA) Commanders, DOT&E hosted a meeting of OTA technical and executive agents on February 20,2009 to consider a common approach to utilizing DOE in operational test and evaluation endeavors. Representatives from ATEC, OPTEVFOR, AFOTEC, JTIC, DOT&E and two experts in DOE from the National Institute of Standards and Technology (NIST) met to discuss the applicability of DOE principles to support test and evaluation efforts.

This group endorses the use of DOE as a discipline to improve the planning, execution, analysis, and reporting of integrated testing. DOE offers a systematic, rigorous, data-based approach to test and evaluation. DOE is appropriate for serious consideration in every case when applied in a testing program,…

Dr. Charles E. McQueary
Director, Operational Test & Evaluation

David L. Reeves, Colonel, USMC
Director, MCOTEA

David A. Dunaway, Rear Admiral, USN
Commander, OPTEVFOR

Roger A. Nadeau, Major General, USA
Commander, ATEC

Stephen T. Sargeant, Major General, USAF
Commander, AFOTEC

Ronald C. Stephens, Colonel, USA
Commander, JITC

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Leading Change & Driving for Business Results

"There is no way around it - we have to find ways to do more with less. The integrated program use of statistical techniques such as Design of Experiments, have proven themselves to be powerful enablers in our test optimization efforts to reduce cost and cycle time while providing our customers with confidence that our systems will perform."

Dr. Tom Kennedy

President, Raytheon Integrated Defense Systems

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Challenges & What Worked Well

Challenges:

– "We test one Shall at a time…"

– "I can see how this approach could really help others…"

– The myth of the all knowing subject matter expert

– Fear of exposure

What worked well:

– The integrated application of proven best practice methods

– Reference to Customer Memorandum of Agreement

– Ability to efficiently and objectively assess existing plans for their Risk & Opportunity

– User friendly supporting tools & enablers

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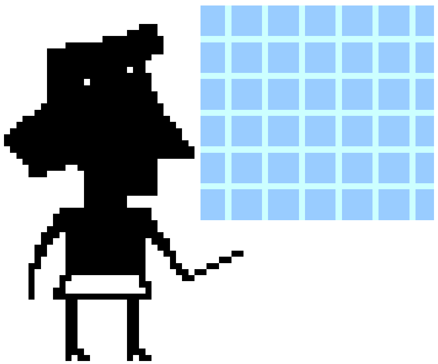
Summary

- The challenge is clear: We need to become more efficient and effective in the test space in order to remain competitive and achieve unparalleled levels of Mission Assurance.

- Use of high maturity statistical techniques on the latter end of the product lifecycle – specifically the IV&V phase – where costs typically run very high and schedule pressure is often the greatest - offers tremendous opportunity to improve performance in alignment with quality and process performance objectives.

- Use of rdExpert Suite of Test Optimization tools & techniques has greatly enabled our efforts. Achieved benefits include:
  - Increased Mission Assurance
  - Optimized performance
  - Improved cycle time
  - Increased productivity
  - Reduced cost



References

1. Mackertich & Campo, *"Scheduling Analysis of Variability Engine(SAVE)"*, 3rd SEI High Maturity Measurement and Analysis Workshop, March 2009.
2. Phadke & Phadke, *"Utilizing Design of Experiments to Reduce IT System Testing Cost"*, CrossTalk, November/December 2011. http://www.phadkeassociates.com/index_rdexperttestplanning.htm
3. Kacker, "Evolution of Advanced Combinatorial Testing for Software and Systems from Design of Experiments", National Institute of Standards and Technology, June 2011. https://docs.google.com/viewer?a=v&pid=explorer&chrome=true&srcid=0B7d3x4tT9gq3NGVmYmM2ZTAtYWY2Yi00MmQ2LWE2YWMtNzZiMzAzNTg2MjRl&hl=en_US&authkey=CNTWxqIC
4. Huller, "Reducing Time to Market with Combinatorial Design Method Testing", Proceedings of the 2000 International Council on Systems Engineering (INCOSE) Conference, Englewood, CO, March 2000.
5. Kuhn & Reilly, "An Investigation of the Applicability of Design of Experiments to Software Testing", Proceedings of the 27th NASA/IEEE Software Engineering Workshop, NASA Goddard Space Flight Center, Greenbelt, Maryland, December 2002.