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Customer Success Is Our Mission

# Test Optimization Utilizing Design Of Experiments


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# Agenda

- Test Optimization Challenge
- Combinatorial Design Methods(CDM) & Design of Experiments(DOE)
- rdExpert Analysis
  – Coverage analysis
  – Design development
- Deployment Results
- Raytheon Case Study
  – Customer involvement – what’s important
  – Design constraints
  – Design space
  – Design evaluation/coverage
  – Results
- Resources

# The Test Optimization Challenge

*"We are being challenged by our customers and by the marketplace to develop 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.

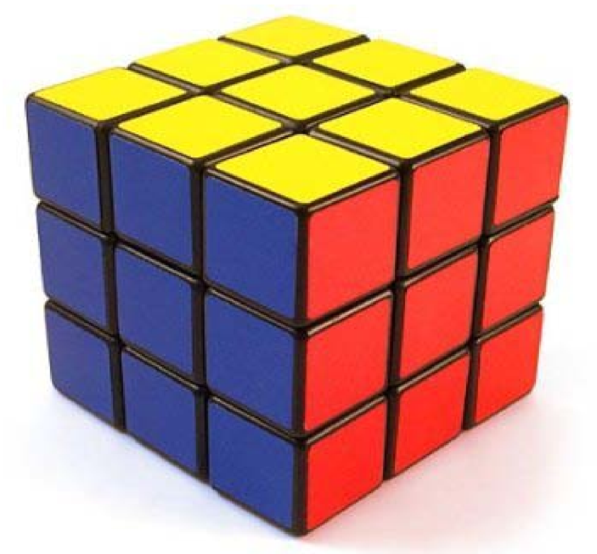
Industry studies have shown test and rework to represent between 30 and 50% of product development costs. If this is even close to accurate, test represents fertile ground for optimization. Typical benefits of statistically-based test optimization include:

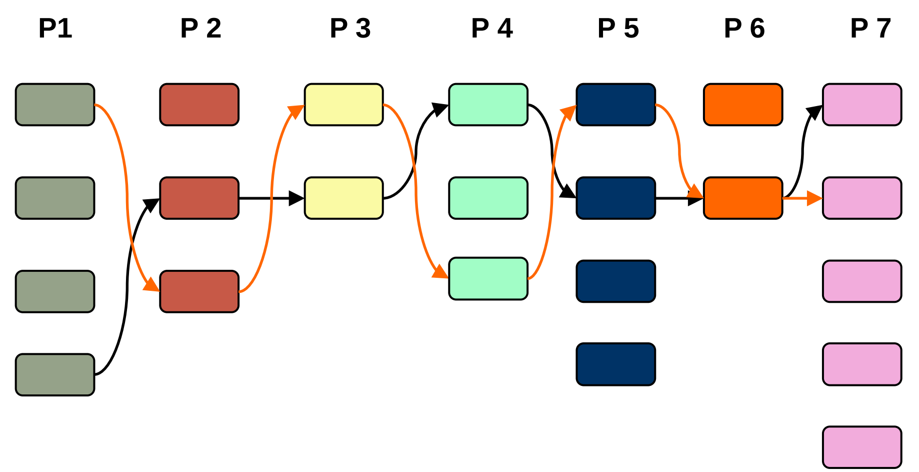
- Increased Mission Assurance
- Optimized performance
- Improved cycle time
- Increased Productivity
- Reduced cost

# Combinatorial Design Methods & Design of Experiments

## 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.






**Full Factorial Testing**

**2880 Tests**

**Efficient /Effective Testing**

**? Tests**

# Enabling Test Optimization through CDM & DOE

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

- **Design of Experiments (DOE)** enable development of highly efficient test plans while ensuring critical test coverage.
  - Because test is multi-factor, multi-level, orthogonal d-optimal experimental designs are utilized.

# Coverage Assessment

## Design Space

| Factors | Windows Version | File Size | Source Format | Destination Format |
|---|---|---|---|---|
| Levels | OS1 | S | GIF | GIF |
| | OS2 | M | TIFF | TIFF |
| | OS3 | L | | |
| | OS4 | | | |

| Windows Version | File Size | Source Format | Destination Format |
|---|---|---|---|
| OS1 | S | GIF | GIF |
| OS2 | M | TIFF | TIFF |
| OS3 | L | | |
| OS4 | | | |

**Pairwise Combinations 4 x 7=28**

| Windows Version | File Size | Source Format | Destination Format |
|---|---|---|---|
| 95 | S | GIF | GIF |
| 98 | M | TIFF | TIFF |
| NT | L | | |
| 2000 | | | |

**Pairwise Combinations 3 x 4= 12**

| Windows Version | File Size | Source Format | Destination Format |
|---|---|---|---|
| 95 | S | GIF | GIF |
| 98 | M | TIFF | TIFF |
| NT | L | | |
| 2000 | | | |

**Pairwise Combinations 2 x 2 = 4**

**Total Pairwise Combinations: 44**

| Example test condition: | OS1 | L | GIF | TIFF | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | # of conditions | total # possible | %coverage |
| main coverage | OS1 | L | GIF | TIFF | | | | 4 | 11 | 36% |
| | | | | | | | | | | |
| pairwise coverage | OS1*L | OS1*GIF$_S$ | OS1*TIFF$_D$ | L*GIF$_S$ | L*TIFF$_D$ | GIF$_S$*TIFF$_D$ | | 6 | 44 | 14% |

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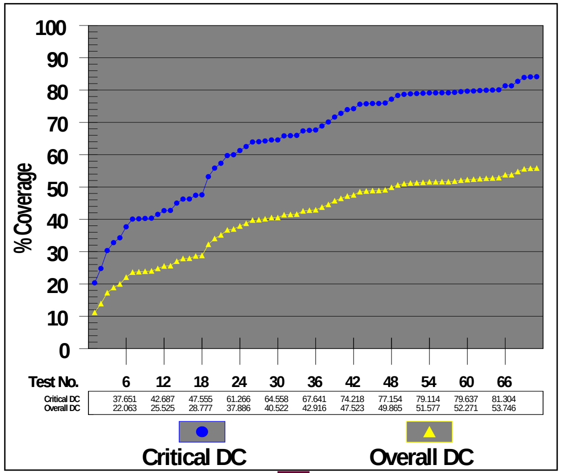
# Test Optimization using rdExpert²

- 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

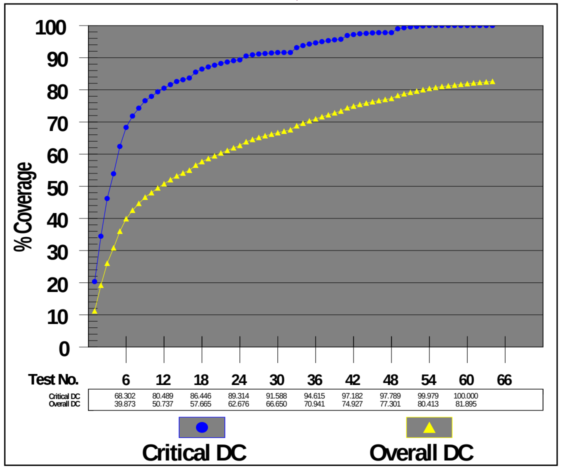
## Weapons Fire Detection & Classification System Industry Case Study




| Test No. | 6 | 12 | 18 | 24 | 30 | 36 | 42 | 48 | 54 | 60 | 66 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Critical DC | 37.651 | 42.687 | 47.555 | 61.266 | 64.558 | 67.641 | 74.218 | 77.154 | 79.114 | 79.637 | 81.304 |
| Overall DC | 22.063 | 25.525 | 28.777 | 37.886 | 40.522 | 42.916 | 47.523 | 49.865 | 51.577 | 52.271 | 53.746 |

### T&E Assessment

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




| Test No. | 6 | 12 | 18 | 24 | 30 | 36 | 42 | 48 | 54 | 60 | 66 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Critical DC | 68.302 | 80.489 | 86.446 | 89.314 | 91.588 | 94.615 | 97.182 | 97.789 | 99.979 | 100.000 | |
| Overall DC | 39.873 | 50.737 | 57.665 | 62.676 | 66.650 | 70.941 | 74.927 | 77.301 | 80.413 | 81.895 | |

### 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**

# 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) |

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

# Case Study

- **Test Optimization**
  - Utilized a DOE to define the optimum number of experiments ( A/C  missions) to evaluate performance across the requirements test space
    - Prioritized Key Performance Parameters
      - Mandatory assigned to Test Event #1
      - Required and Desired assigned to Test Event #2
    - Prioritized utilizing details of the Performance Spec to define factors/constraints

- **History**
  - Original Flight Test matrix developed by grouping ‘like’ Verification Steps
    - A/C selected to meet point objectives
    - A/C flight profiles developed independent of ‘requirement’ space
      - Missions identified against specific objectives
      - Targets identified that could satisfy the objectives
      - Flight profiles and scenarios developed
    - A New Flight Test matrix desired to reduce number of A/C missions, but achieve the same or greater coverage of the requirements test space

- **Criteria of DOE Exercise**
  - Maximize re-use of existing missions to satisfy DOE experiments
  - Maximize re-use of existing target performance parameters

**DOE Applied to Flight Test Program**

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# Test Optimization –Event #1

- **Approach**
  - Characterize the requirement ‘test space’ in terms of RCS, speed, maneuverability, altitude and range
  - Supplement resulting test cases with additional assets to capture other requirements such as external communication nodes, IFF, etc
  - Maximize re-use of existing missions to satisfy DOE experiments
  - Utilized known target performance parameters

| Factor Name | No. of Levels | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Manueverability | 3 | high | medium | low |
| Speed | 3 | high | medium | low |
| Altitude | 3 | high | medium | low |
| Range | 3 | long | medium | short |
| Size | 3 | large | medium | small |
| Target Type | 2 | A | B | |

| | If Factor ... | is at level ... | then Factor ... | can't be ... |
|---|---|---|---|---|
| Constraint 1 | Target Type | B | man | high |
| Constraint 2 | Target Type | B | Alt | high |
| Constraint 3 | Target Type | B | speed | med |
| Constraint 4 | Target Type | B | Size | large |
| Constraint 5 | Target Type | B | Alt | med |
| Constraint 6 | Target Type | B | speed | high |
| Constraint 7 | Size | small | Range | long |
| Constraint 8 | Range | long | Alt | low |
| Constraint 9 | Target Type | B | Size | med |

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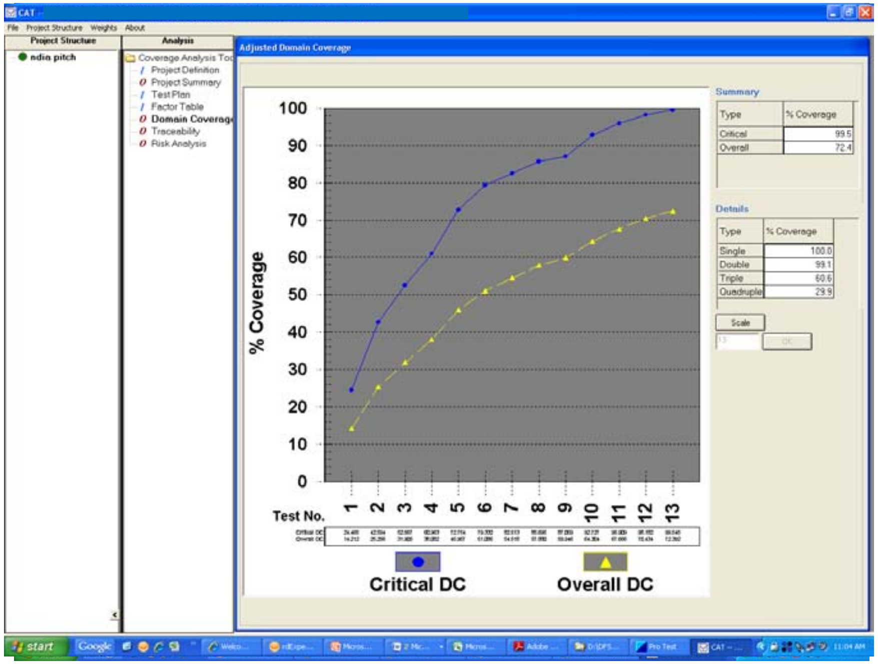
# Event #1 Experiment Results

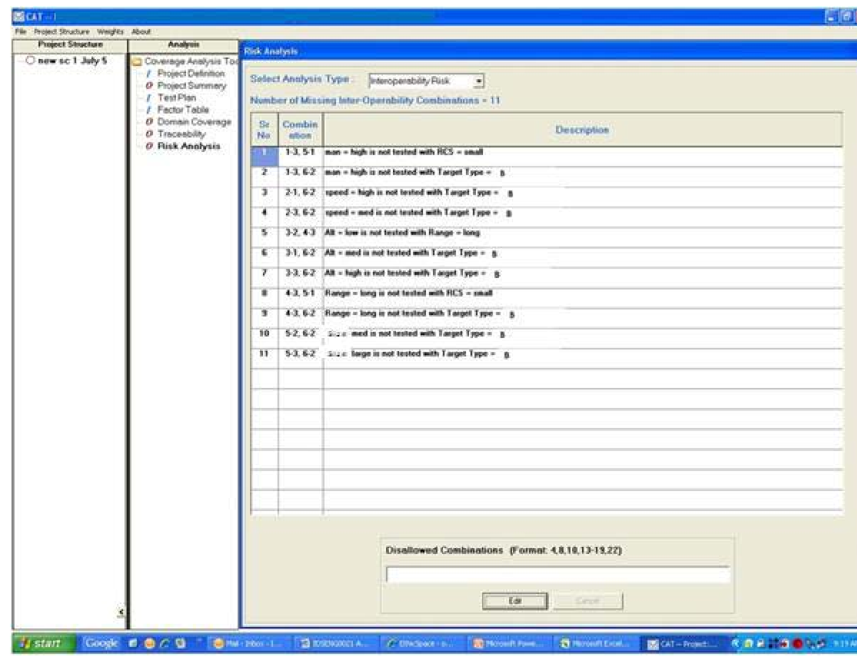
| Test Number | Manuevability | Speed | Altitude | Range | RCS | Target Type |
|---|---|---|---|---|---|---|
| 1 | high | med | low | short | large | A |
| 2 | high | high | med | med | large | A |
| 3 | med | high | high | long | large | A |
| 4 | high | low | high | long | large | A |
| 5 | low | med | med | long | large | A |
| 6 | low | med | high | med | med | A |
| 7 | low | high | low | short | med | A |
| 8 | high | high | high | short | med | A |
| 9 | med | low | med | long | med | A |
| 10 | med | high | med | short | small | A |
| 11 | med | med | high | med | small | A |
| 12 | low | low | low | med | small | B |
| 13 | med | low | low | short | small | B |

# Coverage/Risk Assessment




99.1% Critical Coverage

2-way Risk Assessment



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# Experiments w Associated Targets

| Experiment | Maneuverability | Speed | Altitude | Range | Size | Target Type | Scenario |
|---|---|---|---|---|---|---|---|
| 1 | high | med | low | short | large | A | Mission A |
| 2 | high | high | med | med | large | A | |
| 3 | med | high | high | long | large | A | |
| 4 | high | low | high | long | large | A | |
| 5 | low | med | med | long | large | A | Mission B |
| 6 | low | med | high | med | med | A | |
| 7 | low | high | low | short | med | A | |
| 8 | high | high | high | short | med | A | |
| 9 | med | low | med | long | med | A | Mission C |
| 10 | med | high | med | short | small | A | |
| 11 | med | med | high | med | small | A | |
| 12 | low | low | low | med | small | B | Mission D & E |
| 13 | med | low | low | short | small | B | |

# Test Optimization – Event #1 Results



- Results:
  - Before: "Baseline" Mission Matrix: Event #1 takes 9 weeks
    - 7 unique missions with 18 total presentations
  - After: "Optimized" Mission Matrix: Event #1 takes 6 weeks
    - 5 unique missions with 11 total presentations

| Mission Name | Number of Variations or Repetitions |
|---|---|
| A | 2 |
| B | 4 |
| C | 2 |
| D | **2** |
| E | 2 |
| F | 5 |
| G | 1 |
| | 18 |

| Mission Name | Number of Variations or Repetitions |
|---|---|
| A | 2 |
| B | 1 |
| C | 2 |
| D | 2 |
| E | 4 |
| | 11 |

**DOE A Success!**
**Number of Missions Reduced**
**Targets and Scenarios Retained**

# Conclusion/Results

- DOE can be applied to Flight Test Program through evaluation of requirement test space

- Resulted in a reduced Flight Test Program schedule

# Additional Resources

- Weblinks
  - rdExpert: http://www.phadkeassociates.com/
  - ACTS: http://csrc.nist.gov/groups/SNS/acts/index.html
  - ProTest: http://homenet.ray.com/sixsigma/tools/sw
  - General Information: http://pairwise.org
  - White Papers: http://aetgweb.argreenhouse.com/papers.shtml

# Bios

Tonja Rogers is a Director of Systems Engineering who earned her Masters of Science in Electromagnetics from New Mexico State University. She joined Raytheon in 1981 and has supported the development and test of numerous tactical systems such as Patriot, HAWK, Standard Missile, Cobra Judy, Zumwalt, and THAAD, Her roles have spanned the system life cycle from requirements development, models and simulation, manufacture assembly and test, to live fire field test. She is currently the Test Architect for a Cruise Missile Defense System program.

Peter Kraus is an Engineering Fellow focusing on Statistical Engineering training and consulting efforts within Raytheon Integrated Defense Systems. Peter is presently responsible for implementing Design for Six Sigma techniques across Engineering and Operations to achieve Mission Assurance. Peter earned a Masters Degree in Mathematics from Northeastern University and a Ph.D. in Operations Research from the University of Massachusetts-Amherst.