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Test Science Website Videos - Test Planning and Design

Rebecca Medlin, Project Leader

Kelly Avery
Caitlan Fealing
Rebecca Medlin
Rachel Haga
Matthew Avery

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4850 Mark Center Drive
Alexandria, Virginia 22311-1882

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For more information:
Rebecca Medlin, Project Leader
rmedlin@ida.org •C9082

Robert R. Soule, Director, Operational Evaluation Division
rsoule@ida.org • (703) 845-2482

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Executive Summary

Understanding the test design process is fundamental to conducting efficient and effective tests of systems. Planning is a critical element of this process. Test planning involves identifying the test objectives, determining the appropriate outcome measure(s), and identifying what factors may influence those outcomes. The first set of website videos introduces the overarching test design process and provides best practices and examples for each of the planning steps.

Test design is the process of actually creating and evaluating a set of experimental test runs. It entails (1) carefully considering the test goals to ensure objectives can be met by the data collected, (2) building the corresponding type of design, and (3) evaluating the design across multiple criteria. The test design should (1) have a large enough sample size to be useful, (2) be executable in the real world, and (3) support the desired analysis. The second set of videos describes and provides recommendations for each element of the test design process, and also introduces considerations for how to manage and store data collected from tests.

A. Test Planning

The test design process, which is essentially an example of the scientific method, represents the gold standard for experimentation. It comprises seven steps:

1. Identify the test objectives
2. Identify the mission-oriented outcome metrics, or response variables
3. Identify the factors or variables that may affect those outcomes
4. Develop the test design
5. Conduct the test and collect the data
6. Analyze that data using statistical methods
7. Draw conclusions and inform your evaluation

This analytical framework for collecting and analyzing data is applicable to nearly every domain and industry. Successfully performing this process requires iteration and collaboration among subject matter experts.

Clearly defined objectives are essential when designing any operational or live fire test, because they will drive the associated test design and analysis. The two most common test objectives used in test and evaluation are (1) screening for influential factors and (2) characterizing a system's performance across a set of conditions. These objectives are best applied sequentially: first a screening experiment narrows down the set of factors that are likely to matter, and then a characterization design details the performance of the system under each of the relevant conditions.

Outcome metrics, also frequently called response variables, are what testers use to assess their test objectives. A good response variable should (1) provide a meaningful measure of performance, (2) support evaluation of requirements, and (3) lend itself well to experimental design, meaning it is measurable, valid, and informative. Oftentimes more than one response variable is necessary to capture the full picture of system performance.

Because defense systems rarely have uniform performance in every situation, it is important for testers to identify factors that may drive changes in performance. These typically relate to the environmental conditions, the threat level, the mission, the user type, or the system configuration. Good factors are significant, controllable, and informative. After brainstorming all potential factors, testers can use a factor management scheme to prioritize which factors should be controlled and systematically varied in a test design, and which will simply be logged, or fixed at a specific level. Modern Design of Experiments (DOE) techniques can investigate a large number of factors very efficiently.

B. Test Design

The best approach for collecting data from several factors is to conduct a statistically designed experiment. DOE is an experimentation strategy in which testers vary factors in a coordinated, strategic way, instead varying them one at a time, or arbitrarily choosing test cases. A test strategy that employs DOE will always provide the most powerful allocation of test resources for a given number of tests.

The specific choice of design should be tied to the test objectives and the anticipated analysis. For example, designs meant for factor screening have fundamentally different properties than designs meant to characterize or optimize. Sequential test design strategies, where the results of early tests inform the construction of future tests, are highly recommended and can provide additional resource savings.

Common test designs include factorial designs, response surface methodology, and optimal designs. The decision on which test design method is most appropriate depends on the question, metrics, types of factors (numeric or categorical), and available test resources. Many software packages are available to build and evaluate each of these designs.

The question of "How much testing is enough?" is persistent across Department of Defense test and evaluation endeavors. DOE can help decision makers "right-size" a test, providing a framework for building and evaluating test plans and assessing risk. Leveraging statistical techniques in both test design and test analysis helps decision makers reach correct conclusions about system performance.

Test designs should be realistic and executable. This might mean that factors cannot be perfectly randomized or that certain factor combinations will be disallowed. To avoid reporting artificially inflated metrics, design evaluations should always account for test structure and randomization.

Having a plan for collecting and managing test data is critical to a successful test program. A successful plan will include guidance on (1) how to collect data in the appropriate format, (2) where and how to store acquired data, (3) how to document, organize, and potentially automate data cleaning, reduction, and analysis, and (4) how to handle data access and distribution.

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Test Planning

Lesson 1: Introduction to Test Planning

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What is the Purpose of Test and Evaluation?

To provide **warfighters** and **decision makers** with information about military systems that is

RELEVANT

CREDIBLE

OBJECTIVE

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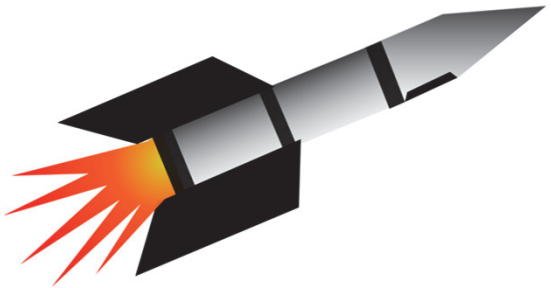

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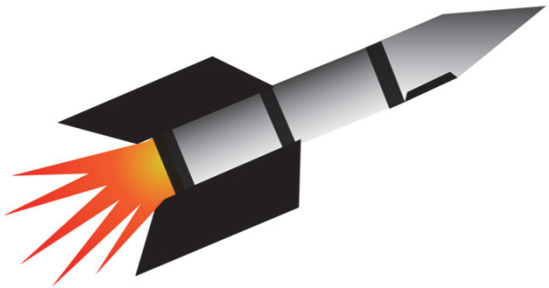

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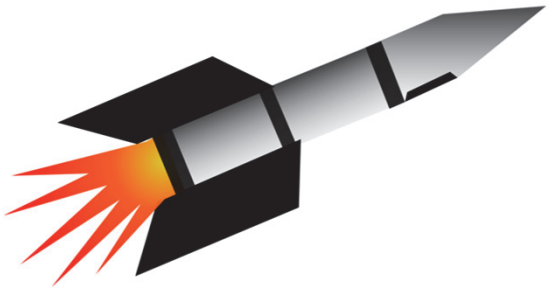

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What is the Purpose of Test and Evaluation?

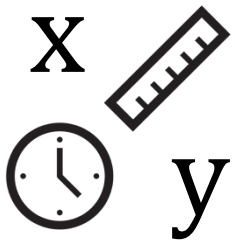
The **Design of Experiments** process
provides a framework
and an analytical basis
to help us do T&E
systematically and **efficiently**.

Testing Framework:
The Gold Standard of Experimentation

- The DOE process, at its core, is the scientific method.

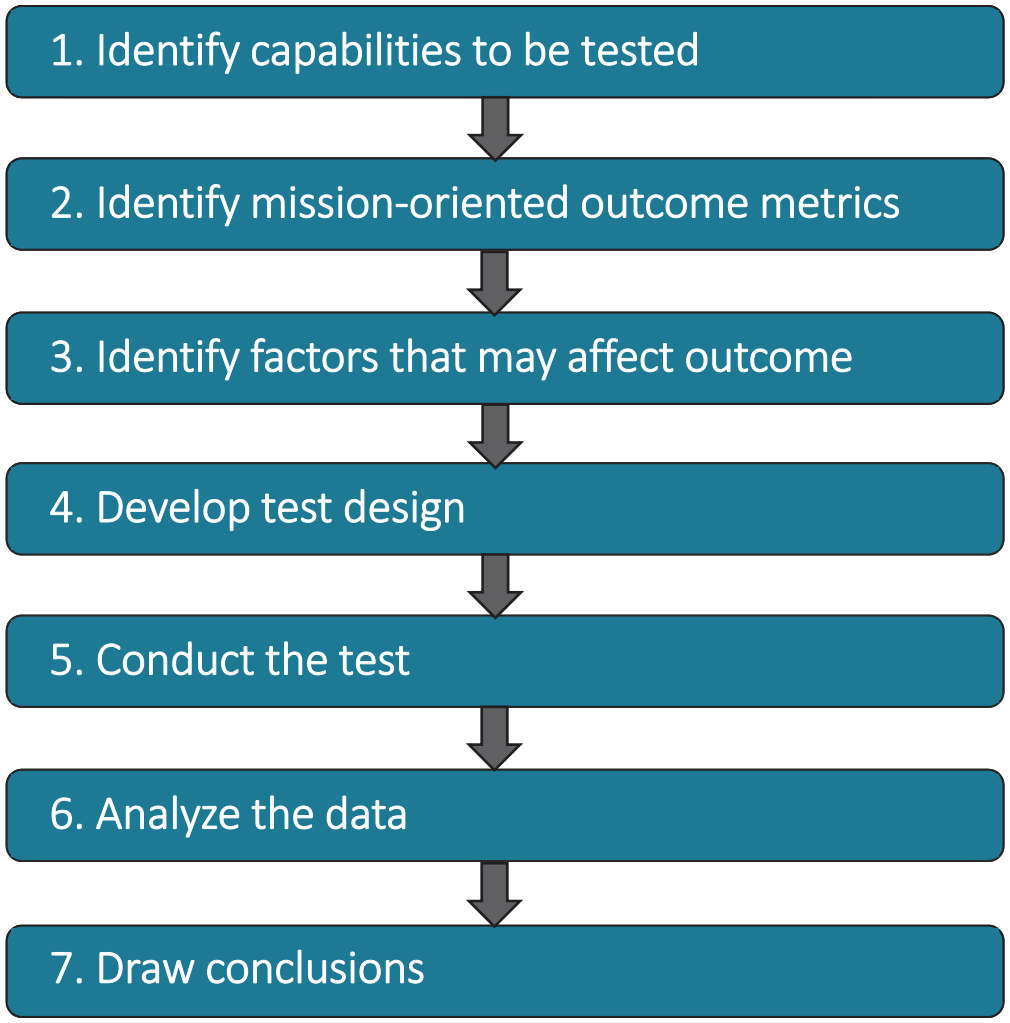
- It is the gold standard for performing experiments and determining cause and effect.

- What we mean by “experiment” goes well beyond the ‘chemistry lab’ scenario it often evokes.



- An experiment includes any test where variables are purposefully manipulated or inputs are purposefully set.
- So, the types of operational and live fire tests we conduct would certainly count as experiments.

Testing Framework:
The Gold Standard of Experimentation



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Testing Framework:
The Gold Standard of Experimentation

1. Identify capabilities to be tested

Testing Framework:
The Gold Standard of Experimentation

2. Identify the mission-oriented outcome metrics

Testing Framework:
The Gold Standard of Experimentation

3. Identify factors that may affect outcome

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4. Develop the test design

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7. Draw conclusions

Testing Framework:
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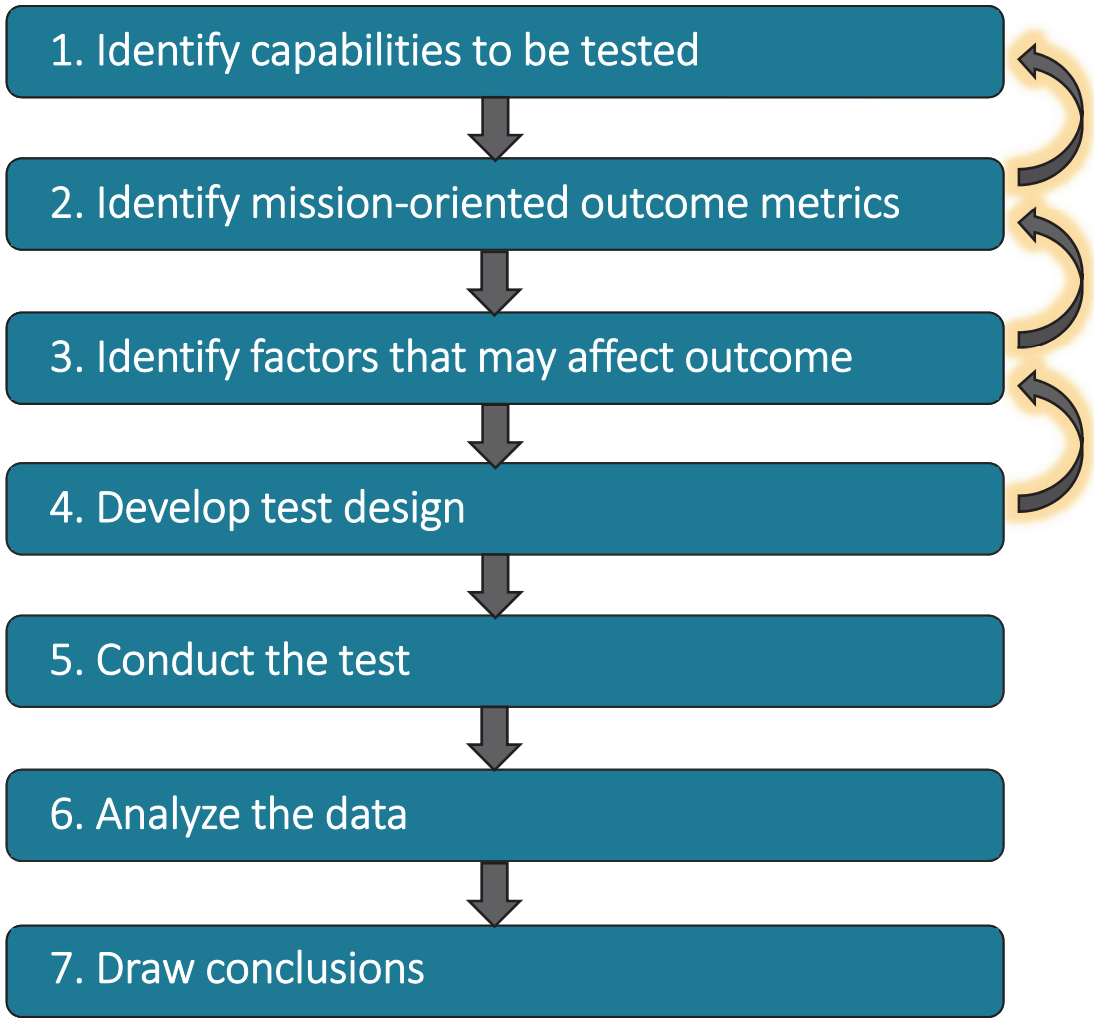

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Applying the Testing Framework

The test design process is applicable to any type of test:

- System Performance
- Human Factors
- Reliability
- Cybersecurity
- Live Fire
- Etc.

Applying the Testing Framework

Keys to success:

- Frequent **communication**
- **Collaboration** among technical, operational, and statistical experts
- Openness to **iteration**

The Three 'Test Planning' Steps are Crucial for Successful T&E

1. Identify capabilities to be tested

- Objectives of the test
- Questions you can ask about the system

2. Identify mission-oriented outcome metrics

- How you should measure system performance
- Response variables

3. Identify factors that may affect outcome

- Conditions or configurations under which the system may operate
- Operational envelope

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The next three lessons cover each of these planning steps in more detail…

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Lesson 2: Identify Test Objectives

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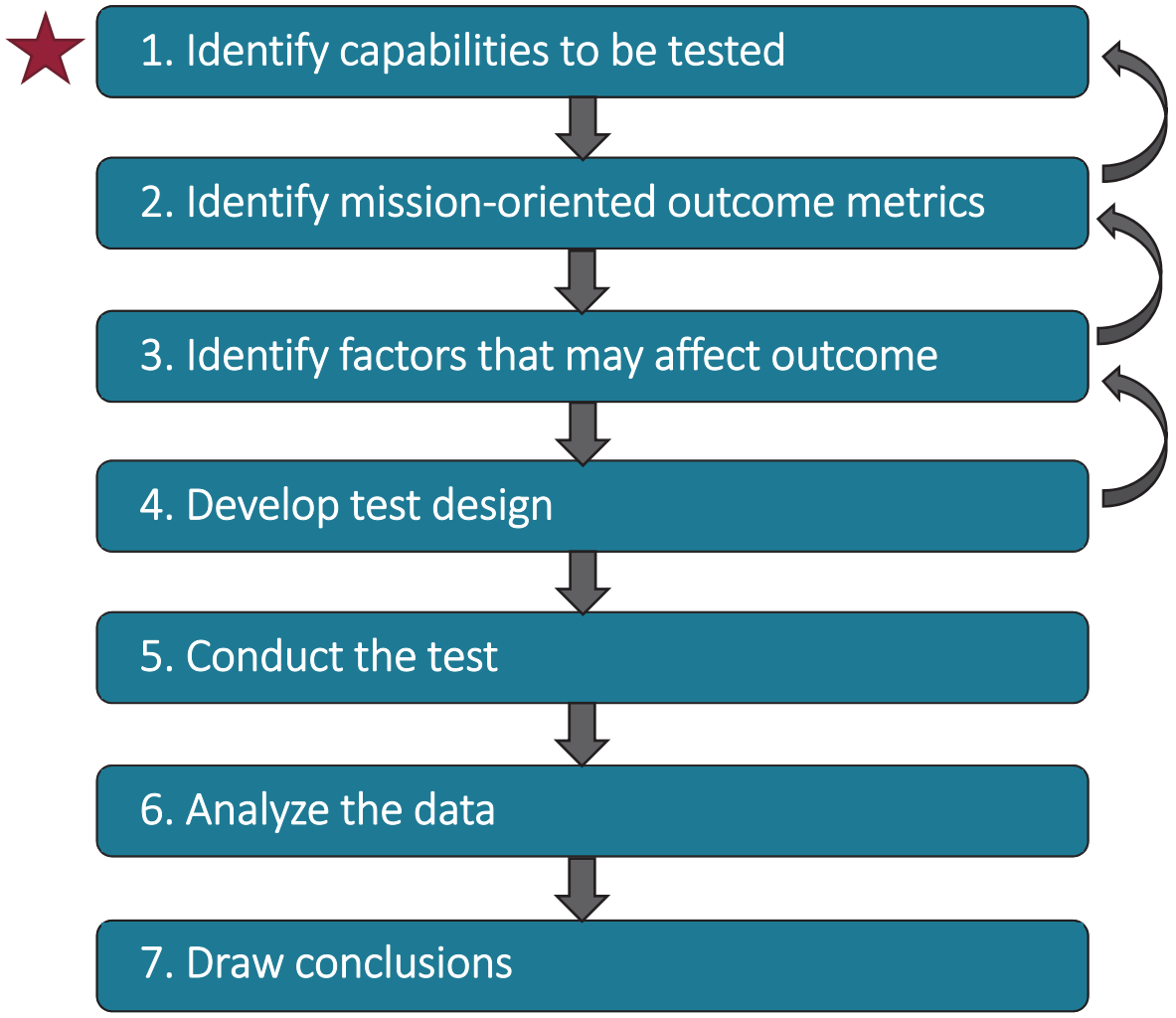

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Suppose I ask you to make a paper aerial delivery vehicle

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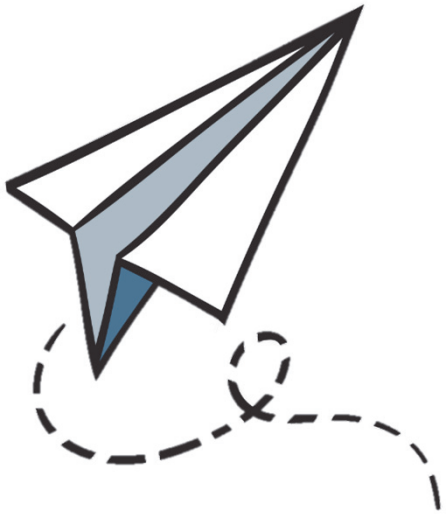

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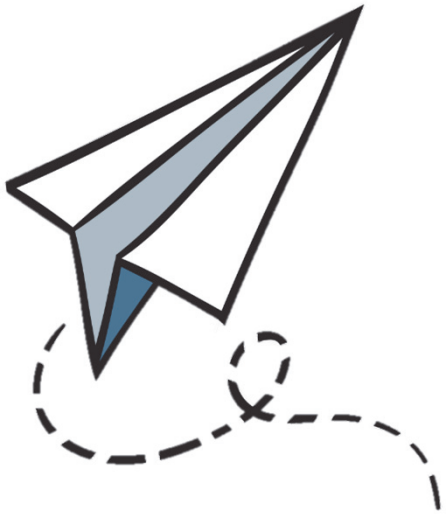

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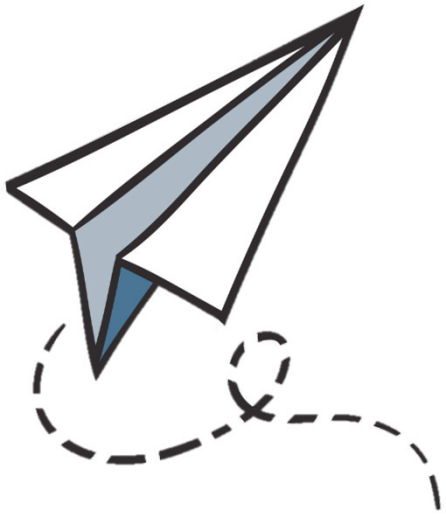

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Suppose I ask you to make a paper aerial delivery vehicle

It is essential to have a clear goal when designing an experiment

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   - Objectives of the test
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Test objectives will drive all future steps, including the test design and statistical analysis.

Common Test Objectives

- Screen for influential factors driving performance.
- Characterize performance across an operational envelope.
- Compare two systems (or more) across a variety of operating conditions.
- Identify problems that degrade system performance.
- Optimize system performance with respect to a set of conditions.

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> DoDI 5000.02: The test program should produce "data to **characterize** combat mission capability across an appropriately selected set of factors and conditions."

Screen for Influential Factors

- Screening is useful early on in testing when we may know little about how the system responds to various factors.
- General approach:
  - Identify all potential factors that are thought to affect the response variable.
  - Choose an initial experimental design that uses minimal test resources.
  - Through analysis, identify the factors that have the largest impact on the response.
  - Update next test design to characterize the response (performance) as a function of only the important factors.

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(Screening is essential to integrated and sequential testing.)

Characterize performance across conditions

- Characterization tests describe performance at all relevant conditions and configurations in which the system may operate (i.e., across the operational envelope).
- They are also useful for determining if a system meets requirements across a variety of operational conditions.
- Characterization designs facilitate building precise mathematical models of performance based on test data.

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- Characterization designs facilitate building precise mathematical models of performance based on test data.

> Characterization is the most important and common goal for operational testing.

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Lesson 3: Select Outcome Measures

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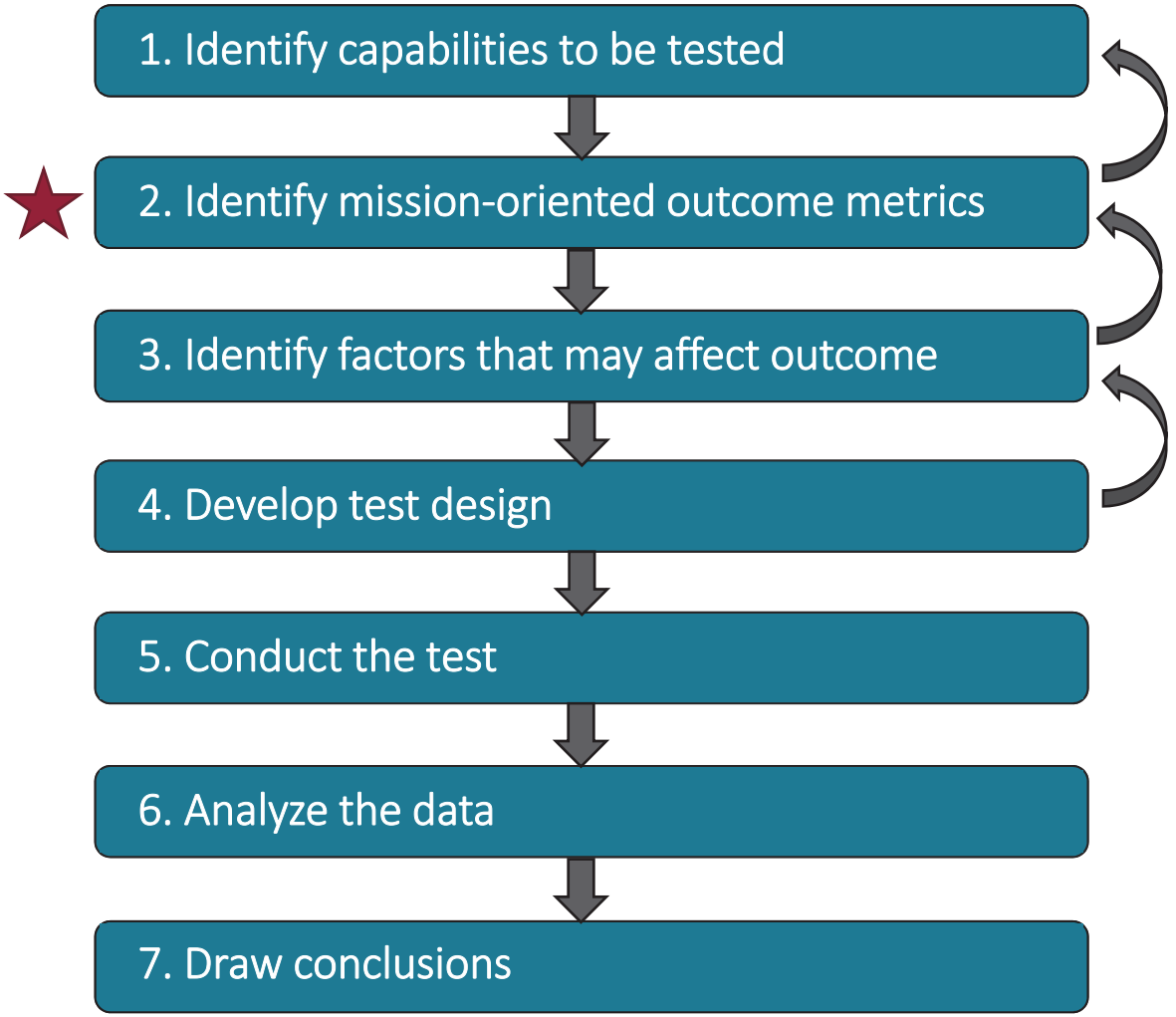

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Response variables measure the outcome of your test

2. Identify mission-oriented outcome metrics
   - How you should measure system performance
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Good response variables…

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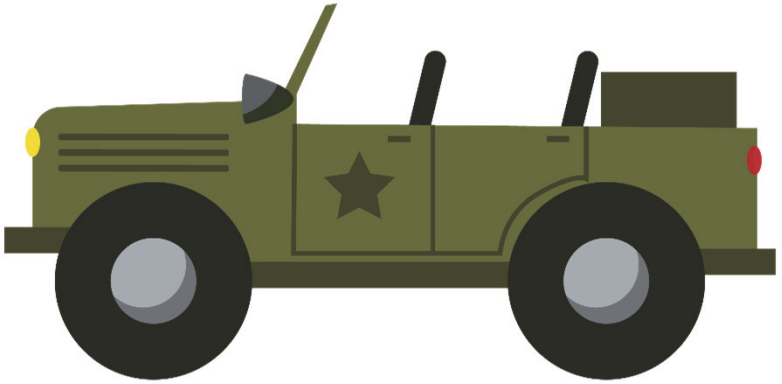

Good response variables...

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- Lend themselves well to defensible experimental design, which means they are:
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  - Valid. They directly address the test objective.
  - Informative. Continuous responses always provide more information per test point than pass/fail metrics.

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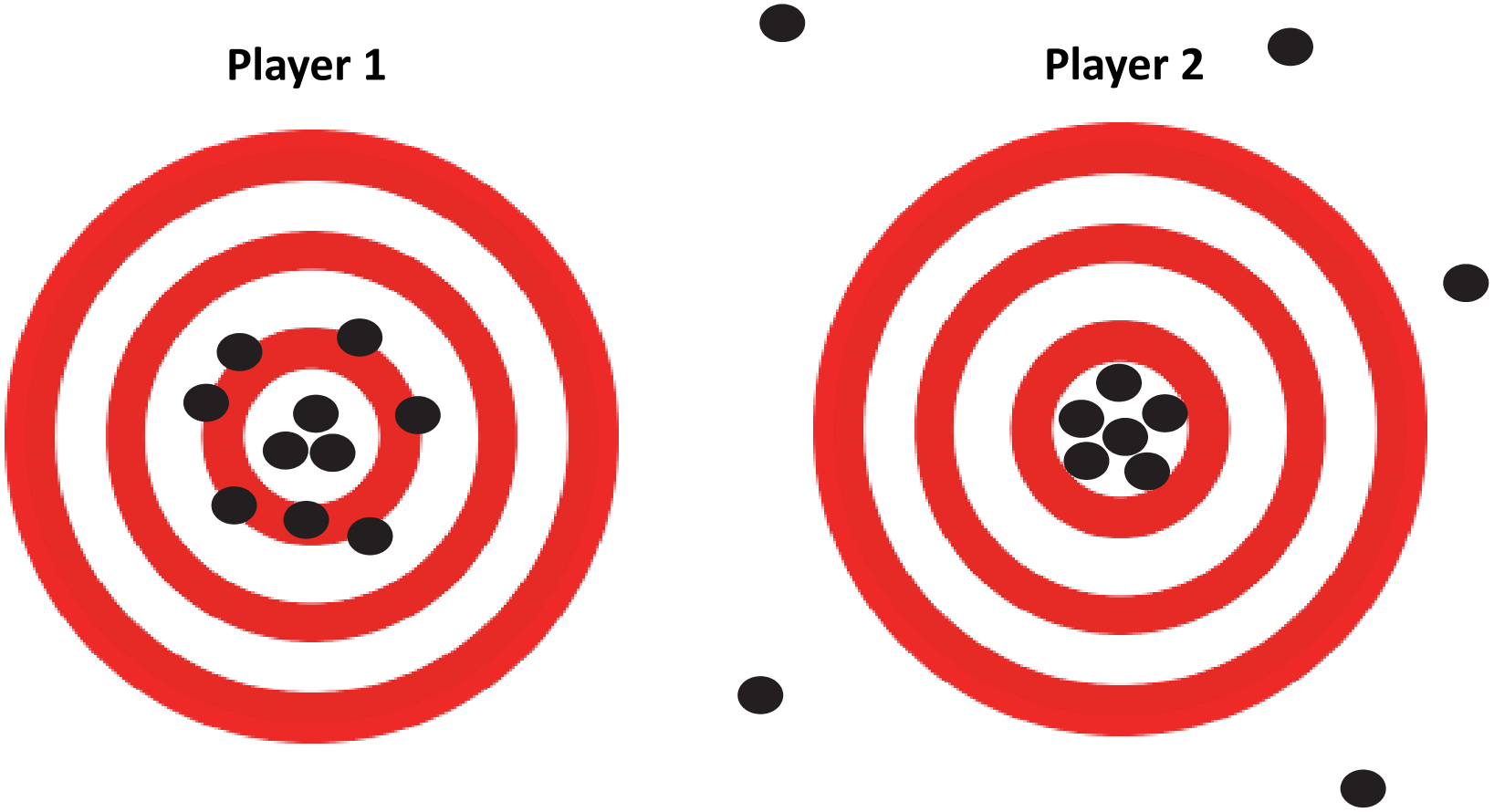
Multiple responses are common and almost always necessary!

Who is the better dart player?



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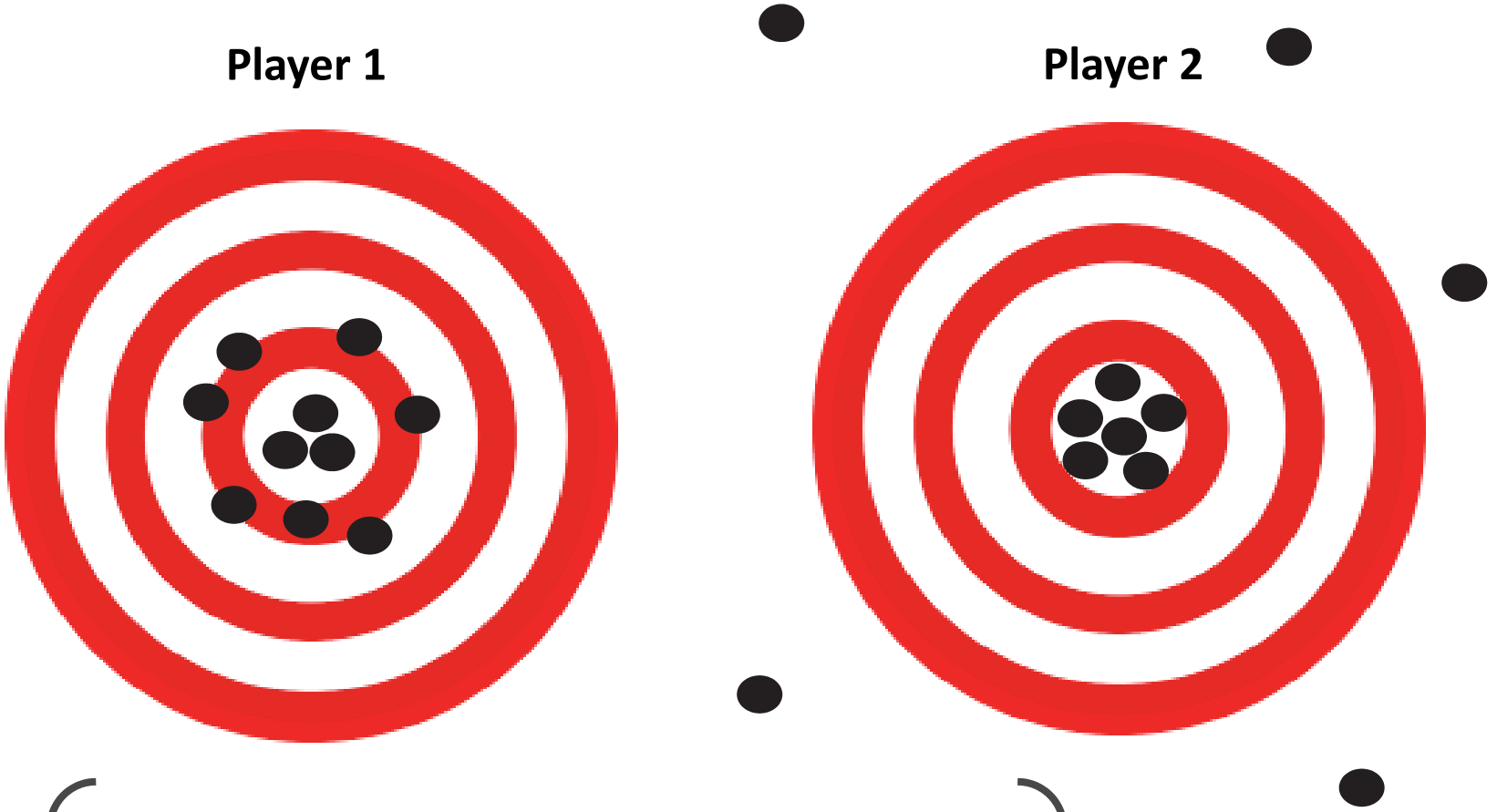

We have a much better picture of the players' abilities by looking at the miss distances from bullseye compared to just a bullseye hit/miss!

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We can often convert probability requirements into continuous measures

	Chemical Agent Detector	Submarine Mine Detection	Missile/Bomb	Radar Detection
Requirement	Probability of detection greater than 85% after one minute of exposure	Probability of detection greater than 80% outside 200 meters	Probability of hit at least 90%	Probability of detection greater than 90% at 300 kilometers.
Original Test Measurement	Detect prior to 1 minute? (Yes/No)	Detect/Non-Detect	Hit/Miss	Detect/Non-Detect
Modified Test Measurement	Detection Time	Detection Range	Miss Distance	Detection Range

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Lesson 4: Select Factors Affecting Outcomes

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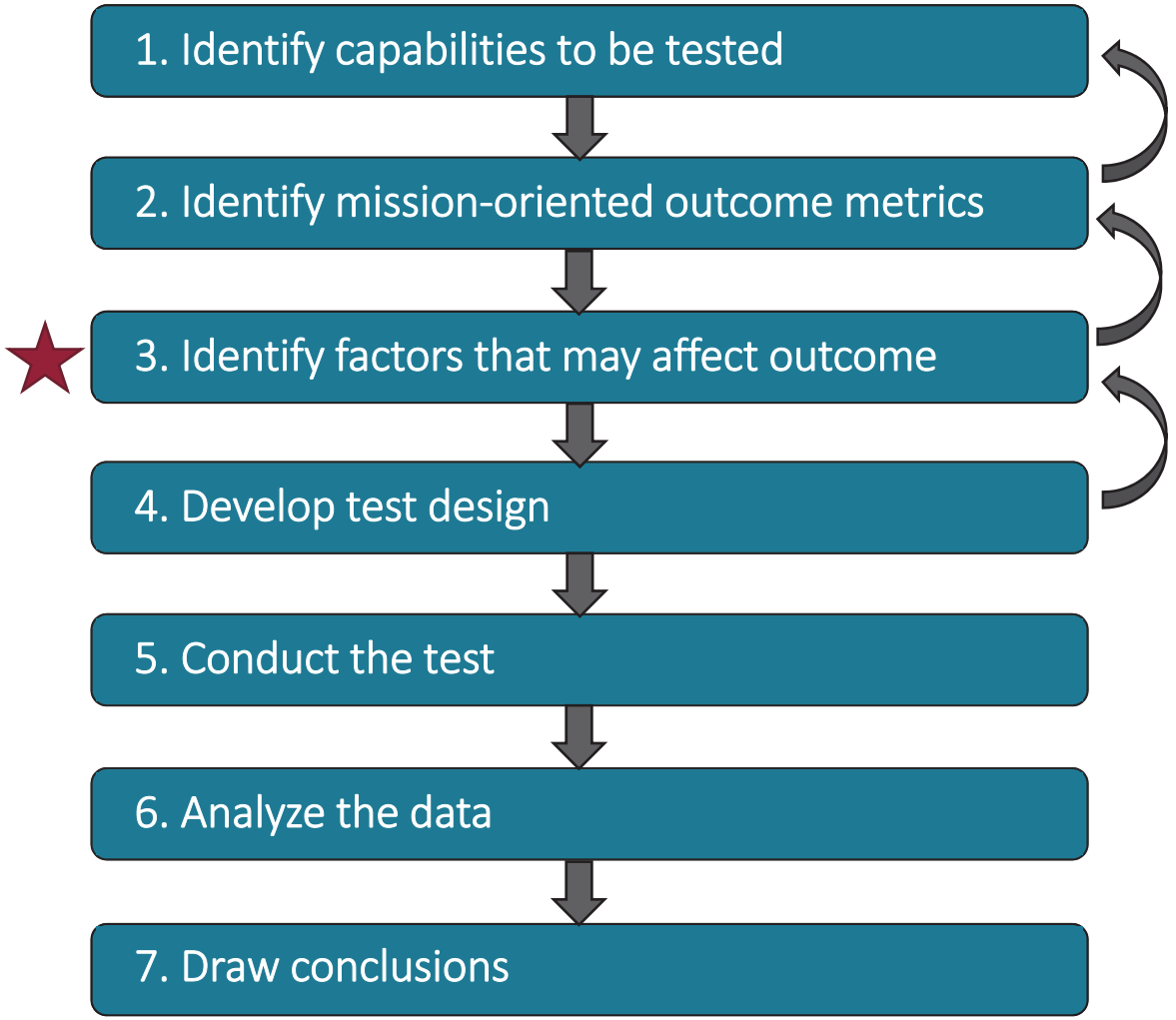

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What might influence the performance of the process or system under test?

3. Identify factors that may affect outcome
    - Conditions or configurations under which the system may operate
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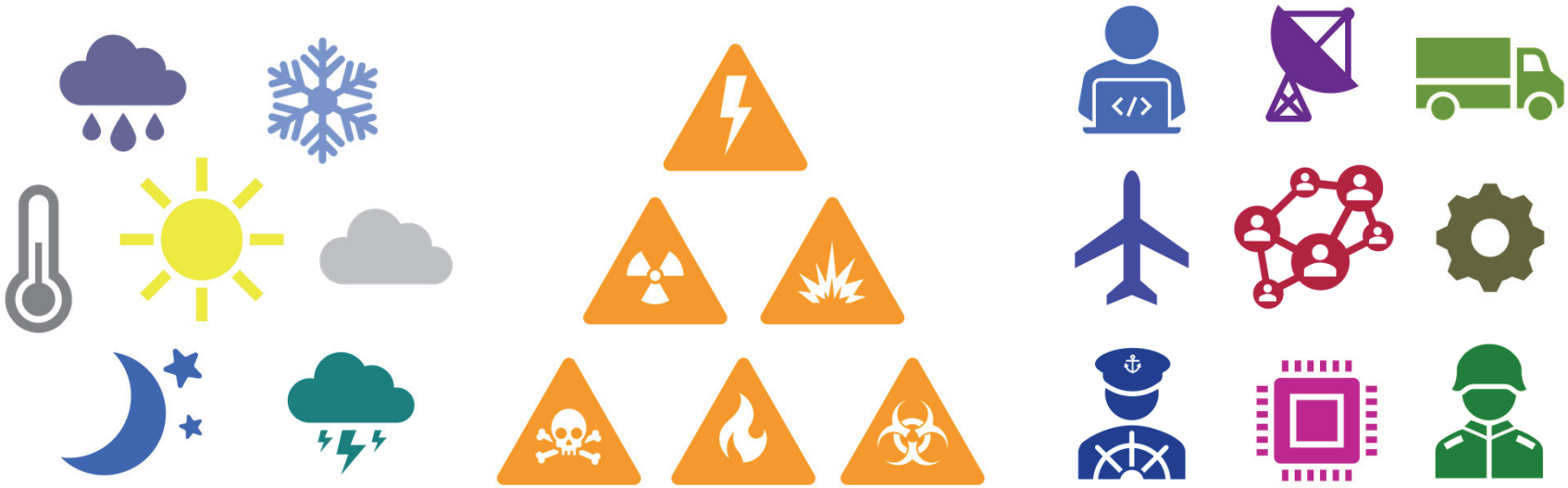

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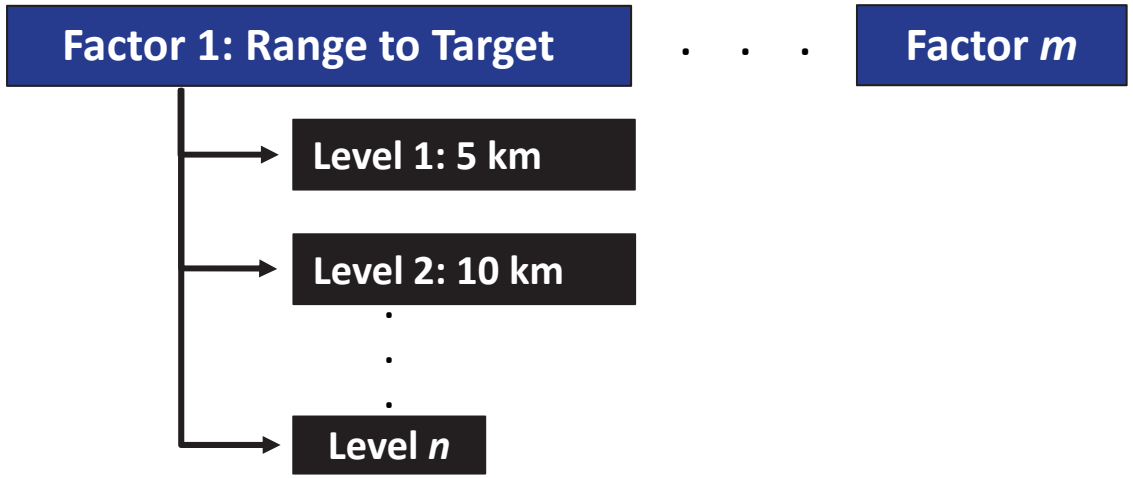
Terminology

Factors are independent variables that are expected to affect the outcome of a test.

Levels are the specific values that the factors assume. Factor levels are often referred to as the test conditions.



Good test design factors are…

Important: Factors are expected to have an effect on the test outcome.

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Informative: Continuous factors are preferred to categorical factors.

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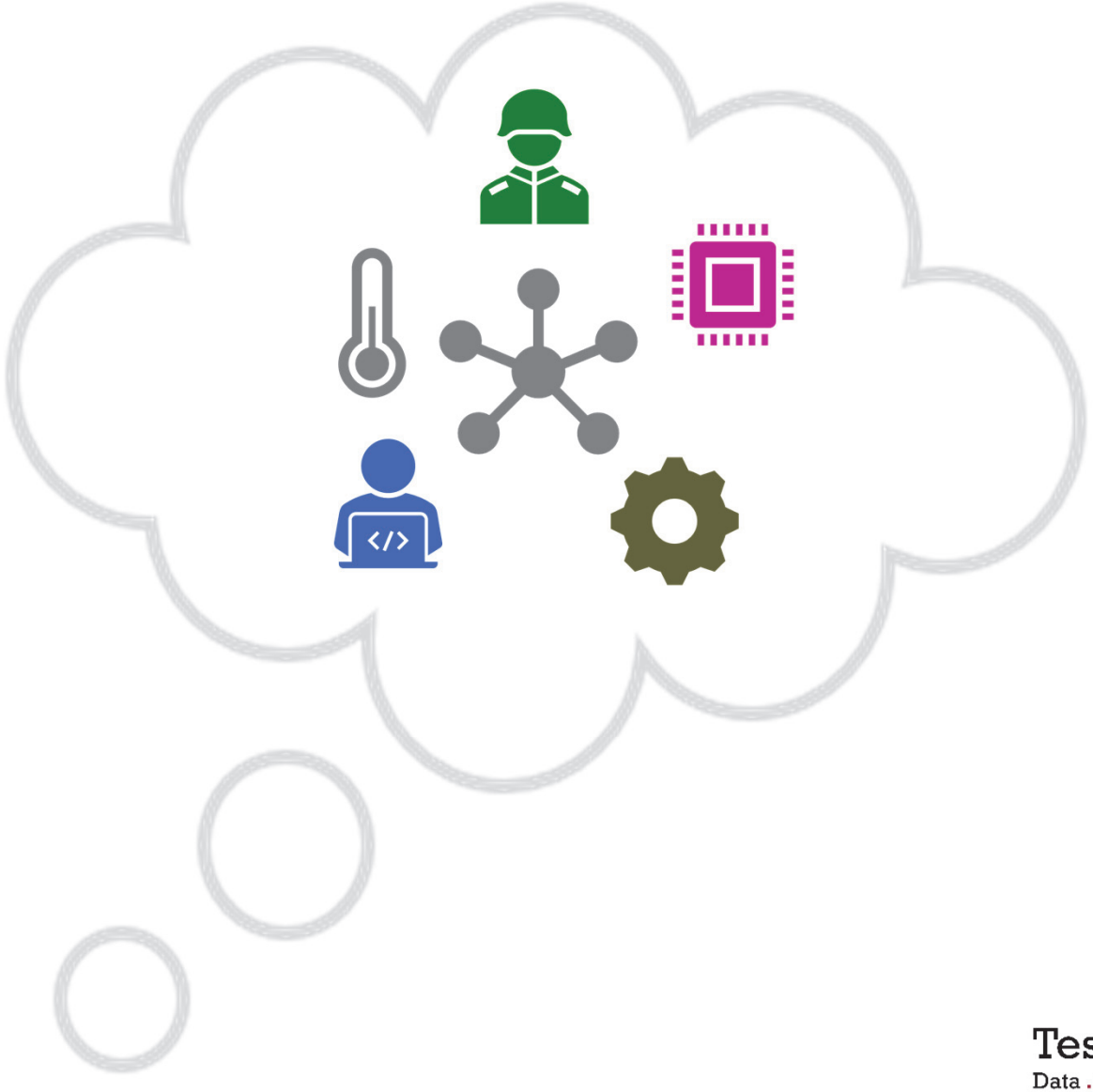
Important: Factors are expected to have an effect on the test outcome.

Controllable: Factors can be controlled (i.e., set to a specific level) at a reasonable cost.

Informative: Continuous factors are preferred to categorical factors.

- Continuous factors allow for:
  - Interpolation
  - Higher power to detect significance of a factor
  - Strategic point placement

Testers should brainstorm ALL potential factors that could affect test outcomes



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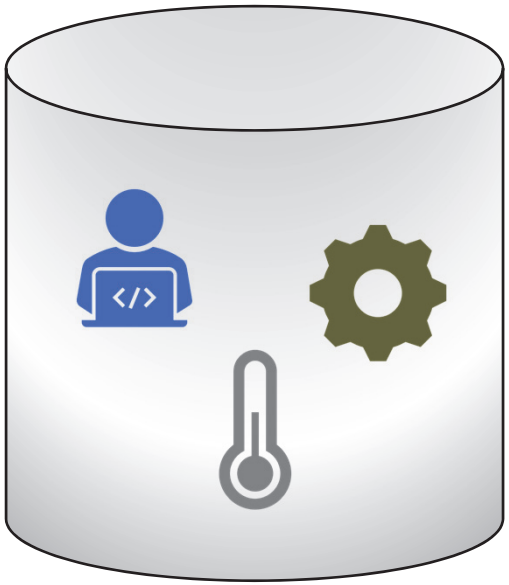

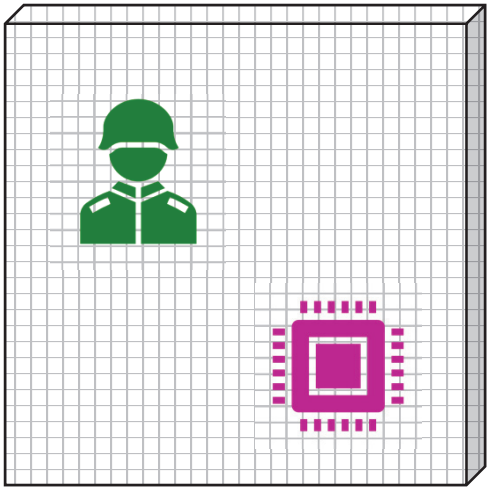

Factors can be prioritized and sorted using a Factor Management Scheme

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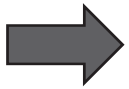
Testers should brainstorm ALL potential factors that could affect test outcomes

- Factors of particular interest to the experimenter
- Factors that are measurable, controllable, and thought to be (very) influential



Strategically Vary

Factors can be prioritized and sorted using a Factor Management Scheme

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Testers should brainstorm ALL potential factors that could affect test outcomes

- Factors of particular interest to the experimenter
- Factors that are measurable, controllable, and thought to be (very) influential

→ Strategically Vary

- Factors that are not of particular interest for the experiment
- Factors that seldom change levels
- Factors that are unlikely to have a large effect on the outcome
- Factors that cannot be controlled, but have too much of an influence on the response variable to simply ignore

→ Fix or Record

Factors can be prioritized and sorted using a Factor Management Scheme

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Modern experimental designs can investigate a large number of factors efficiently

Testers should err on the side of strategically varying factors

Fixing factors limits conclusions about the system to the one condition tested

For recorded factors there is no guarantee that all levels of interest will be observed

- Potential tradeoff with operational realism

Adding factors does not cause the test size to grow exponentially!

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Lesson 1: Introduction to Test Design

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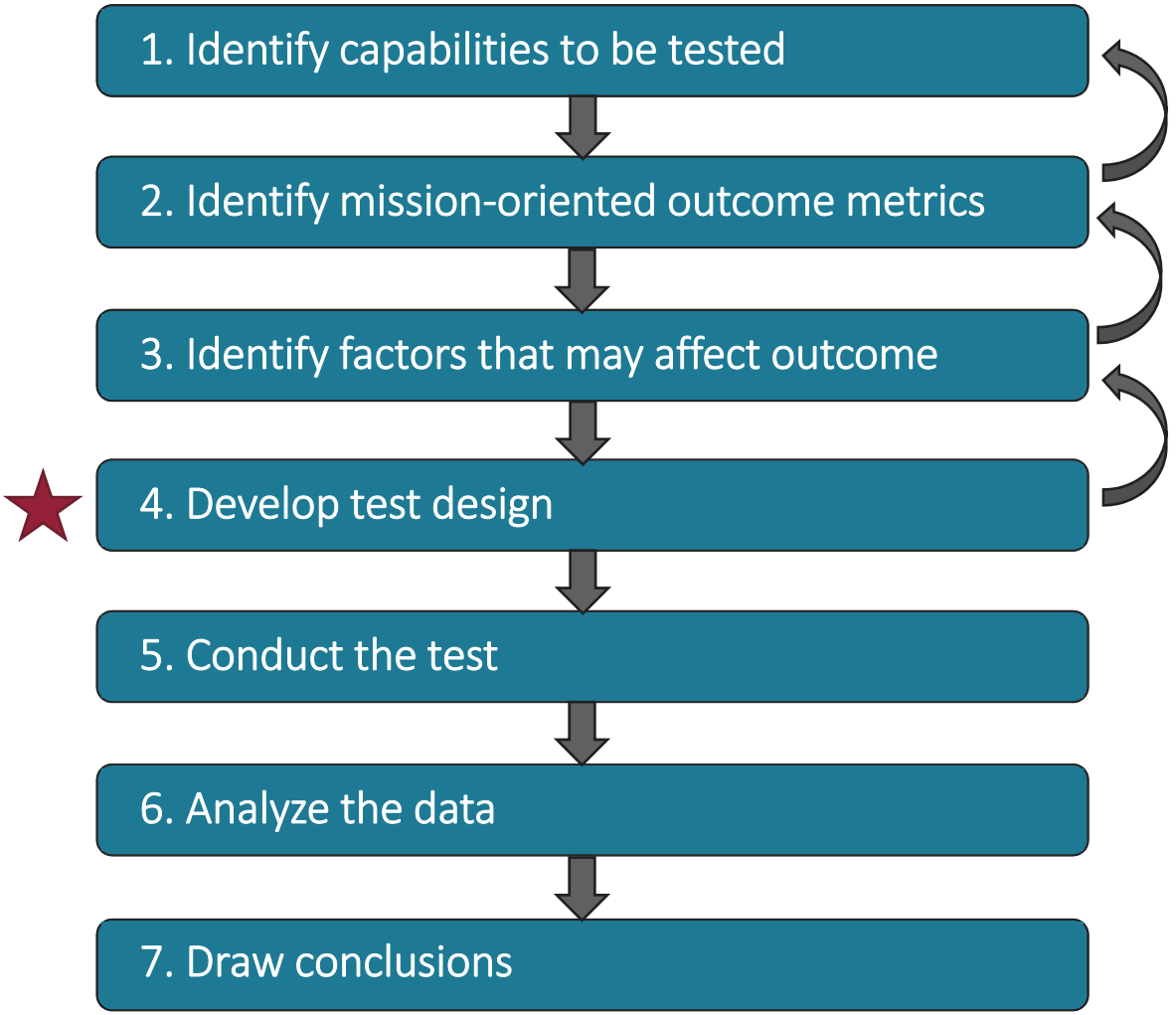
Testing Framework: The Gold Standard of Experimentation



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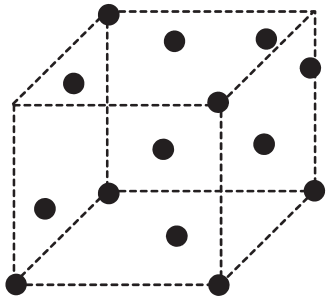
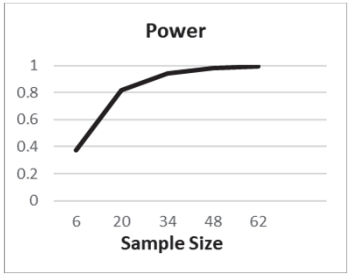
Common Challenges to Test

What Goal(s)?

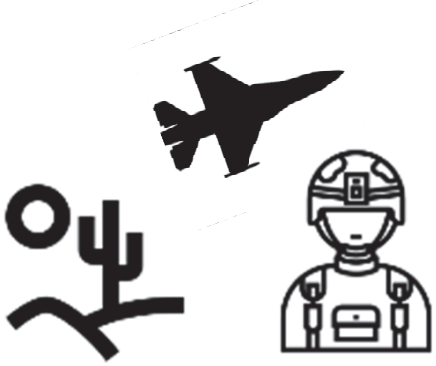
Which Points?



How Many Points?



How to Execute?



How to Capture?

What Conclusion(s)?

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Test *Goals* Influence Test *Designs*

Screen

Characterize

Optimize

Compare

Identify Problems

Predict

Improve

Demonstrate

All tests are designed, many poorly.

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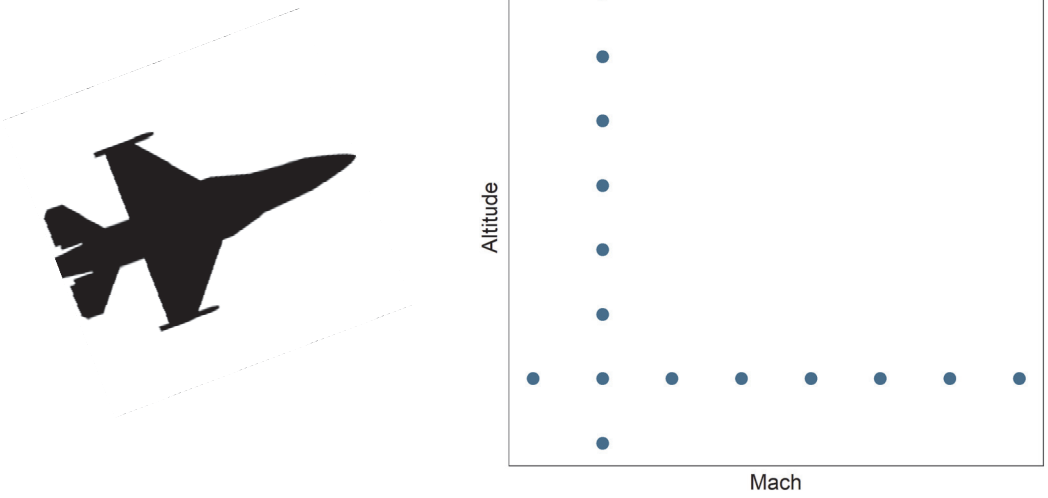
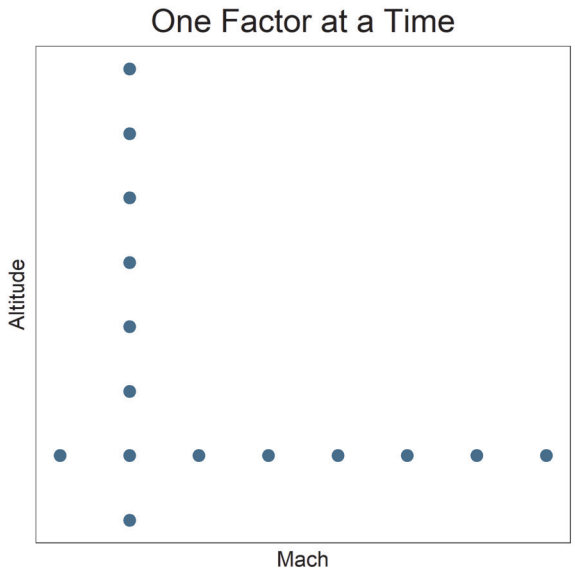
A one-factor-at-a-time test strategy is inefficient and fails to detect interactions

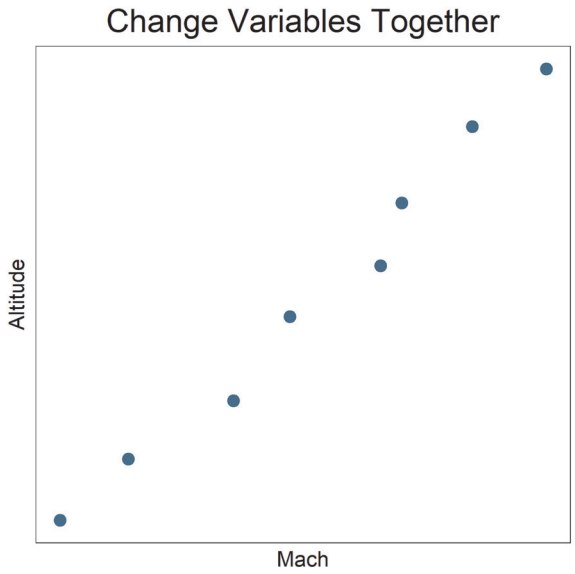


All tests are designed, many poorly.

A **one-factor-at-a-time** test strategy is inefficient and fails to detect interactions

Changing the variables together prevents the ability to detect cause end effect.





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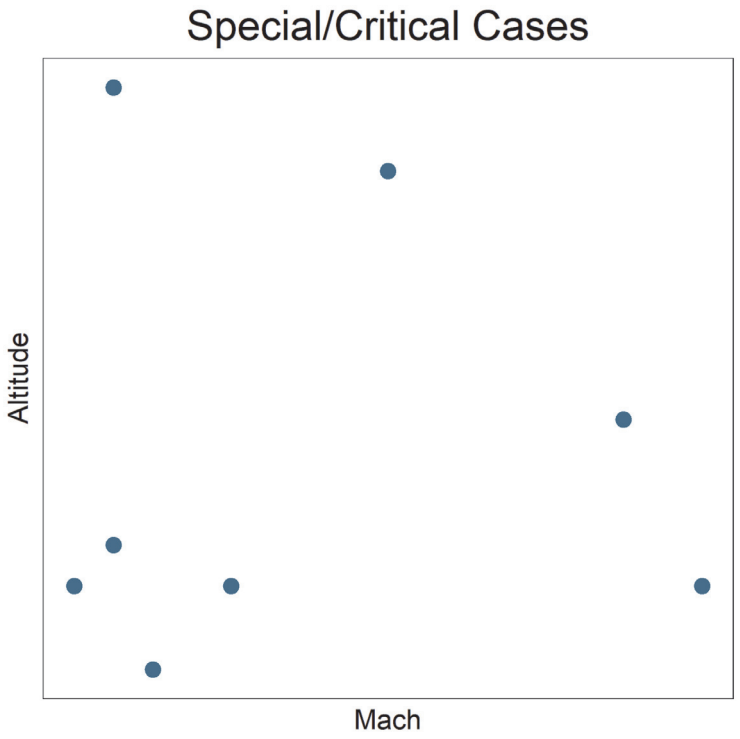
All tests are designed, many poorly.

A test strategy of “We’ll just do what we did last time” or “We’ll test the special cases” might miss important performance shortfalls.



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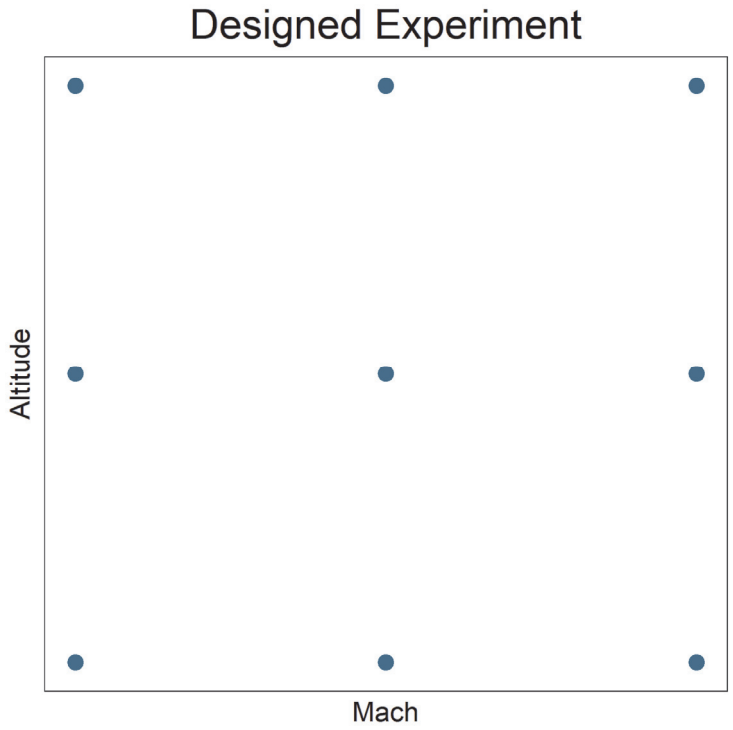
DOE changes “I think” to “I know”

A test strategy that employs DOE will provide the most powerful allocation of test resources for a given number of tests.



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DOE Provides a Structured Approach to Picking Test Points

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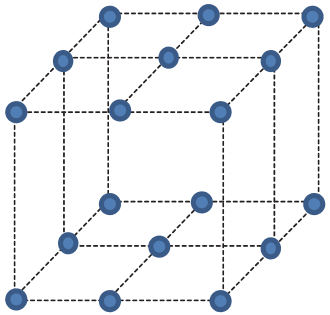
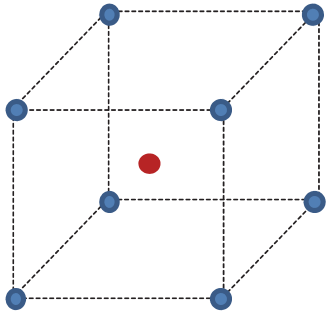
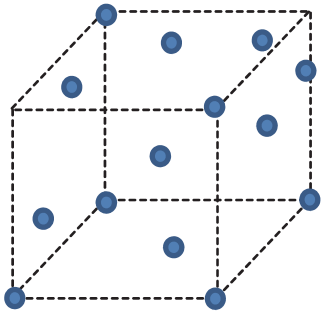


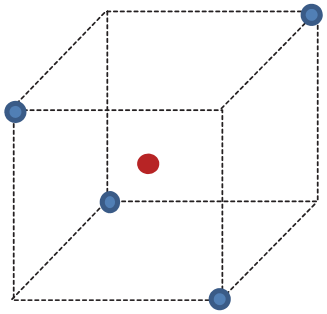
General Factorial
3x3x2 design



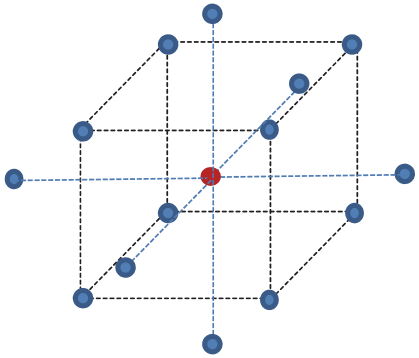
2-level Factorial
2^3 design



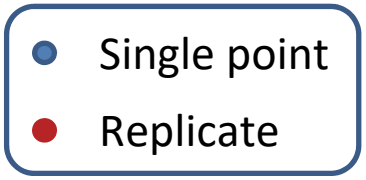
Optimal Design
D-optimal



Fractional Factorial
2^{3-1} design



Response Surface
Central Composite design



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“How much testing is enough?”

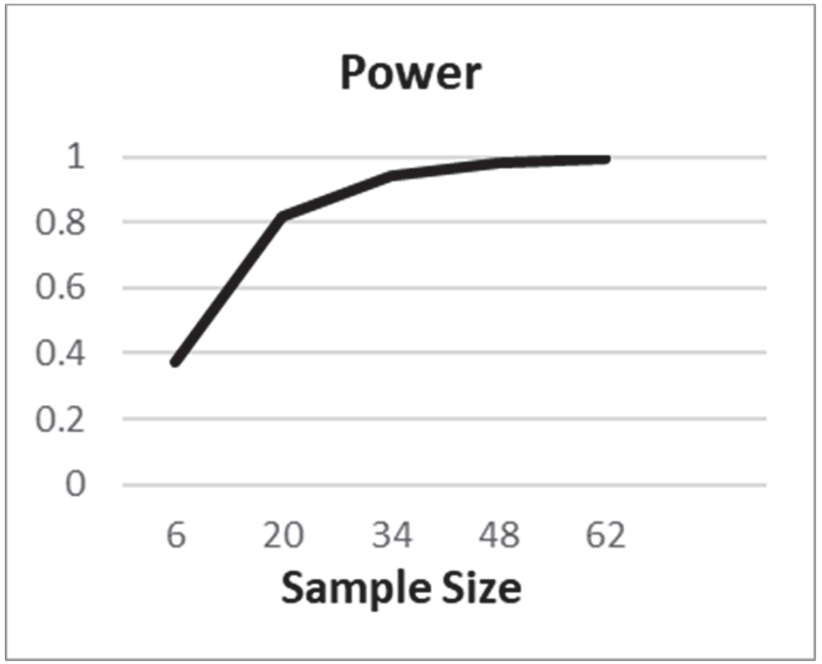
How many test points are enough to get it *right*?

3 ? That’s how much money/time we have.

8-10 ? That’s what we did last time.

30 ? From my high school stats class, something good happens at 30!

DOE methods provide tools to assess the risk of drawing incorrect conclusions



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Design your test around how it will be executed

Executing an operationally realistic test means your factors might not be **randomized** or that certain factor combinations will be **disallowed**.

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Executing an operationally realistic test means your factors might not be **randomized** or that certain factor combinations will be **disallowed**.

Response Variable

Miss Distance

Factor	Level
Illumination	Light, Dark
Range to Target	Short, Medium, Long
Fuze Type	A, B
Angle of Fire	Low, High

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CONOPS:

Fire → Move → Fire

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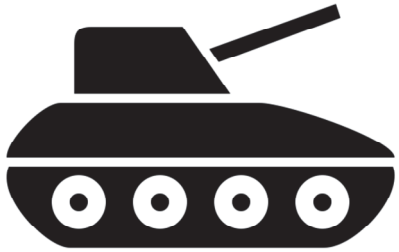

CONOPS:

Fire → Move → Fire

Factor	Level	Difficulty of Randomization
Illumination	Light, Dark	Hard
Range to Target	Short, Medium, Long	Hard
Fuze Type	A, B	Easy
Angle of Fire	Low, High	Easy

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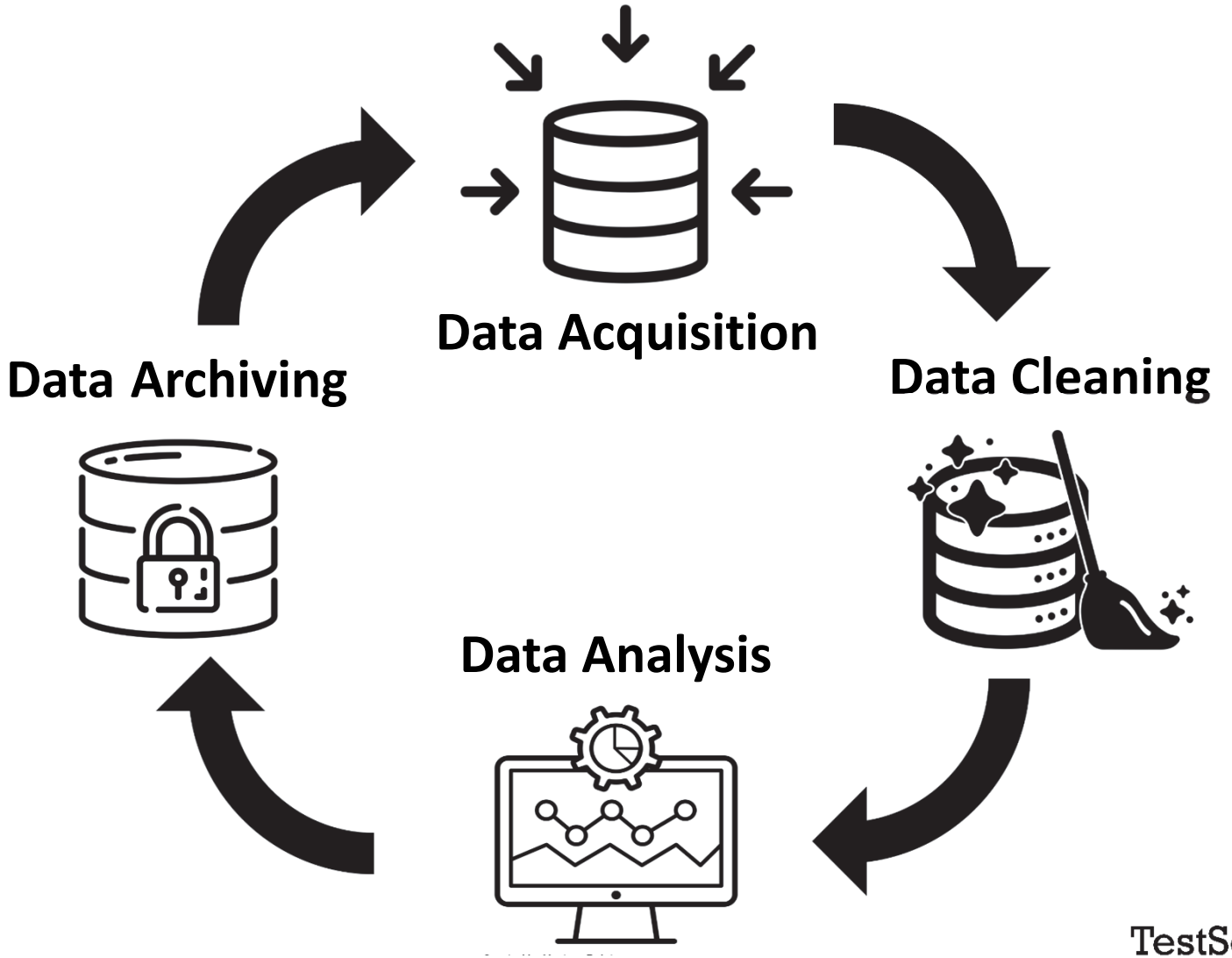
Data Management Plays a Key Role throughout the T&E Lifecycle



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A Good Test Design Supports Credible and Clear Analyses

A successful analysis should follow
the structure of the test design.

Building a statistical model using the factors
specified in our test design allows us to
quantify differences across relevant conditions
and draw conclusions with confidence.

All experiments are designed with an analysis methodology in mind:
to reap the benefits, we need to follow through to the analysis!

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Lesson 2: Determine Design Goals

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Before creating a test design, ensure you have the answers to these questions:

Are the system, mission, and operating environment clearly defined?

Are the goals of the test clearly defined?

What are the question(s) to be answered in testing?

Does the overall test strategy support characterization of combat mission capability?

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What are some common design goals?

Screen	for influential factors driving performance
Characterize	performance across an operational envelope
Optimize	system performance with respect to a set of conditions
Compare	two systems (or more) across a variety of operating conditions
Identify Problems	that degrade system performance

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What are reasons to screen for factors?

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Screening is useful early in testing when we know little about how the system responds to various factors.

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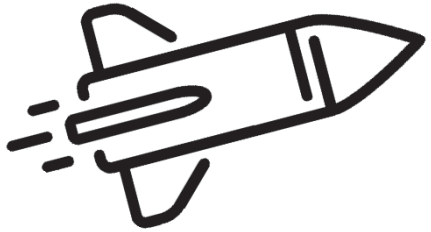
Screening is useful early in testing when we know little about how the system responds to various factors.

Screening is essential to integrated & sequential testing to reduce the factor space prior to operational testing.

Consider a novel hypersonic missile



What factors will impact its performance?

Long list of factors that may or may not be relevant

Large design space is too expensive to optimize or characterize

We need to identify relevant factors with minimal test resources

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How do you pick a screening design?

Design Space Features

Many factors

Typically 2 levels per factor

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Screening Design Features

Sparse designs

Cover large spaces efficiently

Some higher-order terms confounded

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Common Screening Designs

Fractional factorial

Optimal

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What are reasons to characterize performance?

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Characterization tests describe system performance across the operational envelope

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Characterization tests determine if a system meets requirements across operational conditions

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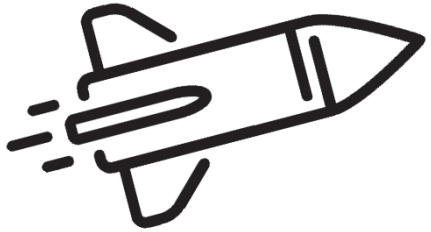
Characterization tests describe system performance across the operational envelope

Characterization tests determine if a system meets requirements across operational conditions

DoDI 5000.02: The test program should produce "**data to characterize combat mission capability across an appropriately selected set of factors and conditions.**"

Consider our screened hypersonic missile



How will our factors impact its performance?

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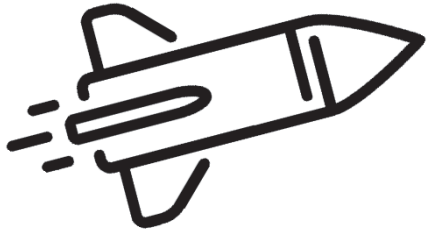

How will our factors impact its performance?

We identified factors relevant to performance through screening

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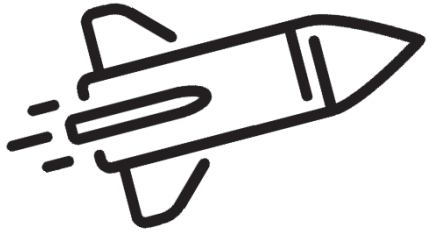
Consider our screened hypersonic missile



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We identified factors relevant to performance through screening

We need to test across a variety of operational conditions …

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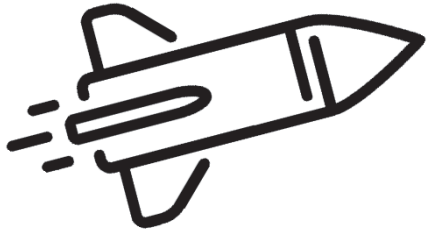

How will our factors impact its performance?

We identified factors relevant to performance through screening

We need to test across a variety of operational conditions …

… to adequately understand performance using minimal resources

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How do you pick a characterizing design?

Design Space Features

Fewer factors; more levels

Anticipated variation in performance

How do you pick a characterizing design?

Design Space Features

Fewer factors; more levels

Anticipated variation in performance

Characterizing Design Features

Determine factor impact

Allows for adequate precision

No/little confounding

How do you pick a characterizing design?

Design Space Features	Characterizing Design Features	Common Characterizing Designs
Fewer factors; more levels	Determine factor impact	Factorial
Anticipated variation in performance	Allows for adequate precision	Optimal
	No/little confounding	

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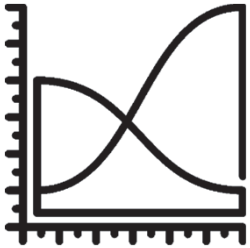
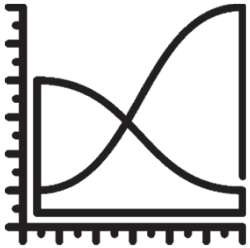
What are reasons to optimize performance?



Optimization test designs seek the combination of controllable factors that optimizes test outcomes

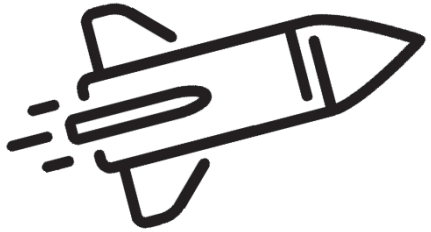
What are reasons to optimize performance?



Optimization test designs seek the combination of controllable factors that optimizes test outcomes

Optimization tests are useful in design, manufacturing, and the development of tactics, techniques, & procedures

(Re-)consider our screened hypersonic missile



What factors will optimize its performance?

We identified factors relevant to performance through screening

We need identify the optimal flight profile settings …

… for minimizing missile miss distance

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How do you pick an optimization design?

Design Space Features

Few factors;
many levels

Precision needed

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How do you pick an optimization design?

Design Space Features

Few factors; many levels

Precision needed

Optimizing Design Features

Dense designs

Often iterative

Searching for a local or global optimum (min/max)

How do you pick an optimization design?

Design Space Features	Optimizing Design Features	Common Optimizing Designs
Few factors; many levels	Dense designs	Response Surface Methods (RSM)
Precision needed	Often iterative	Optimal
	Searching for a local or global optimum (min/max)	

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An effective test depends upon good, clearly articulated design goals

We have learned about 3 common design goals and how to approach them:

- **Screening**
- **Characterizing**
- **Optimizing**

An effective test depends upon good, clearly articulated design goals

- We have learned about 3 common design goals and how to approach them:
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- We have learning that screening is a great tool in sequential and integrated testing to better constrain the design space for characterization and optimization tests.

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- We have learned about 3 common design goals and how to approach them:
  - **Screening**
  - **Characterizing**
  - **Optimizing**
- We have learning that screening is a great tool in sequential and integrated testing to better constrain the design space for characterization and optimization tests.
- In the next lesson, *Creating the Design*, we will learn more about common experimental designs.

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Lesson 3: Create the Test Design

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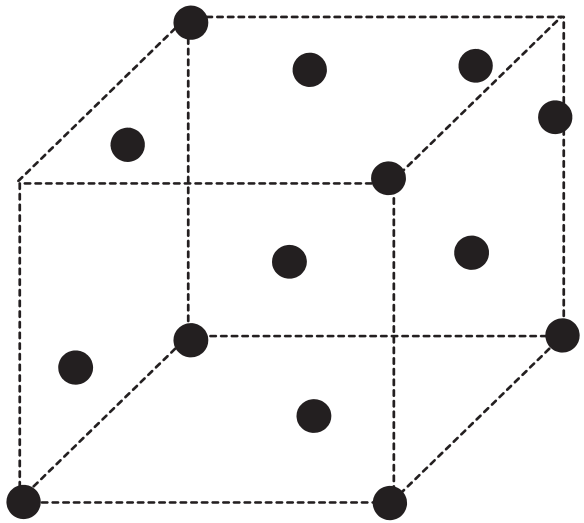
Design of experiments (DOE)

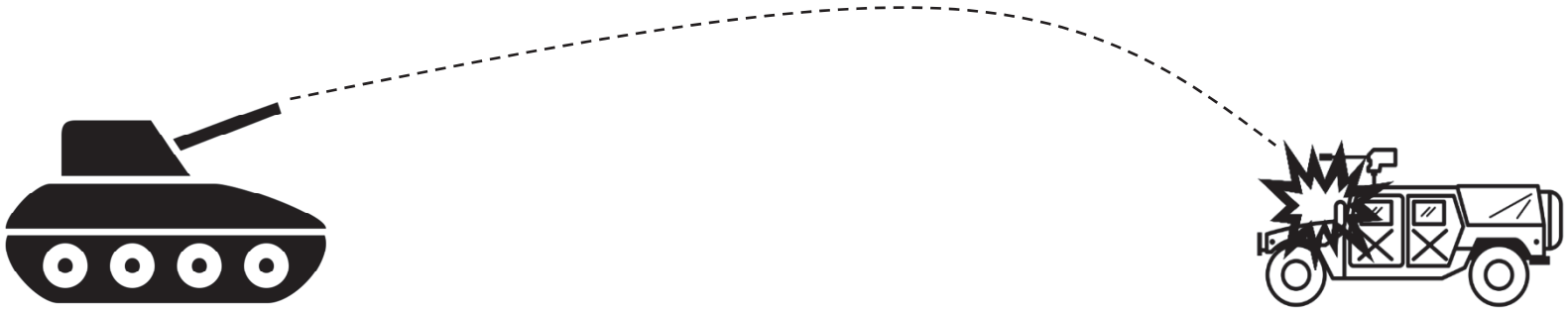
Which Points?



Which Points? Testing a New Artillery Cannon

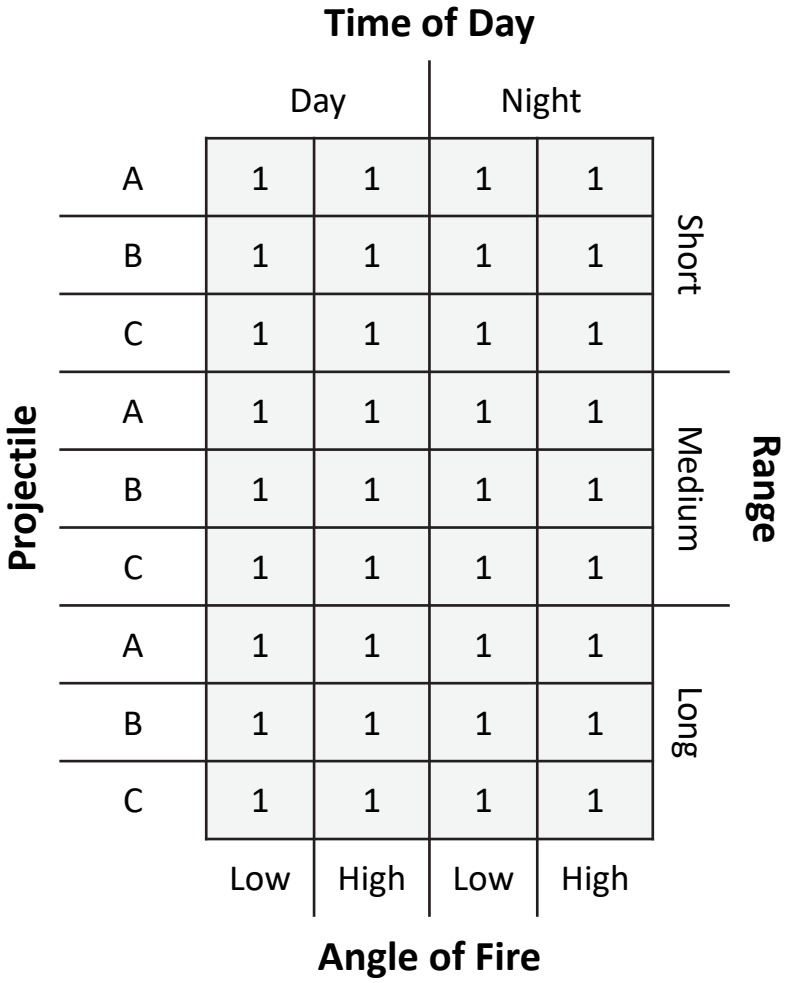
Response Variable

Accuracy of Fires - Miss Distance



Factor	Level
Time of Day	Day, Night
Range to Target	Short, Medium, Long
Projectile Type	A, B, C
Angle of Fire	Low, High

Factorial Designs Examine All Possible Combinations of Each Factor Level



Full Factorial Designs:

- Support the test goals of characterize or compare.
- Examine every possible combination of each level.
- Allow for the estimation of all main effects and all possible interactions.
- Are highly efficient and informative, though potentially prohibitively costly.

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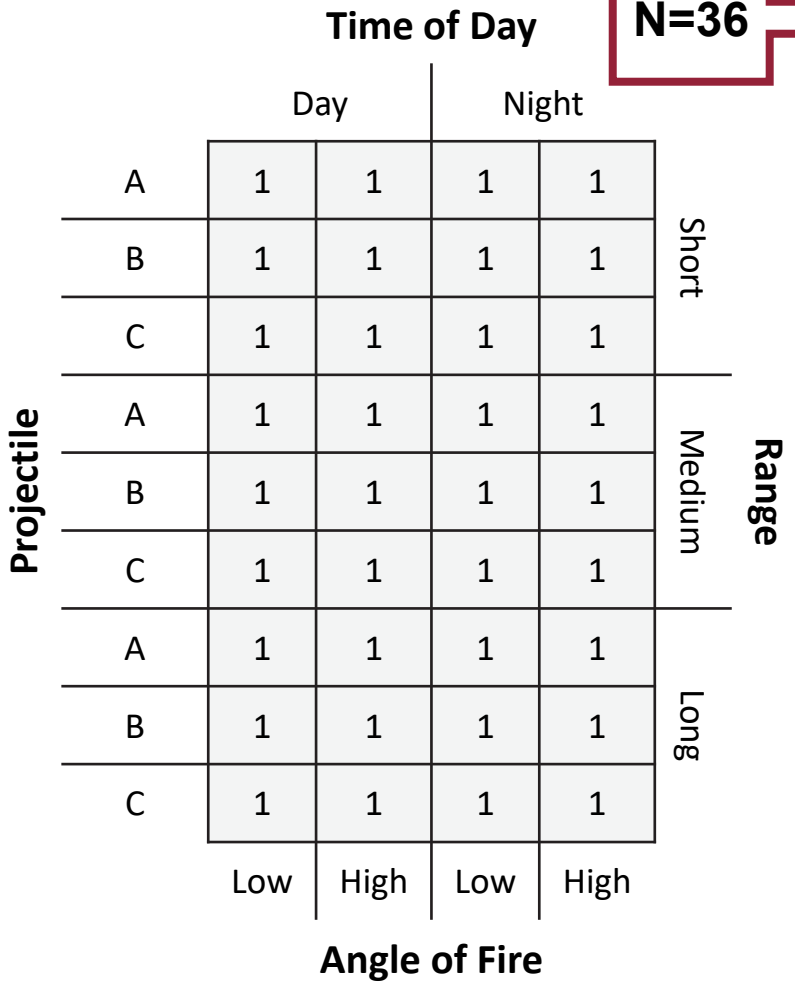
Factorial Designs Examine All Possible Combinations of Each Factor Level



N=36

Tests all possible combinations. The first fire mission is conducted during the *Day* at *Short* Range for *Low* Angle using *Projectile A*

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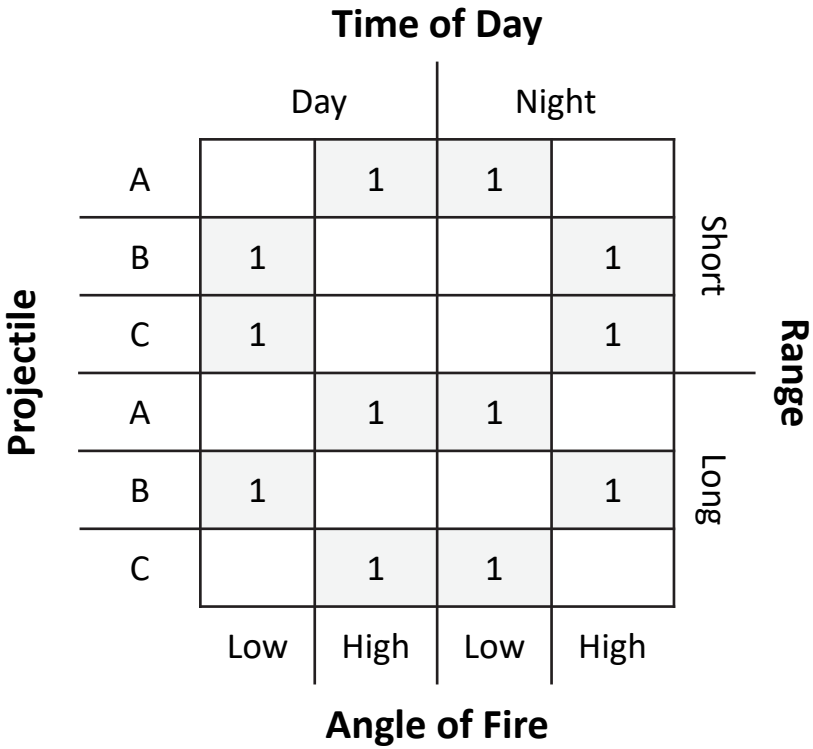
Typically, Screening Or Characterization Experiments Involve a Fractional Factorial Design



Fractional Factorial Designs:

- Support the test goals of screen, characterize, or compare.
- Require a subset of the runs required for a full factorial.
- Achieve a large reduction in test points by trading off the ability to estimate high-order interaction effects.

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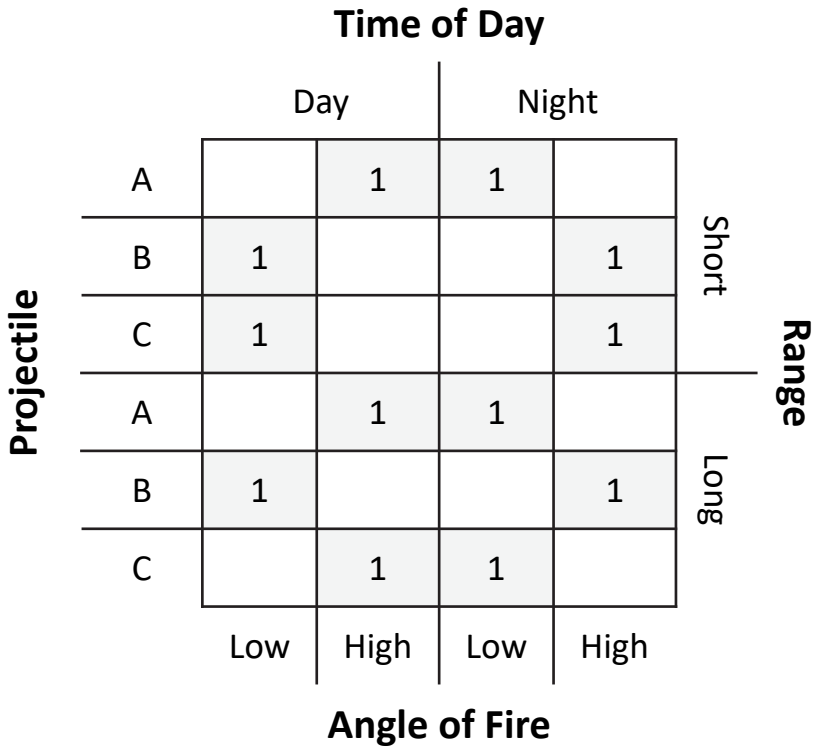
Typically, Screening Or Characterization Experiments Involve a Fractional Factorial Design

N=12

Places test points at the right conditions to support a main effects model



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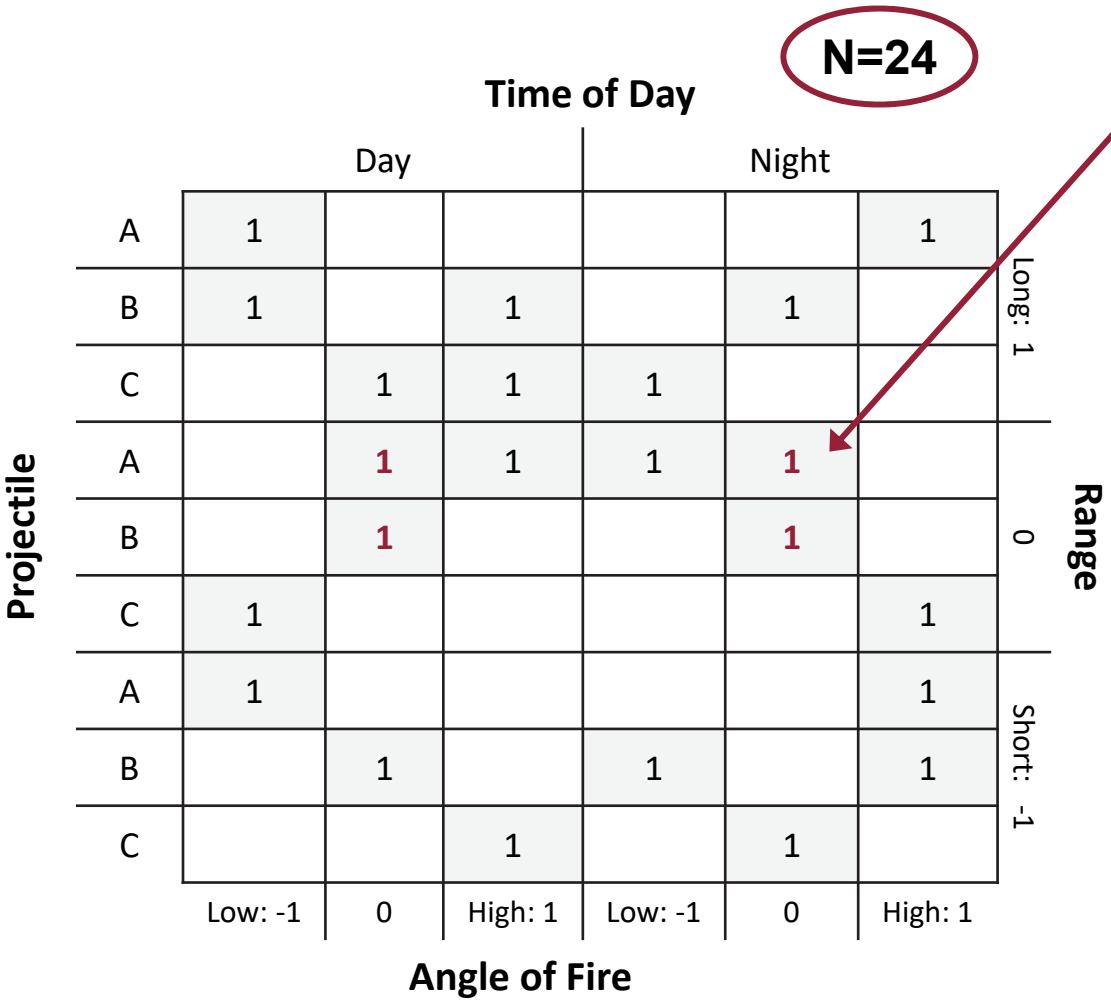
Response Surface Designs spread test points to collect data throughout the experimental region to support a detailed model of the response



Includes center points to check for curvature.

Response Surface Designs

- Support the test goals of characterize, optimize, predict, improve.
- Helpful in locating where in the design space response are optimal.

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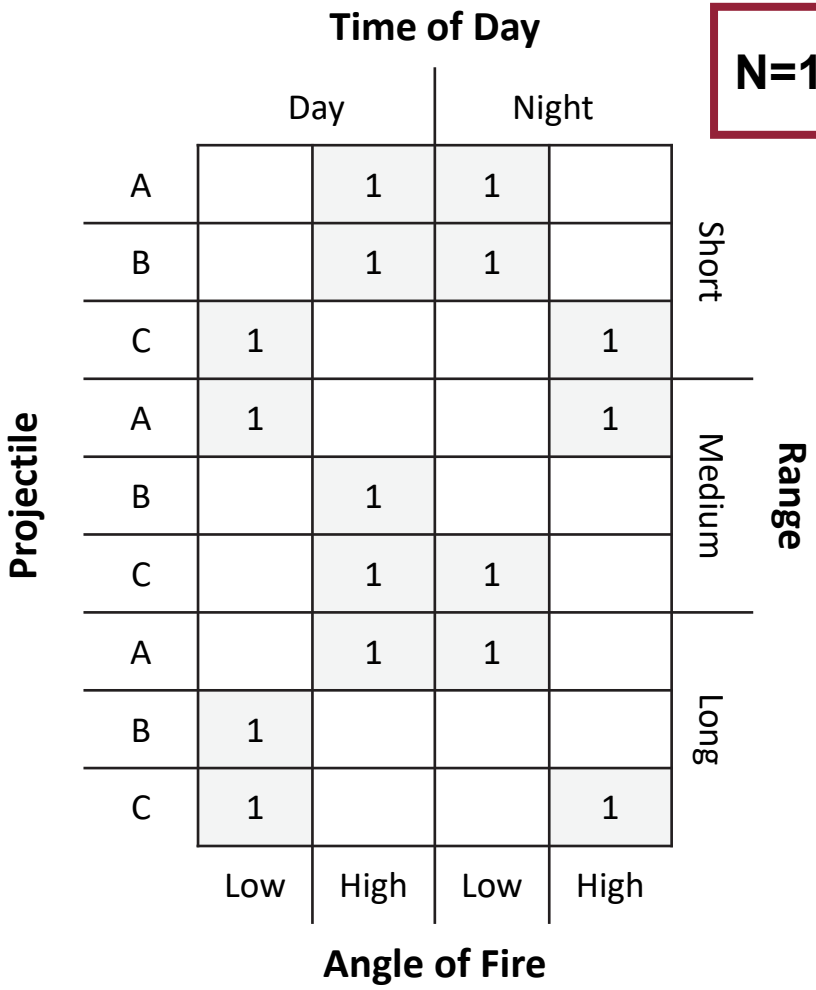
Optimal Designs Are Most Useful When The Number Of Test Points Is Constrained To Preclude A Factorial Design



N=16

Places test points at the right conditions to estimate specified model terms

Optimal Designs

- Support the test goals of characterize, optimize, predict.
- Useful when the number of test points is constrained to preclude a factorial design.
- Requires researcher-specified model and a fixed sample size (a subset of the runs required for a full factorial).

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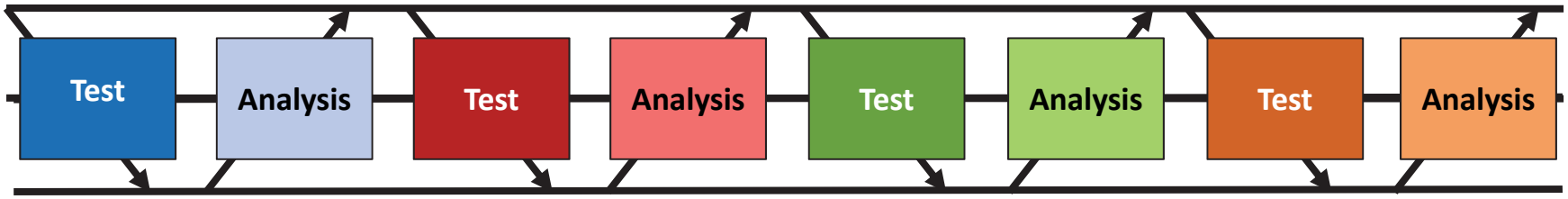
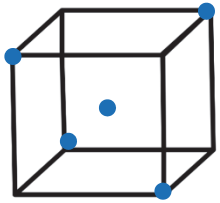
Plan for a Sequential Experimental Campaign

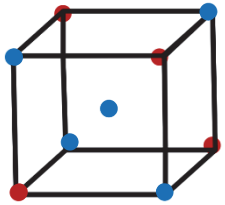
Experiments, Data, and Observations



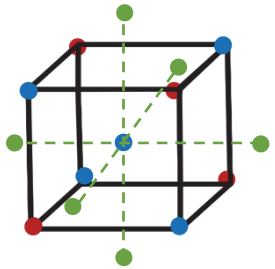
Theories, Hypotheses, Expert Opinion



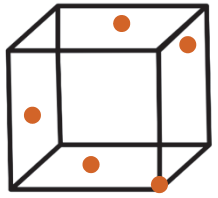
Screening Designs



Interaction Designs



Higher-Order Designs



Validation Designs

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Rarely is the Test Design Process Simple

Multidimensional Evaluation

Many Categorical Factors with More than Two Levels

Restrictions on Randomization

Disallowed Factor Combinations

Limited Resources for Replication

Our test of the new cannon includes factors that are Difficult to Completely Randomize and have Disallowed Combinations

Factor	Level	Difficult to Randomize	Disallowed Combinations
Time of Day	Day, Night	Hard	Night and Short Range
Range to Target	Short, Medium, Long	Hard	
Projectile Type	A, B, C	Easy	A and Long Range
Angle of Fire	Low, High	Easy	

Split-plot designs allow your DOE to reflect your test execution

Time of Day	Range	Angle of Fire	Projectile Type
Day	Long	Low	B
		Low	C
		High	B
		High	C
Tactical Move			
Day	Short	Low	A
		Low	B
		High	C
		High	B
Tactical Move			
Night	Medium	Low	C
		High	B
		Low	B
		Low	A
Tactical Move			
Day	Medium	High	A
		High	B
		Low	C
		Low	A
Tactical Move			
Night	Medium	High	A
		Low	B
		Low	A
		High	C
Tactical Move			
Night	Long	High	B
		Low	B
		High	C
		Low	C
Tactical Move			
Night	Long	Low	B
		Low	C
		High	C
		High	C
Tactical Move			
Day	Medium	High	C
		High	B
		High	A
		Low	B

Whole-Plot

Sub-Plots

Failing to correctly design and account for execution order could lead to wrong conclusions.

Lighting and **Range** are ***hard*** to change between Tactical Moves

Angle of Fire and **Projectile Type** are ***easy*** to vary from one fire mission to the next

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Which Points? Testing for Problem Cases in a Software System Application

System required to pull and integrate information from multiple sources and display via applications.

Response Variable

Works as Expected /

Does not Work as Expected

There are 22 applications total; personnel typically would not need to open more than 8 at a time.

Are there any combinations of applications that do not work together?

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Combinatorial Designs are useful for finding bugs and conditions where the system breaks.

C#	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14	W 15	W 16	W 17	W 18	W 19	W 20	W 21	W 22
1	0	0	0	1	1	1	1	0	1	0	1	0	0	1	1	0	0	0	0	0	0	1
2	0	0	1	0	0	0	0	1	1	0	1	1	1	1	0	1	0	0	0	0	0	1
3	0	1	0	0	0	0	0	0	1	0	1	1	0	0	1	1	1	1	0	0	0	1
4	0	1	1	0	0	0	1	1	0	0	1	0	1	0	1	0	1	0	0	0	0	1
5	1	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	1	1	1	1
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
70	1	1	0	0	0	0	1	1	0	1	1	1	0	1	0	0	0	0	0	0	0	1
71	1	1	1	0	0	0	1	0	1	1	0	1	1	0	0	0	0	0	0	0	0	1
72	0	0	0	1	0	1	0	1	0	1	1	0	0	0	0	1	1	0	1	0	0	1
73	0	0	0	0	1	0	0	1	1	1	0	0	1	0	1	1	1	0	0	0	0	1
74	0	0	0	1	0	0	1	1	1	0	0	1	1	0	1	1	0	0	0	0	0	1
75	0	0	0	1	1	0	0	0	0	1	1	1	1	1	0	0	1	0	0	0	0	1

BUT because of their inability to determine cause and effect,
Combinatorial Designs are not the best choice for Operational Tests.

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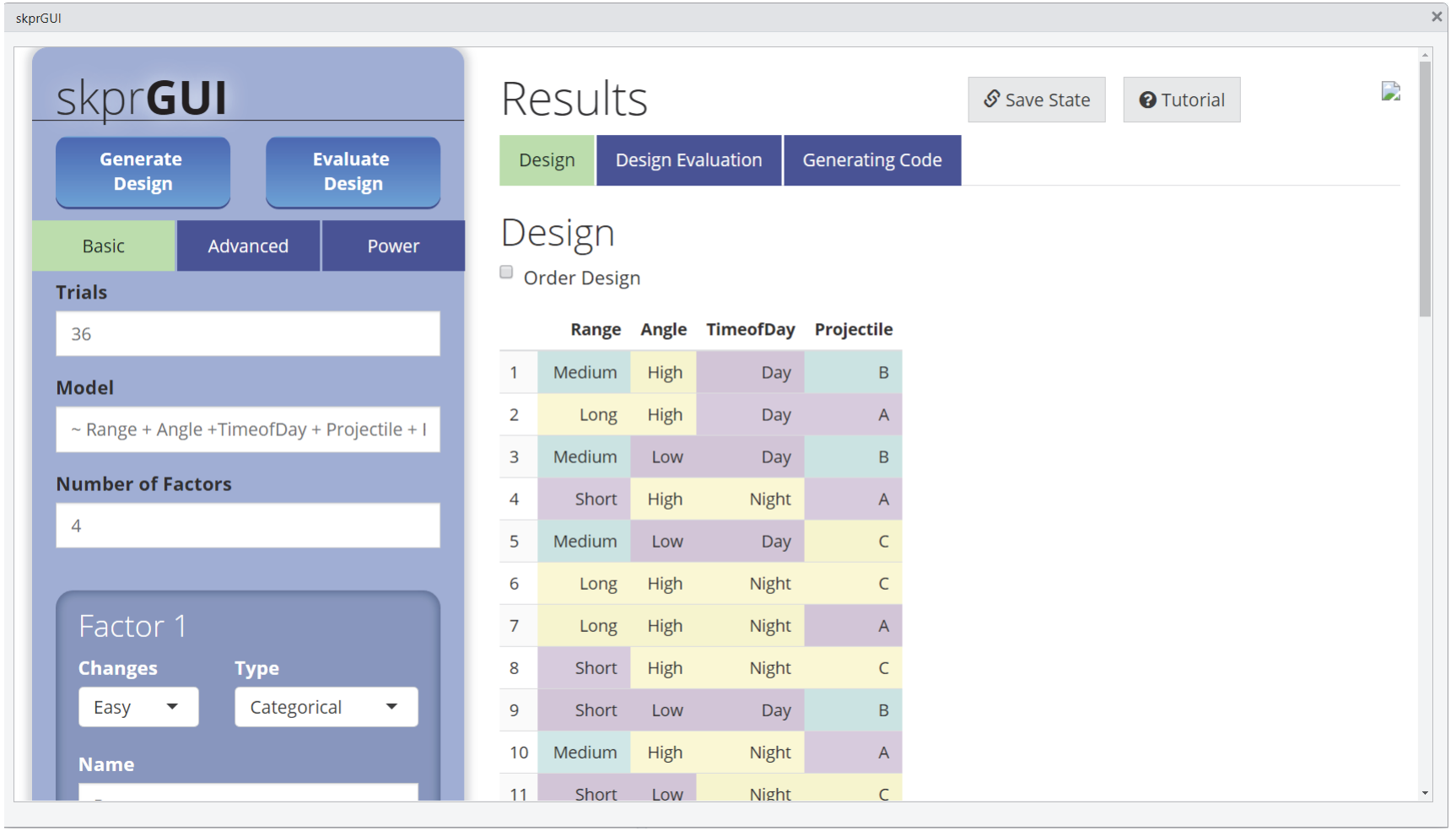
Software programs assist testers in selecting and constructing the test designs



skpr: Design of Experiments Suite: Generate and Evaluate Optimal Design

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Summary of Test Designs

Type of DOE	Size	Size Scales With …	Uses	Robustness
Factorial Designs (Full factorial, fractional factorial, factorial with center point, replicated factorial)	Large to medium	Number of factors	Estimate performance at extremes/"corners" of the design space	Very robust to lost data points
Optimal Designs (D-optimal, I-optimal)	Small	Nothing	Design minimal tests when there is minimal risk to lost data, and factors affecting performance are well understood	Fragile design; lost data can cause major problems
Response Surface Design	Large	Number of factors, flexibility of response surface	Estimate performance with non-linear factor effects and interactions	Somewhat robust to lost data points
Hierarchical Designs (blocking, split-plot designs)	Medium to small	Number of groups/blocks, group/block size	Properly randomize, while accounting for natural grouping in your data	Somewhat robust to lost data points; less robust to losing full groups of data points
Combinatorial Designs	Large	Number of factors, size of combinations	Find problems through systematically testing all possible cases	Not robust; must check all combinations

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Lesson 4: Evaluate the Design

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When evaluating a test design ask:

1. Does this design ensure that **adequate data** are collected?

2. If the system doesn't perform well, will I be able to **determine why**?

3. Does the DOE reflect **the way the test will be conducted**?

4. Will the data collected let me do the **analysis** I want to do?

When evaluating a test design ask:

1. Does this design ensure that **adequate data** are collected?

Power and Confidence

A primary reason to use DOE is to identify the number of observations required to satisfactorily address the test objective

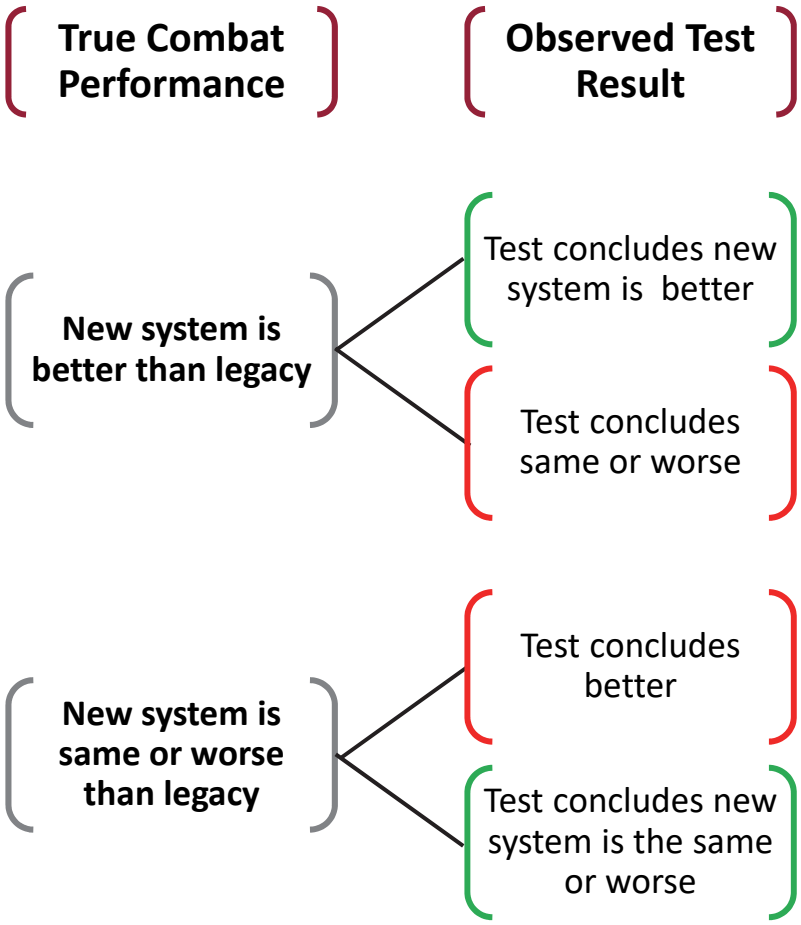
A primary reason to use DOE is to identify the number of observations required to satisfactorily address the test objective

True Combat Performance

New system is better than legacy

New system is same or worse than legacy

A primary reason to use DOE is to identify the number of observations required to satisfactorily address the test objective



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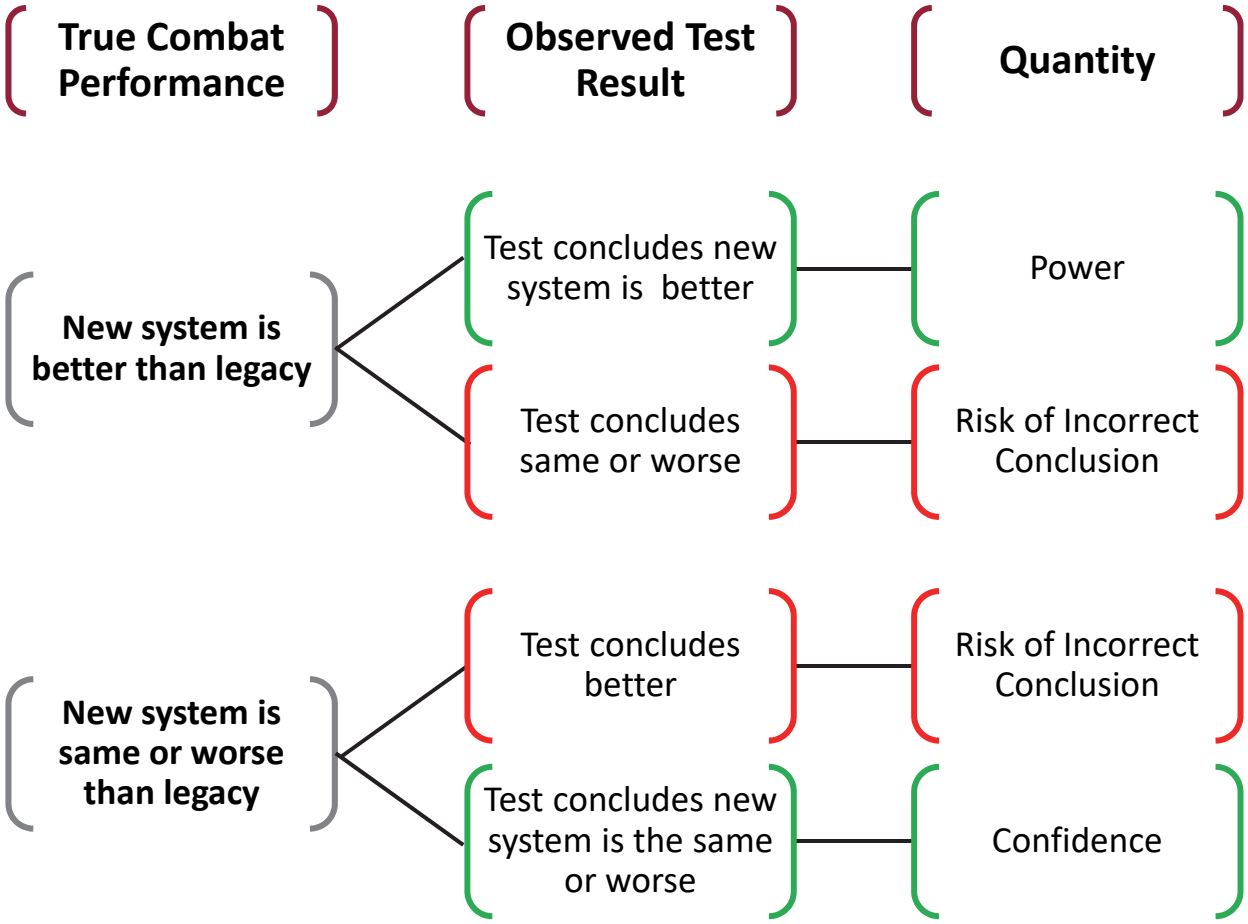
A primary reason to use DOE is to identify the number of observations required to satisfactorily address the test objective



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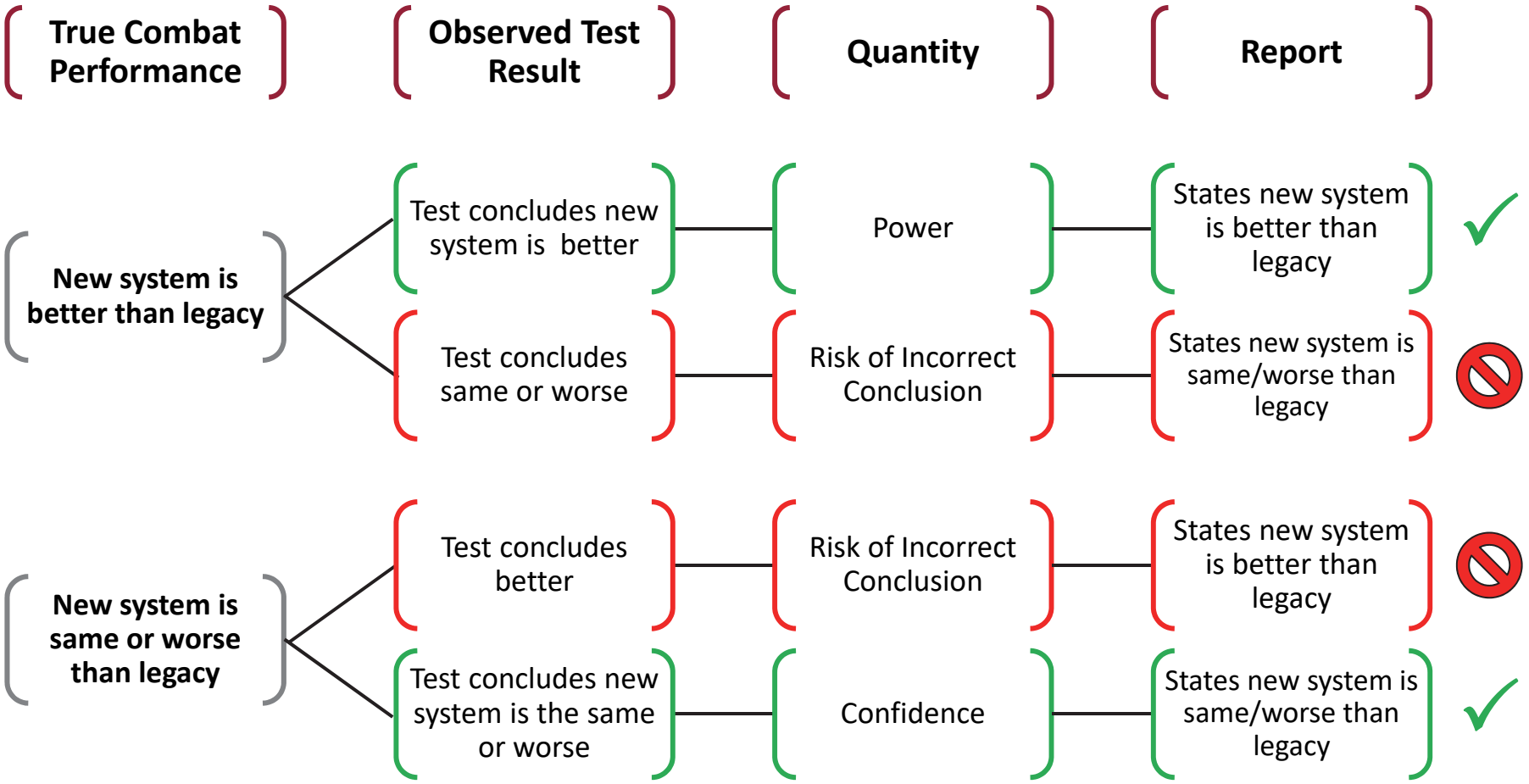
A primary reason to use DOE is to identify the number of observations required to satisfactorily address the test objective



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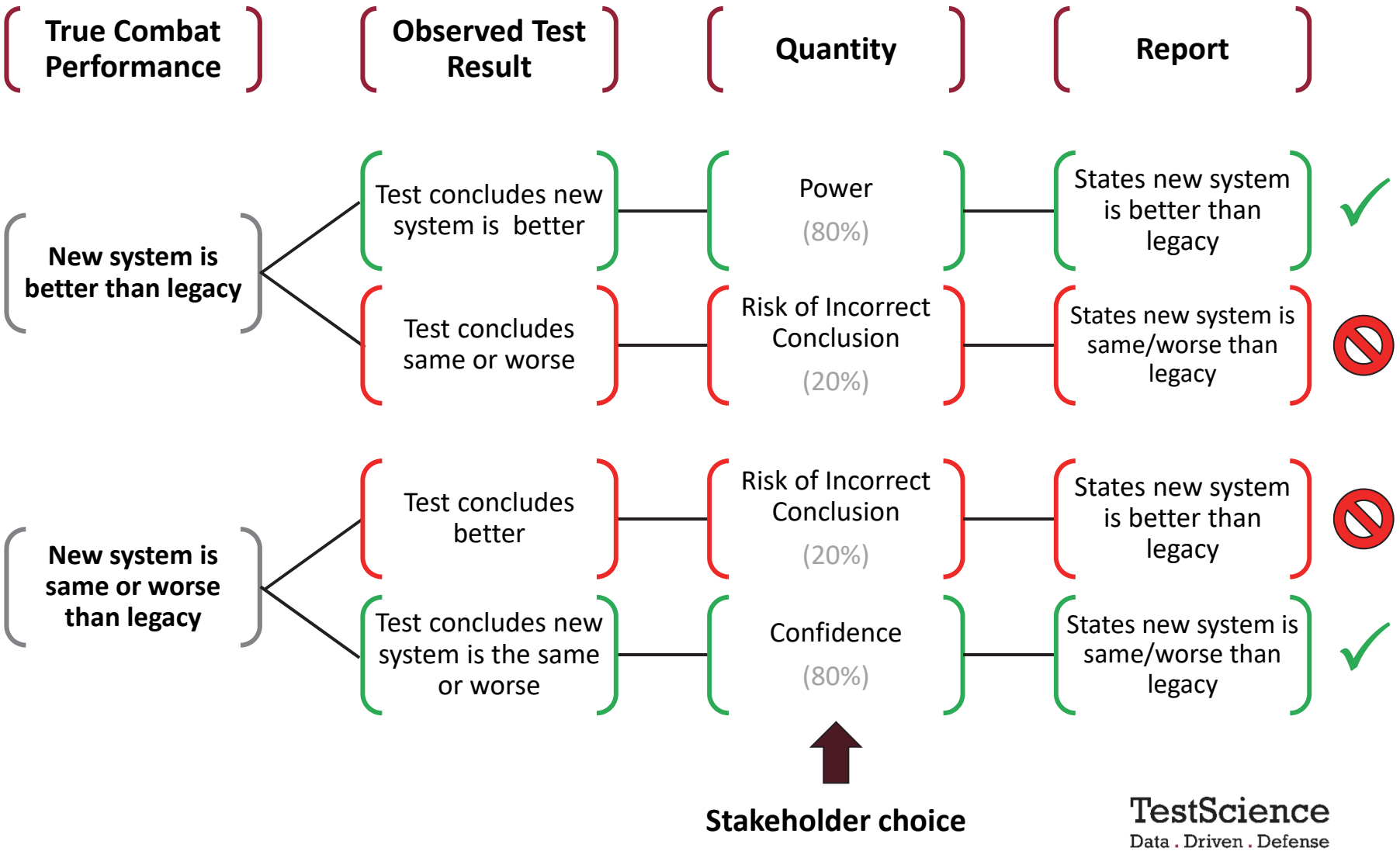
A primary reason to use DOE is to identify the number of observations required to satisfactorily address the test objective



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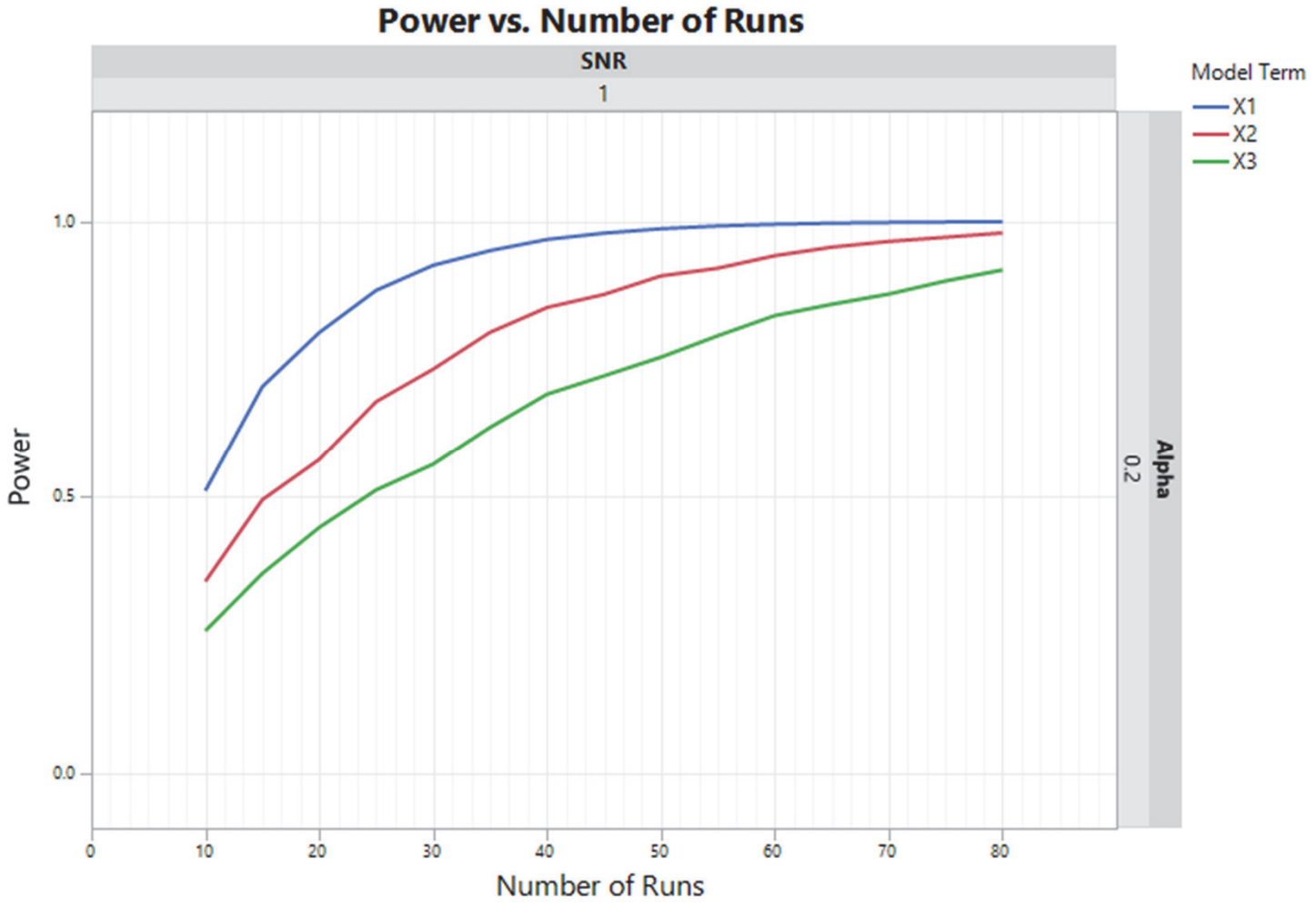
Power curves are good ways to visualize and compare power for different test designs



Power estimated by JEDIS v3.0

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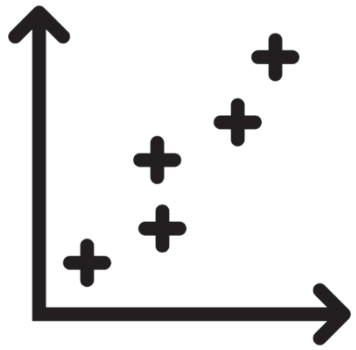
When evaluating a test design ask:

2. If the system doesn't perform well, will I be able to determine why?

Correlation and Identifiability



Tests should be designed so that we can identify the situations or missions where performance drops off

Poor performance during the day?

Poor performance against wheeled targets?

Poor performance against wheeled targets during the day?

Narrow Radius Explosive* Test Design

Time of Day	Target Speed	Target Type	Update Rate	Clutter
Day	Fast	Wheeled	30	Y
Day	Fast	Wheeled	12	N
Day	Fixed	Wheeled	12	N
Day	Fixed	Wheeled	30	N
Day	Slow	Wheeled	12	Y
Day	Slow	Wheeled	30	Y
Night	Fast	Tracked	30	N
Night	Fast	Tracked	12	Y
Night	Fixed	Tracked	30	Y
Night	Fixed	Tracked	12	Y
Night	Slow	Tracked	12	N
Night	Slow	Tracked	30	N

*Notional

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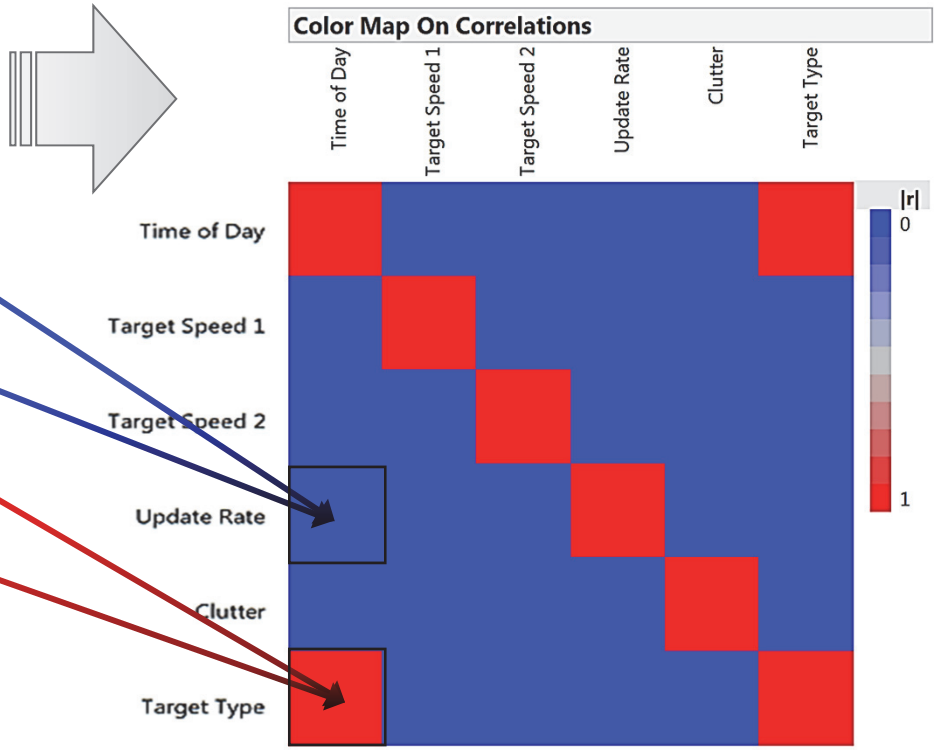
Use correlation maps to quickly visualize how hard it will be to distinguish between factors

Time of Day	Target Speed	Target Type	Update Rate	Clutter
Day	Fast	Wheeled	30	Y
Day	Fast	Wheeled	12	N
Day	Fixed	Wheeled	12	N
Day	Fixed	Wheeled	30	N
Day	Slow	Wheeled	12	Y
Day	Slow	Wheeled	30	Y
Night	Fast	Tracked	30	N
Night	Fast	Tracked	12	Y
Night	Fixed	Tracked	30	Y
Night	Fixed	Tracked	12	Y
Night	Slow	Tracked	12	N
Night	Slow	Tracked	30	N



- Blue means perfectly uncorrelated (No problems!)
- Red is perfectly (100%) correlated (Cannot differentiate)
- Colors in between indicate some degree of correlation (Can differentiate, but estimates may be biased/incorrect)

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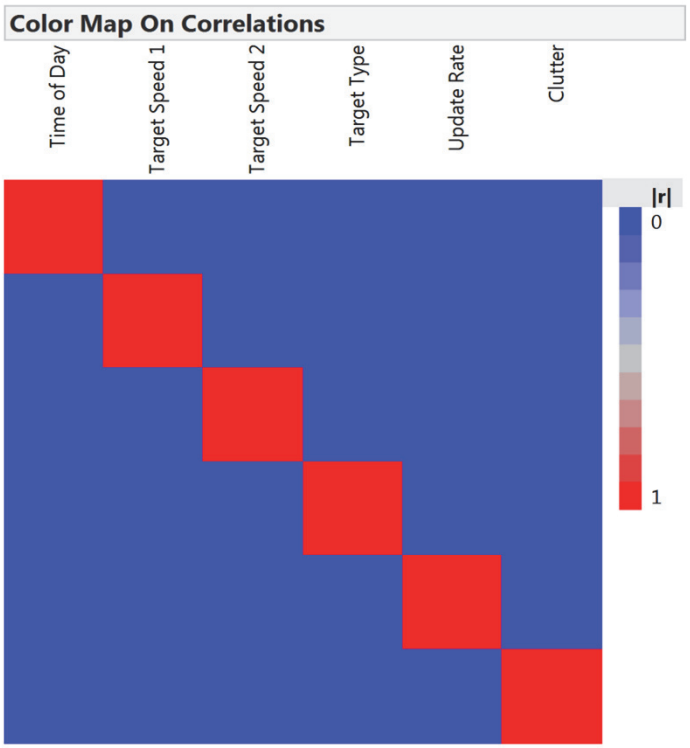
Ideally, your test design will have factors completely independent to ensure identifiability



Time of Day	Target Speed	Target Type	Update Rate	Clutter
Day	Fast	Tracked	30	Y
Day	Fast	Wheeled	12	N
Day	Fixed	Tracked	12	N
Day	Fixed	Wheeled	30	N
Day	Slow	Tracked	12	Y
Day	Slow	Wheeled	30	Y
Night	Fast	Tracked	30	N
Night	Fast	Wheeled	12	Y
Night	Fixed	Tracked	30	Y
Night	Fixed	Wheeled	12	Y
Night	Slow	Tracked	12	N
Night	Slow	Wheeled	30	N

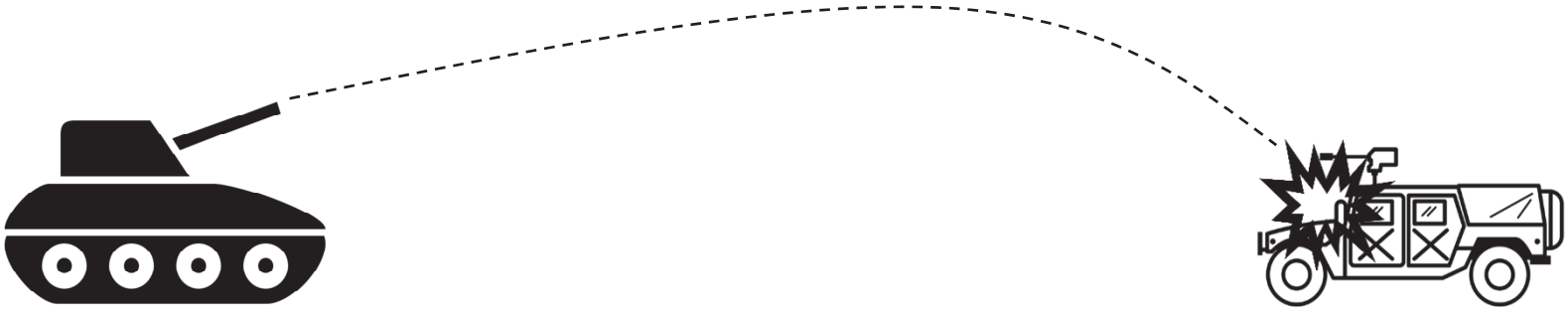
When evaluating a test design ask:

3. Does the DOE reflect the way the test will be conducted?

Restricted Randomization and Disallowed Combinations

RECALL: Our test of the new cannon includes factors that are Difficult to Completely Randomize and have Disallowed Combinations

Factor	Level	Difficult to Randomize	Disallowed Combinations
Time of Day	Day, Night	Hard	Night and Short Range
Range to Target	Short, Medium, Long	Hard	
Projectile Type	A, B, C	Easy	A and Long Range
Angle of Fire	Low, High	Easy	
Traverse Angle	0-15, 16-30, 31-45	Easy	



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Time of Day	Range	Angle of Fire	Projectile Type
Day	Long	Low	B
		Low	C
		High	B
		High	C
Tactical Move			
Day	Short	Low	A
		Low	B
		High	C
		High	B
Tactical Move			
Night	Medium	Low	C
		High	B
		Low	B
		Low	A
Tactical Move			
Day	Medium	High	A
		High	B
		Low	C
		Low	A
Tactical Move			
Night	Medium	High	A
		Low	B
		Low	A
		High	C
Tactical Move			
Night	Long	High	B
		Low	B
		High	C
		Low	C
Tactical Move			
Night	Long	Low	B
		Low	C
		High	C
		High	C
Tactical Move			
Day	Medium	High	C
		High	B
		High	A
		Low	B

Split-plot designs allow your DOE to reflect your test execution

Failing to correctly design and account for execution order could lead to wrong conclusions.

Whole-Plot

Sub-Plots

Lighting and **Range** are ***hard*** to change between Tactical Moves

Angle of Fire and **Projectile Type** are ***easy*** to vary from one fire mission to the next

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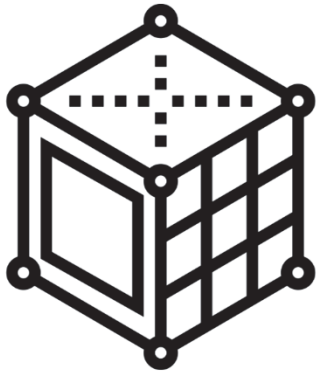
When evaluating a test design ask:

4. Will the data collected let me do the **analysis** I want to do?

Statistical Model Supported



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Determine what you want to learn from the test and build the design accordingly

Factors?

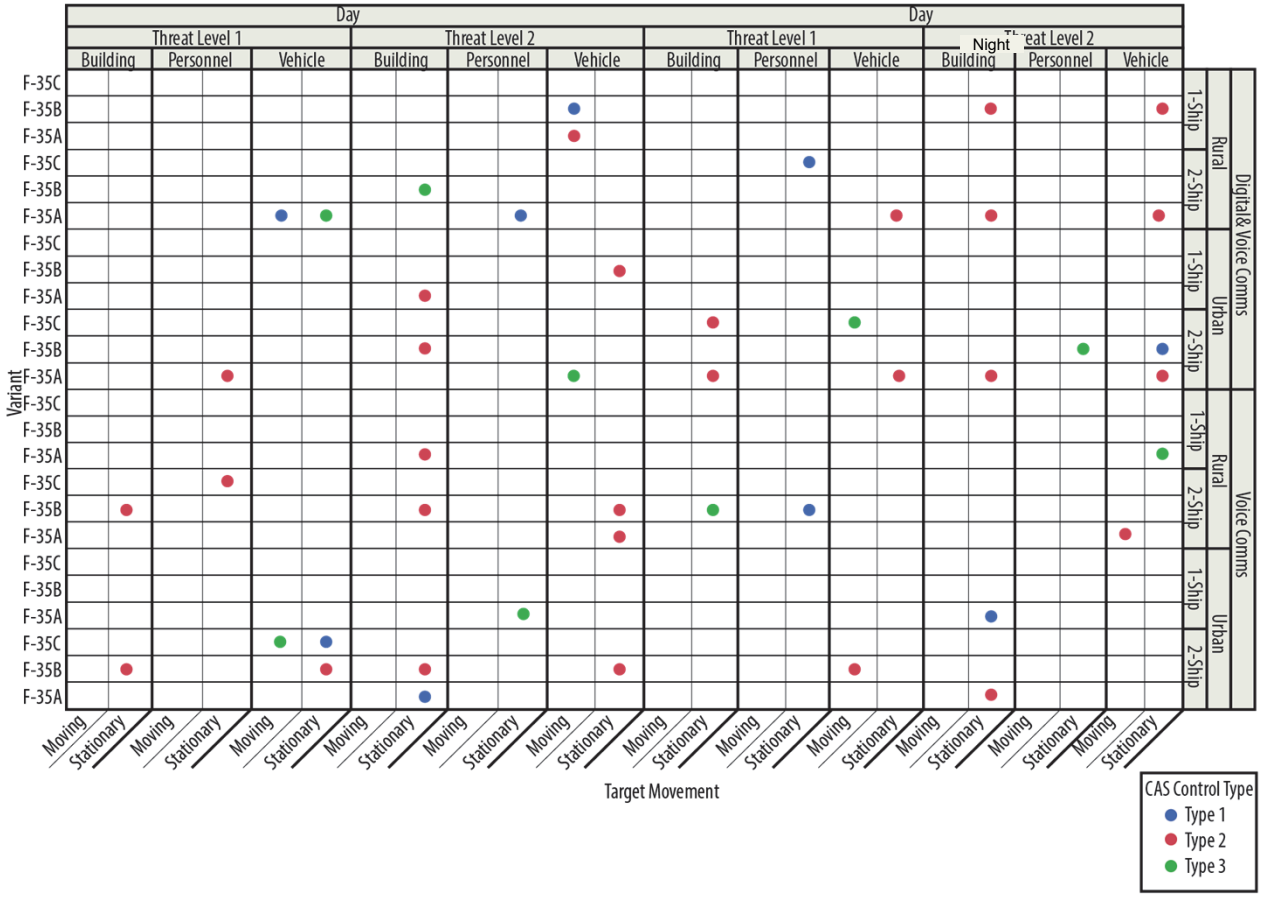
When resources are constrained:

1. Carefully describe the operational conditions in which the system will be employed, and
2. Make sure to get the data points required to fully describe that space.

Interactions?

Curvature?

DOE supports getting the information you need in the most efficient way possible



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Test Design

Lesson 5: Manage and Store the Test Data

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What is Data Management?

Data Management is the development and execution of policies and practices that organize, protect, and control data and information throughout their lifecycle*

- Access restrictions
- Naming conventions
- Software and hardware systems for storage, search, and discovery
- Roles and responsibilities for data management
- Etc.

Data Management plays a key role throughout the T&E Lifecycle

*Adapted from the Data Management Association' (DAMA) Data Management Body of Knowledge (DMBOK) v2

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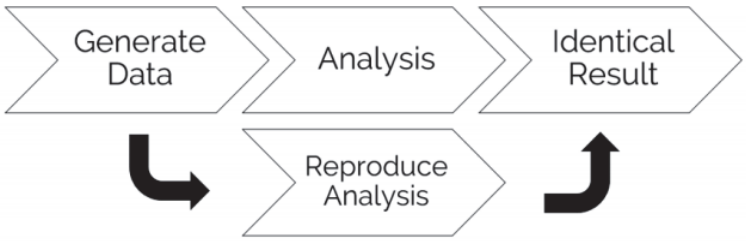
Each organization must define its own goals for data management

FAIR – *Nature* article identifies four properties (Findable, Accessible, Interoperable, Reusable) as goals for research data


SCIENTIFIC DATA

OPEN

Comment: The FAIR Guiding Principles for scientific data management and stewardship



Reproducibility – Manage data to facilitate Reproducible Research*

Security – Ensure that classified, proprietary, and PII data are handled appropriately

* See, e.g., Flack, Kirshenbaum, and Haman tutorial from 2019 DATAWorks, available at www.testcience.org/archive

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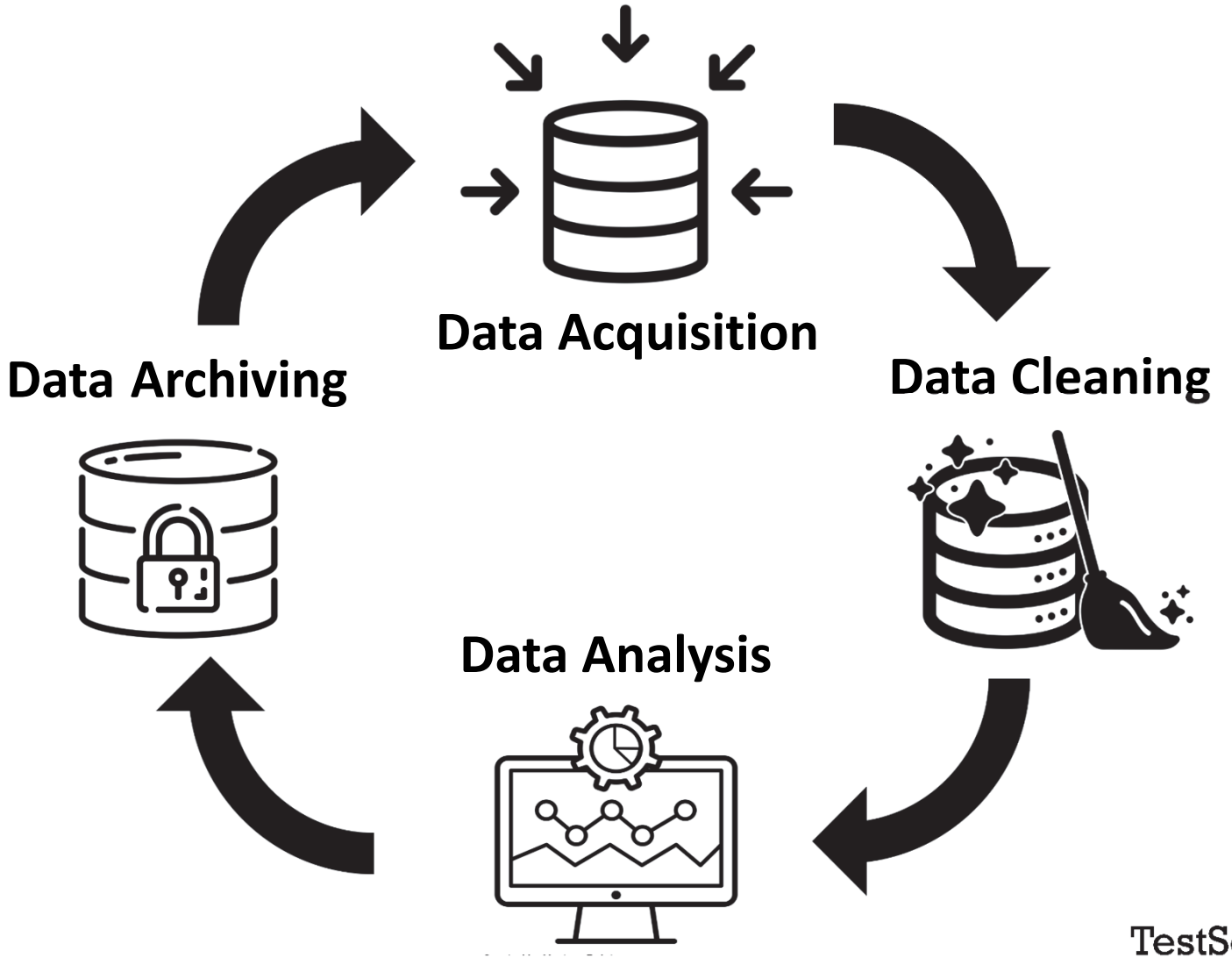
Data Management Plays a Key Role throughout the T&E Lifecycle



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Data Acquisition

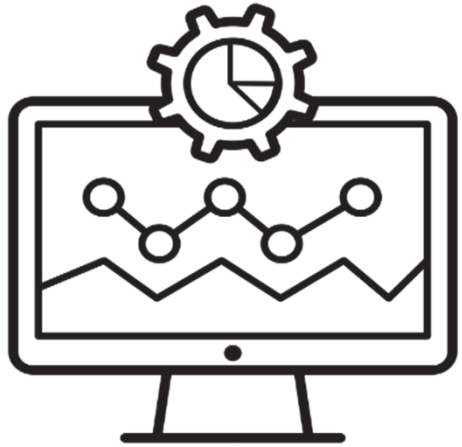
- Storage volume
- Backup options
- Preserving pedigree
- Metadata
- Security

Data Cleaning

- Version control
- Documentation
- Intermediate data products
- Naming conventions
- Automation and repetition

Data Analysis

- Version control
- Documentation
- Organization
- Reproducibility



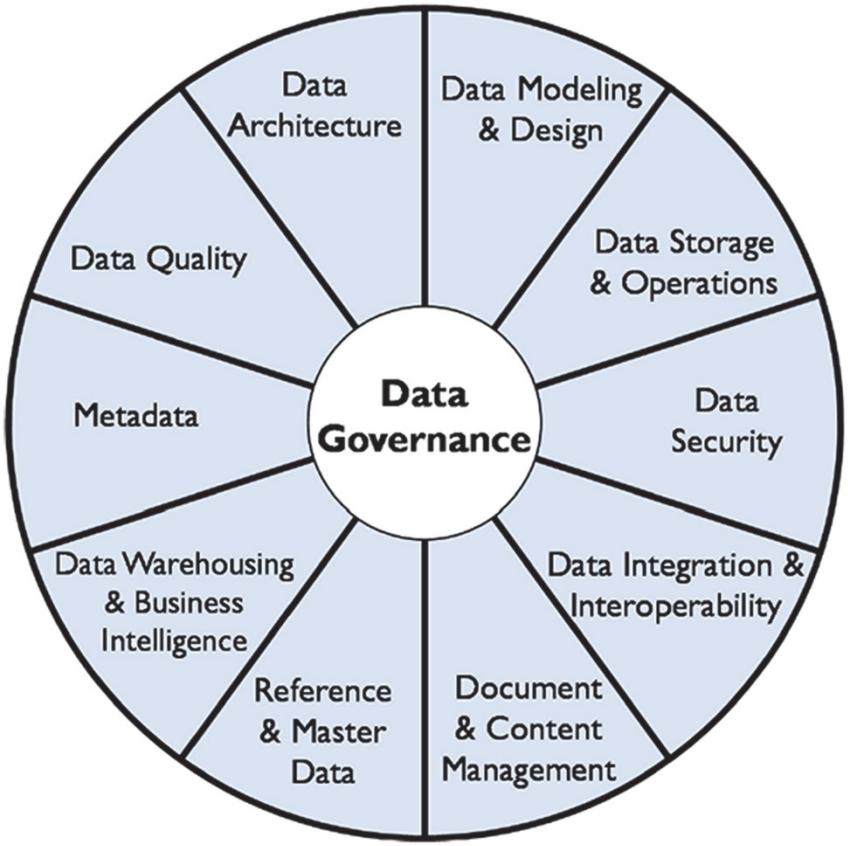
Data Archiving

- Future users
- Findability
- Searchability
- Metadata
- Stewardship

*Adapted from DAMA-DMBOKv2

Just the beginning…

DMBOK identifies 10 key data management functions:



Data are managed – whether through conscious, deliberate process or not.

By building a data management strategy and executing on it, organizations can ensure that their people, practices, and systems are helping them to get the most out of limited data resources and do the best analysis possible.

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Kelly M. Avery (OED); Caitlan A. Fealing (OED); Rebecca M. Medlin (OED); Rachel A. Haga (OED); Matthew R. Avery (OED);

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14. ABSTRACT

Understanding the test design process is fundamental to conducting efficient and effective tests of systems. Planning is a critical element of this process and requires collaboration and iteration among subject matter experts. Test planning involves identifying the test objectives, determining the appropriate outcome measure(s), and identifying what factors may influence those outcomes. The first set of website videos introduces the overarching test design process and provides best practices and examples for each of the three planning steps.

Test design is the process of actually creating and evaluating a set of experimental runs. It entails careful consideration of the test goals to ensure objectives can be met by the data collected, building the corresponding type of design, and then evaluating it across multiple criteria. The test design should have a large enough sample size to be useful, be executable in the real world, and support the desired analysis. The second set of videos describes and provides recommendations for each element of the test design process, and also introduces considerations for how to manage and store data collected from tests.

15. SUBJECT TERMS
Design of Experiments (DOE); OT&E; Statistics; Test Planning

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Unclassified	Unclassified	Unclassified	Unlimited	171	**19b. TELEPHONE NUMBER** *(include area code)* (703) 845-6731