LeanOhio Green Belt:

Transforming the Public Sector

Week Two

Intro to DOE

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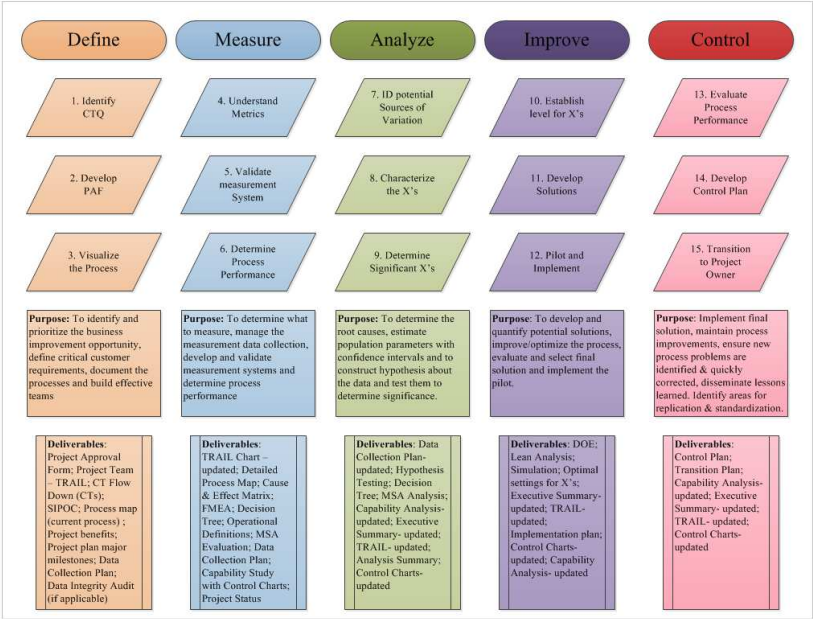
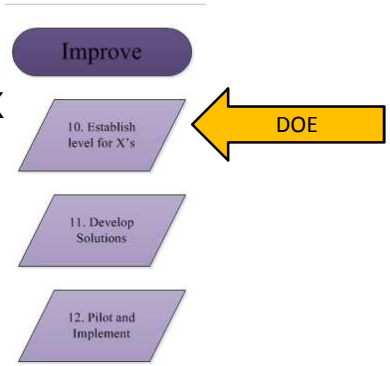


DMAIC Flow

- Improve:
  - Establish Level for X
  - Develop Solutions
  - Pilot and Implement



Define

- Define Purpose: To develop and quantify potential solutions, improve/optimize the process, evaluate and select final solution and implement the pilot.

Define Deliverables

- DOE
- Lean Analysis
- Optimal settings for X's
- Implementation Plan
- Update Control Charts
- Capability Analysis Updated

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Experiments

- Do you conduct Experiments?
- Everyday we conduct Experiments –
  - We try different routes to see if they are faster
  - We try different combinations of food
  - We try different techniques at work
  - We try different routines to see if they are faster

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Experiments

- Most of the Experiments we conduct are not structured
  - Passive
  - Ad Hoc
    - "Trial and Error" Testing
    - "One-Factor-at-a-Time" a.k.a. "OFAT" experiments
- Experiments are human nature

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Experiments

- Design of Experiments – is adding a structured approach.
- A designed experiment allows us to understand how key input variables in a process are related to key output variables

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Background

- Unfortunately there are not many opportunities to conduct true DOEs in government today….BUT as we become more knowledgeable and sophisticated that could change.
- This session is to give you an overview and awareness of DOE only. If you want to conduct a DOE for your project or in the future – please call Casey Cannon!

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Comparing Testing Methods

- Problem
  - Current car gas mileage is 30 mpg, but we would like to get 40 mpg
  - What would you do?

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Trial and Error Testing

- Problem: Current Car gas mileage is 30 mpg, but we would like to get 40 mpg
- We might try:
  - Change brand of gas
  - Change octane rating
  - Drive Slower
  - Tune-up Car
  - Wash and wax car
  - Buy new tires
  - Change Tire Pressure
- What if it works?
- What if it doesn't?

One-Factor-at-a-Time Testing

Problem: Gas mileage is 30 mpg

Speed	Octane	Tire Pressure	Miles per Gallon
55	85	30	23
60	85	30	29
60	90	30	23
60	85	35	24

- How can you explain the above results?
- How many more tests would you need to figure out the best configuration of variables?
- If there were more variables, how long would it take to get a good solution?
- What if there's a specific combination of two or more variables that leads to the best mileage?

One-Factor-at-a-Time

Speed	Octane	Tire Pressure	Miles per Gallon
55	85	30	23
60	85	30	29
55	90	30	37
60	90	30	23
55	85	35	37
60	85	35	24
55	90	35	30
60	90	35	36

OFAT Tests

What conclusion do you make now?

OFAT Testing - Example 2

	Pressure 1	Pressure 2
Temp 1	20	40
Temp 2	50	12

Pressure Tests

Temp Tests

- Assume we did an OFAT study in the above situation:
  - If we held Temp constant at Level 1 and vary Pressure, we would conclude that Pressure at Level 2 is best
  - Then holding Pressure constant at Level 2, we vary Temp and find Temp 1 is best
  - ***We would miss the interaction effect between Temp and Pressure!***

DOE Definition

- **Design of Experiment (DOE)** are used to craft well-designed efforts to identify which process changes yield the best possible results for sustained improvements.
- DOE focuses on multiple factors at one time and provides the data that illustrates the significance to the output of input variables acting alone or interacting with one another.

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DOE Process

- Determine the appropriate experimental design
- Execute the experiment
- Evaluate the resulting data
- Verify the results and make recommendations

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Factorial Design

- Allows us to simultaneously evaluate the effects of several factors on a process

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Full Factorial Experiment

- Measures all combinations of the experiment factor levels
- Varying the levels of factors simultaneously rather than individually has two benefits:
  - Saves time and expense
  - Reveals the interaction between the factors

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Fractional Factorial Experiment

- A subset (fraction) of the factorial design. Typically, the fraction is simple proportion of the full set of possible treatment combinations.
- Half-fractions, quarter-fractions, and so forth are common.

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Independent vs. Dependent Variable

- **Independent Variable**: a variable that can contribute to the explanation of the outcome of an experiment. Also known as a “predictor variable.”
- **Dependent Variable:** A variable representing the outcome of an experiment. The response is often referred to as the “output variable” or “response variable.”

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Key Terms

- **Factors:** A predictor (or independent) variable that is varied with the intent of assessing its effect on a response (or dependent) variable.
- **Levels:** A specific setting for a factor. In DOE, levels are frequently set as high or low for each factor.
- **Response:** A single level assigned to a single factor in an experiment.
- **Treatment Combination:** the set of levels for all factors in a specific experimental run.
- **Treatment:** The specific setting of factor levels for an experimental unit.
- **Error:** An error from an experiment reveals variation in the outcome of identical tests.

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Key Terms

FACTOR FACTOR FACTOR RESPONSE

LEVELS

Speed	Octane	Tire Pressure	Miles per Gallon
55	85	30	23
60	85	30	29
55	90	30	37
60	90	30	23
55	85	35	37
60	85	35	24
55	90	35	30
60	90	35	36

Key Terms

- **Randomization:** assign treatments so that each experimental unit has an equal chance of being assigned a particular treatment.
- **Replication:** Replication is a repeat of the entire experiment. Replication increases the precision of the estimates of the effects on the experiment.

2k Factorial Designs

What Is a '2k' Factorial Design?

- A 2^k Factorial design is most common
- 2^k: indicates we are studying 'k' number of factors, each of which has only two (2) levels.
  - For example: "2^3" means that we are studying three (3) factors, each having only two levels
  - The total number of treatment combinations is 2x2x2 = 8 (=2^3)
  - A "2^3" factorial with 3 replicates will have three observations for each of the 8 treatment combinations, or 24 total observations
- 2^k designs are one of most efficient means of analyzing processes available

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Example - '2k' Factorial Design

- Problem: Gas mileage is 30 mpg
- Response: miles per gallon
- Three factors: speed, octane, tire pressure
- Two levels:
  - Speed – 55, 60
  - Octane – 85,90
  - Tire pressure – 30, 35
- Total number of treatment combinations is 2^3: 2x2x2 = 8

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Advantages of 2k Factorials

- Require relatively few runs per factor studied
- Can be the basis for more complex designs
- Good for early investigations - can look at a large number of factors with relatively few runs
- Lend themselves well to sequential studies
- Analysis is fairly easy

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2k Factorials – Conventional Practices

- As the number of factors in the study increase, so does the total number of treatment combinations, *exponentially*
  - With larger experimental designs, it becomes difficult to identify and keep track of all the various combinations
  - Statisticians have adopted some conventions to help deal with the confusion
- In 2^k designs, there are only two levels for each factor
  - For ordinal, interval and ratio data, the levels can be referred to as “High” and “Low”
    - The “high” level is denoted with the value “1”
    - The “low” level is denoted with the value “-1”

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2k Factorials – Conventional Practices

- The entire experiment is represented in matrix form as shown:

2^2

A	B
-1	-1
1	-1
-1	1
1	1

2^3

A	B	C
-1	-1	-1
1	-1	-1
-1	1	-1
1	1	-1
-1	-1	1
1	-1	1
-1	1	1
1	1	1

2^4

A	B	C	D
-1	-1	-1	-1
1	-1	-1	-1
-1	1	-1	-1
1	1	-1	-1
-1	-1	1	-1
1	-1	1	-1
-1	1	1	-1
1	1	1	-1
-1	-1	-1	1
1	-1	-1	1
-1	1	-1	1
1	1	-1	1
-1	-1	1	1
1	-1	1	1
-1	1	1	1
1	1	1	1

- Notice the patterns in the columns
  - 1st column alternates with each row
  - 2nd column alternates at 2 rows
  - 3rd column alternates at 4 rows
  - Etc.

Things to Watch for in Experimentation

- Unknown or unaccounted input variables affect the output variable(s)
  - Solution: **Randomization**
- Not enough data to detect changes in the outputs
  - Solution: **Replicate the treatment combinations** - repeat the various treatment combinations
- Studying a local event and believing it applies to all
  - Solution: **Replicate the experiment** - Repeat the whole experiment under the other conditions

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What Can go Wrong in Experiments?

- Factor levels can be too close together or too far apart
- No pilot run done: Experimental runs botched because of lack of discipline
- Nonrandom experiments can produce misleading results
- Sample size may be too small
- Data and/or experimental units lost
- Measurement systems may not be adequate
- Measurement systems does not measure what you think it does
- Confirmation runs not done to verify results
- ***You're not present during DOE!***

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General Advice

- Experimentation is a proactive tool
- Always verify results with a follow-on study
- *There is no such thing as a bad experiment - only a poorly designed or executed one!*
- Not every experiment will produce earth shattering discoveries
  - …but something will always be learned!!
  - New data prompts new questions and generates follow-on studies
- A final report is a must!!

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Questions

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