5 Improve (15 Questions)

01 Design of Experiments

02 Root Cause Analysis

03 Lean Tools

5A
Design of Experiments

01 Basic Terms

02 DoE graphs and plots

5A1 Design of Experiments – Basic Terms

01 *Independent and Dependent Variables*

02 *Factors and Levels*

03 *Treatments and Responses*

04 *Errors*

05 *Replication, Blocks and Randomization*

06 *Repetition and Effects*

Introduction

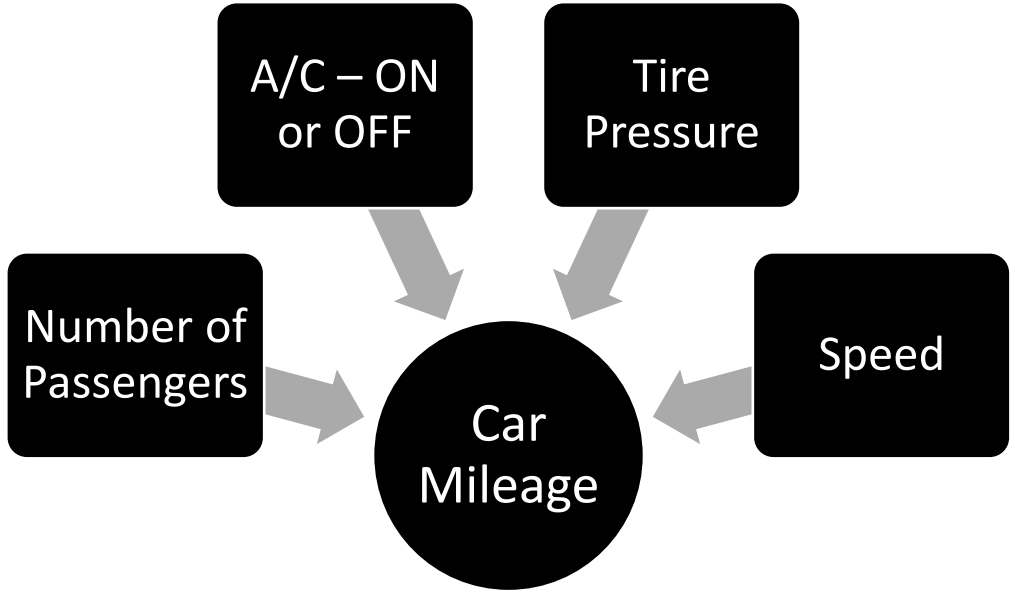
We conduct experiments in our daily life.

- Car:
  - Does AC affect the car mileage?
  - Does number of passengers affect the car mileage?
  - What about tire pressure, speed …..
- Course selling:
  - Does intro video affects the sale?
  - What about course length, quizzes, closed captions …..

Design of Experiments

Design of Experiments

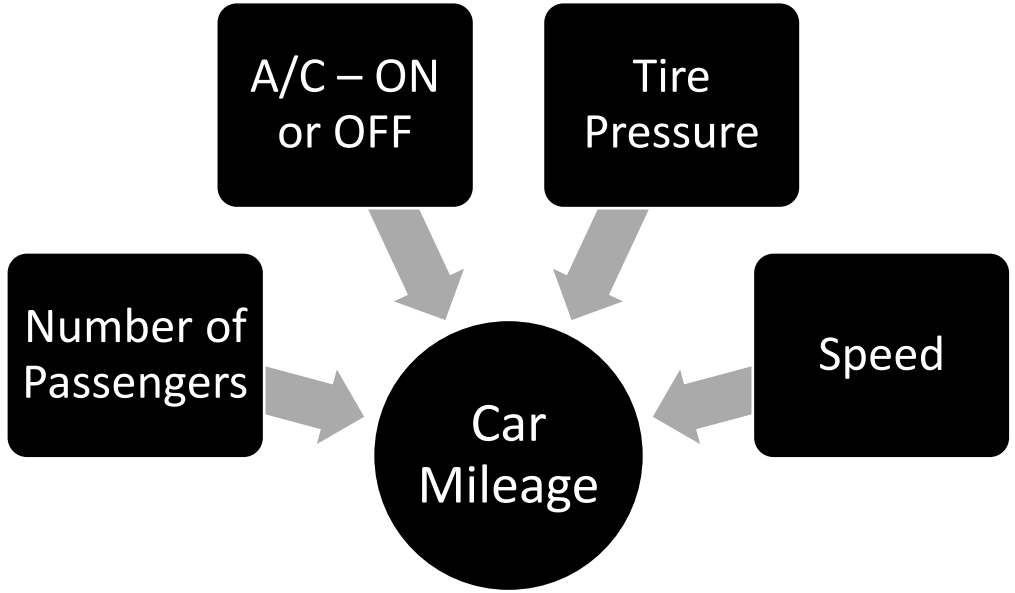
Design of Experiments (DOE) is a method to find out the relation between factors affecting a process and the output of the process.



Design of Experiments

Design of Experiments

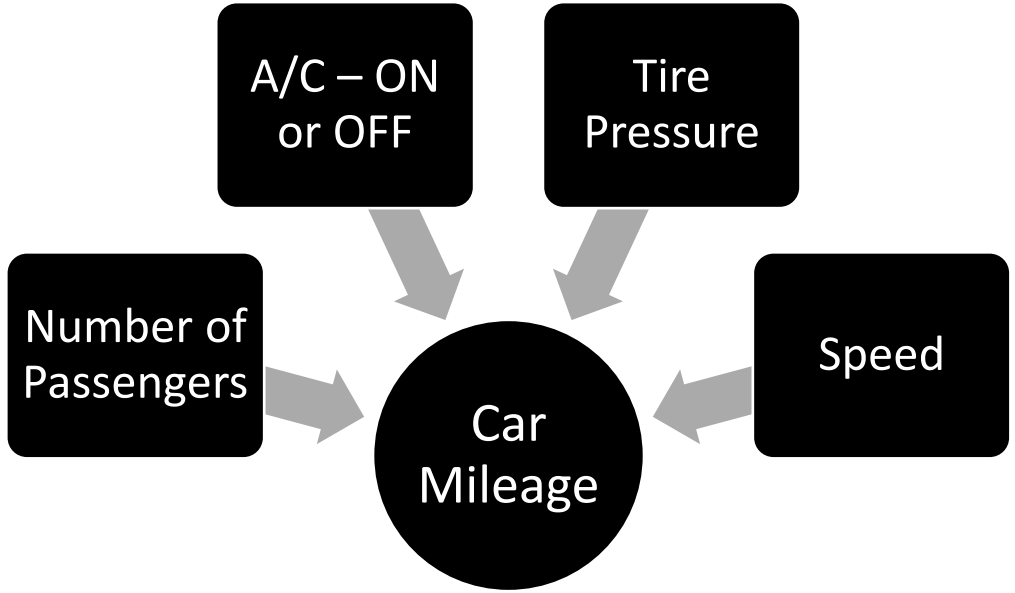
Conventional approach to deal with this type of question is OVAT (One Variable at a time) / OFAT (One Factor at a Time)



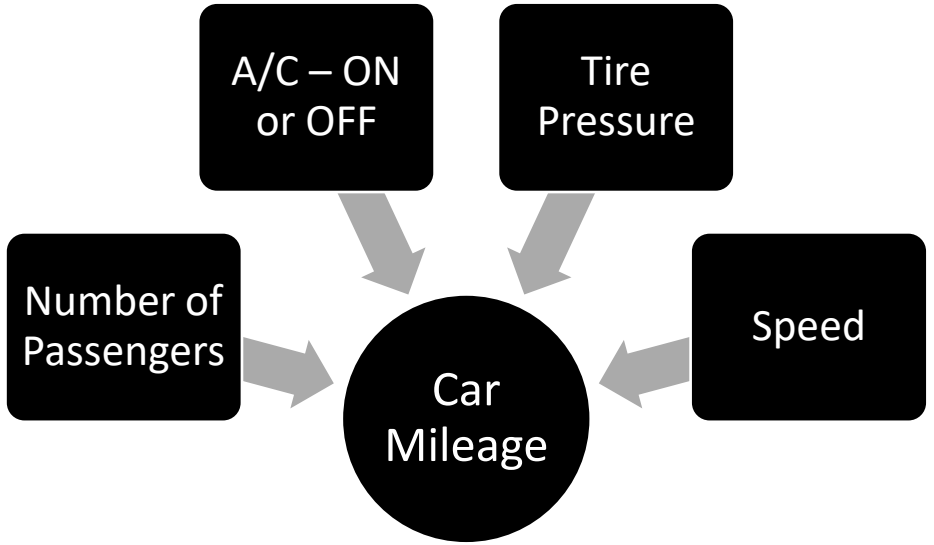
Design of Experiments

Design of Experiments

Using the Design of Experiments we seek the answer to such questions with minimum effort and expenditure.



Design of Experiments



Y	X
Output	Input
Dependent Variable	Independent Variable
Response (or Outcome)	Factor

$$Y = f(X)$$

Output (Y) is the function of inputs (X)

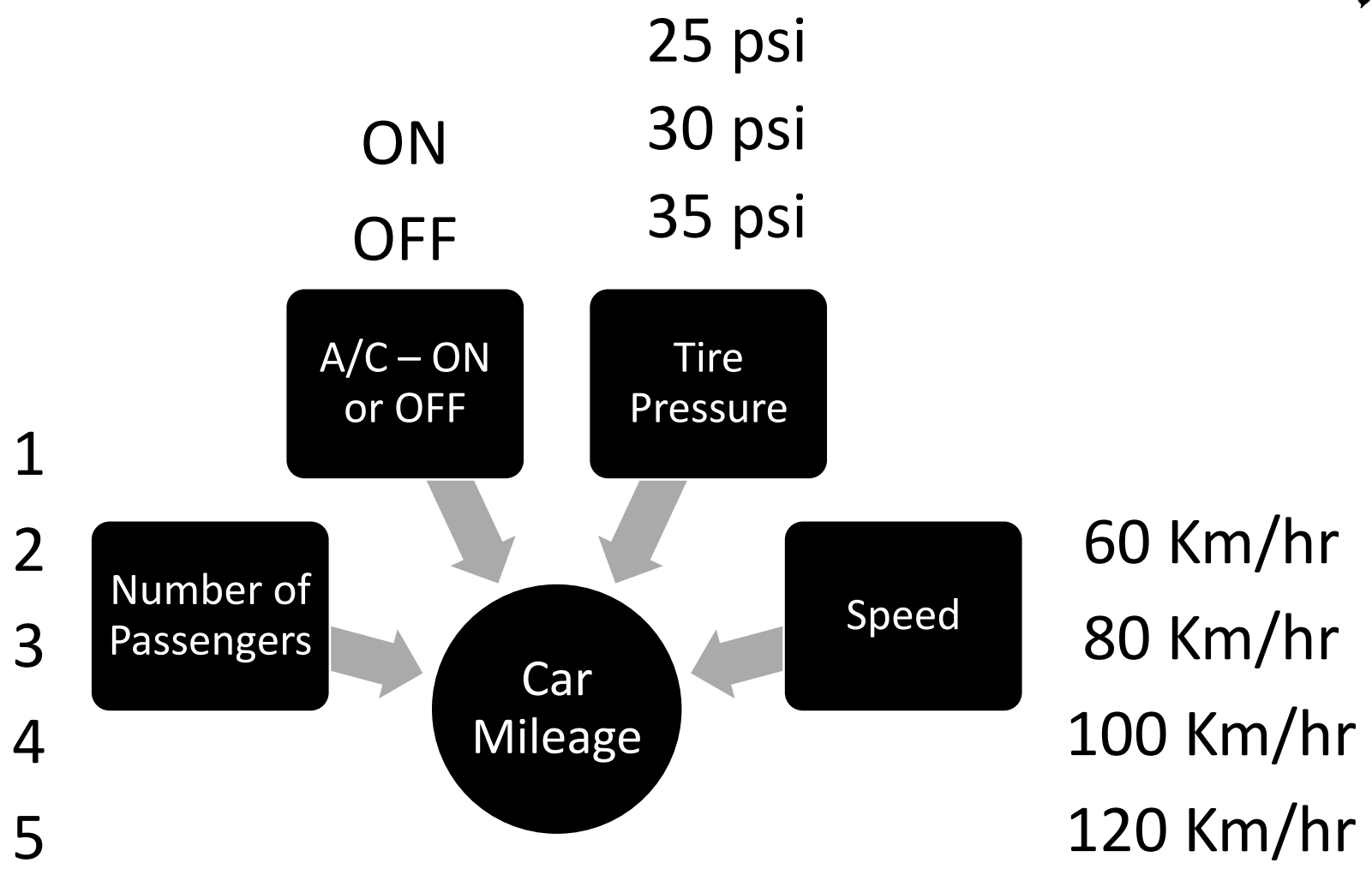
Independent vs Dependent Variables

- **<u>Response</u>:** The output(s) of a process. Sometimes called dependent variable(s).

- **<u>Factor</u>**: A ***factor*** of an experiment is a controlled independent variable; a variable whose levels are set by the experimenter. These can be numeric or categorical.

Response and Factors

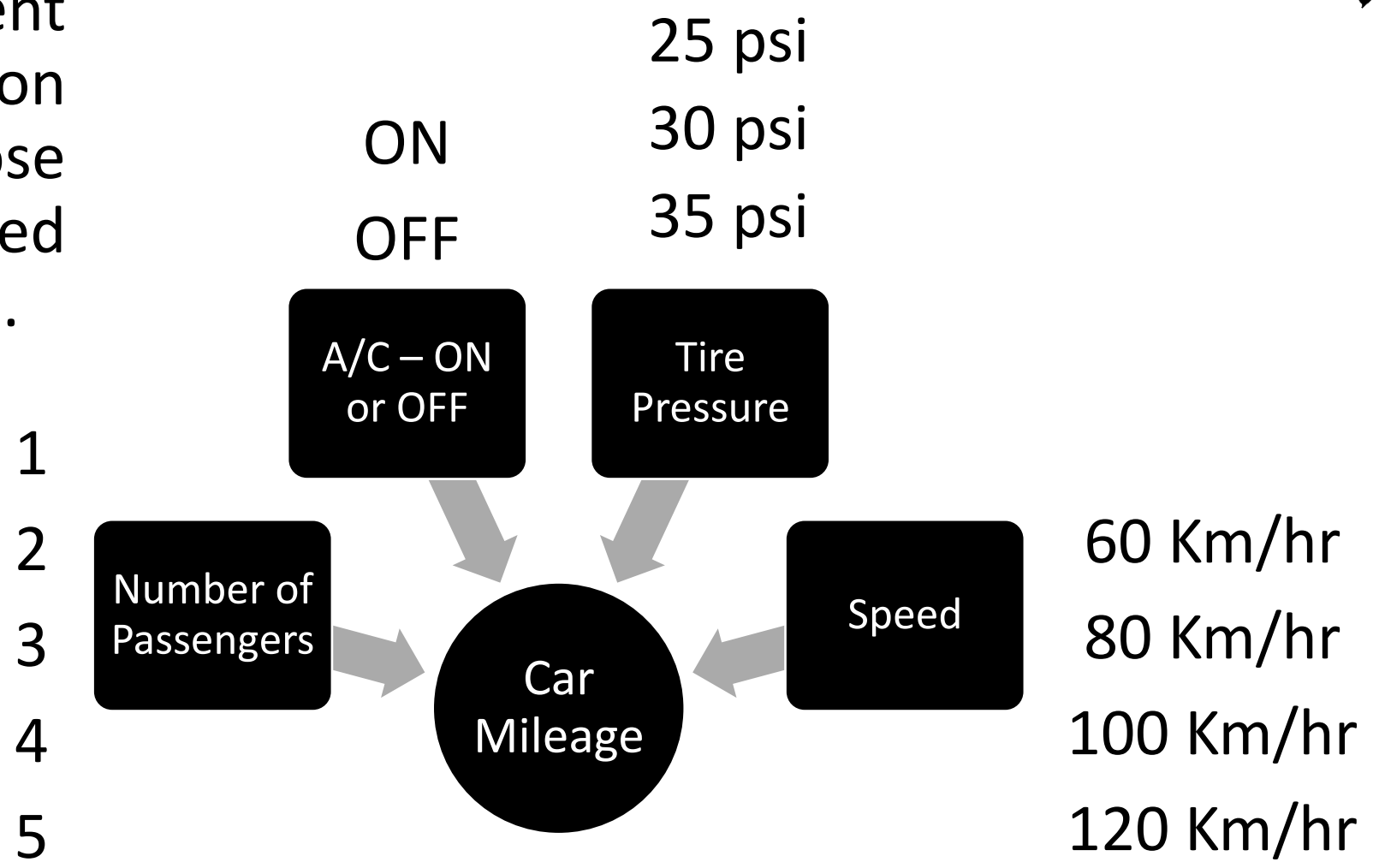
❖ **Level**: Settings of each factor in the study.



Levels

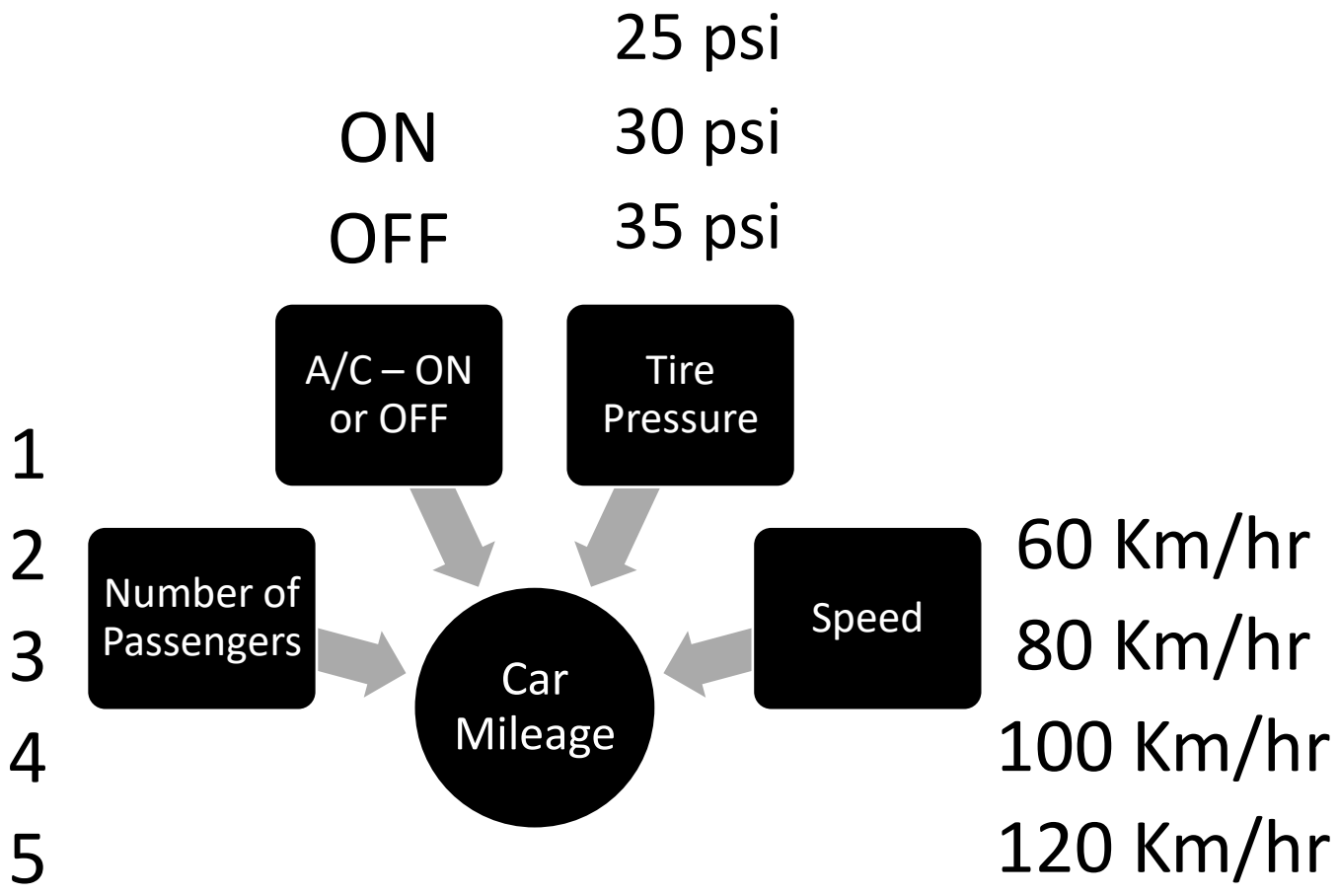
Treatments

❖ **Treatment:** A treatment is a specific combination of factor levels whose effect is to be compared with other treatments.



For first two factors only you will need to conduct 10 experiments

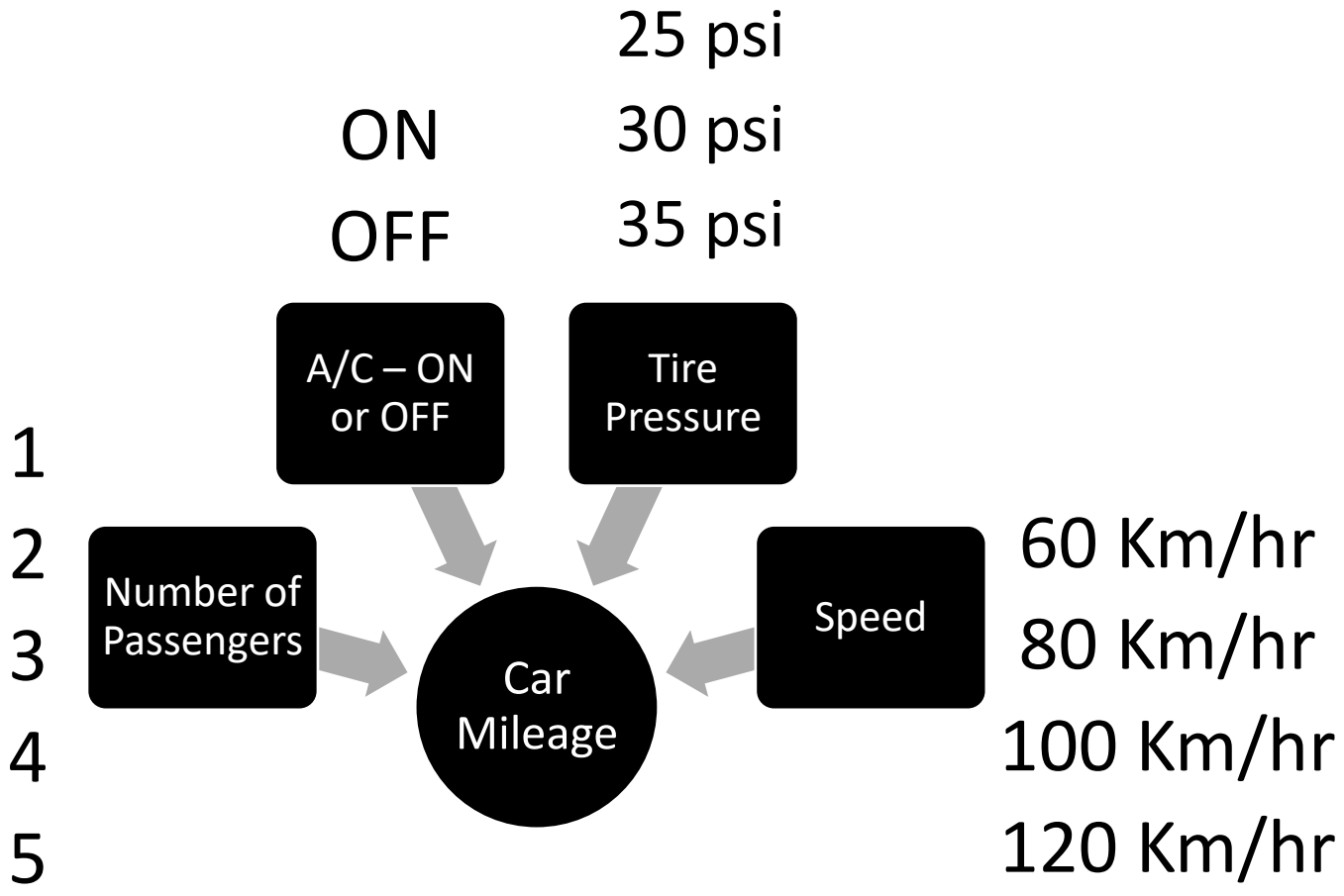
Treatment	# passengers	A/C
1	1	ON
2	1	OFF
3	2	ON
4	2	OFF
5	3	ON
6	3	OFF
7	4	ON
8	4	OFF
9	5	ON
10	5	OFF



Treatments

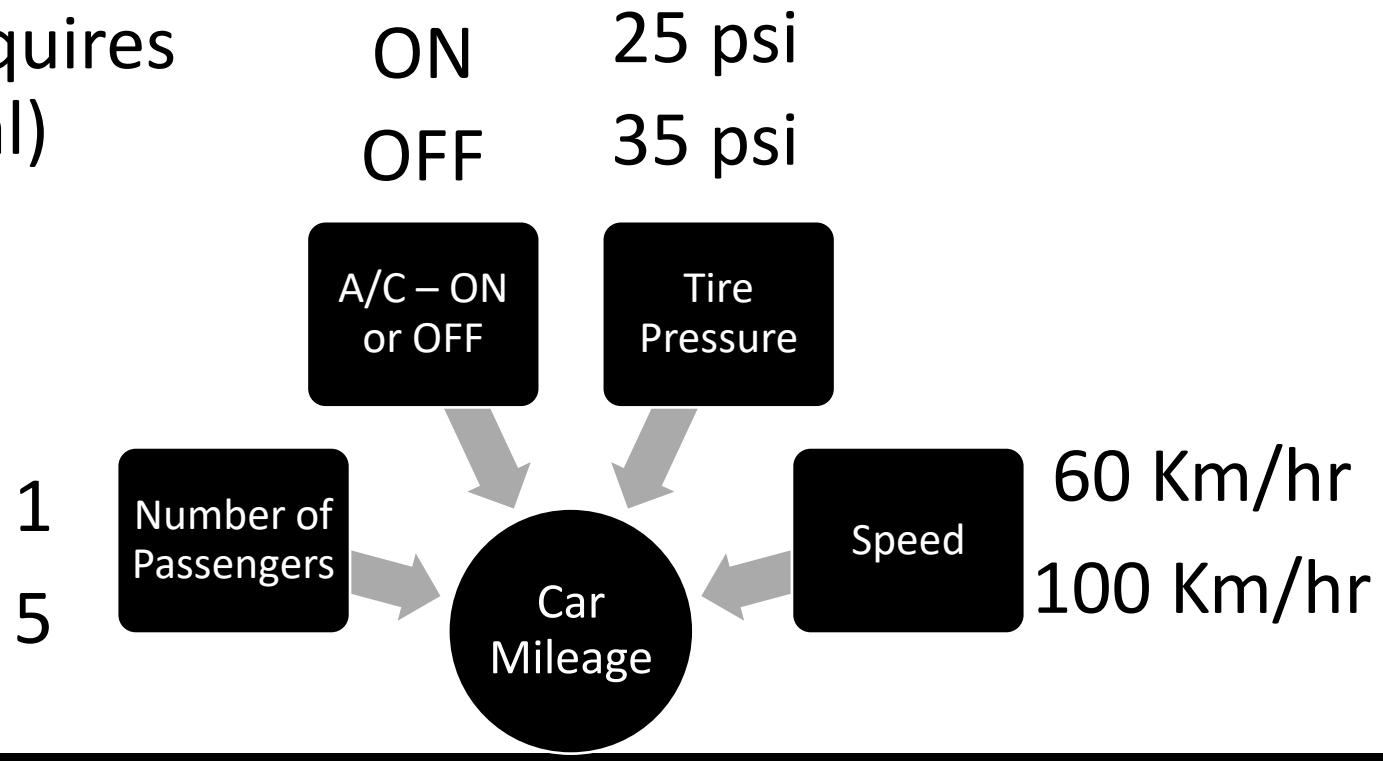
For first three factors you will need to conduct 5x2x3 experiments

Treatment	# passengers	A/C	Tire Pressure
1	1	ON	25 psi
2	1	ON	30 psi
3	1	ON	35 psi
4	1	OFF	25 psi
5	1	OFF	30 psi
6	1	OFF	35 psi
7	2	ON	25 psi
8	2	ON	30 psi
9	2	ON	35 psi
..	..	..	..



Treatments

- Number of experiments = Level $^{\text{Factors}}$
- 4 Factors 2 Level experiment requires
  $2^4 = 16$ experiments (full factorial)
- 5 Factors 2 Level experiment requires
  $2^5 = 32$ experiments (full factorial)



Number of Experiments

- **<u>Response</u>:** The output(s) of a process. Sometimes called dependent variable(s).

Treatment	# passengers	A/C	L/100 km
1	1	ON	13.8
2	1	OFF	13.6
3	2	ON	
4	2	OFF	
5	3	ON	
6	3	OFF	
7	4	ON	
8	4	OFF	
9	5	ON	
10	5	OFF	

Response

- **<u>Errors</u>:** Anything that tends to make our estimate of the difference to be different from the "true" difference.
- Related terms are common causes, noise or nuisance factors

A/C	L/100 km
ON	13.8
OFF	13.6

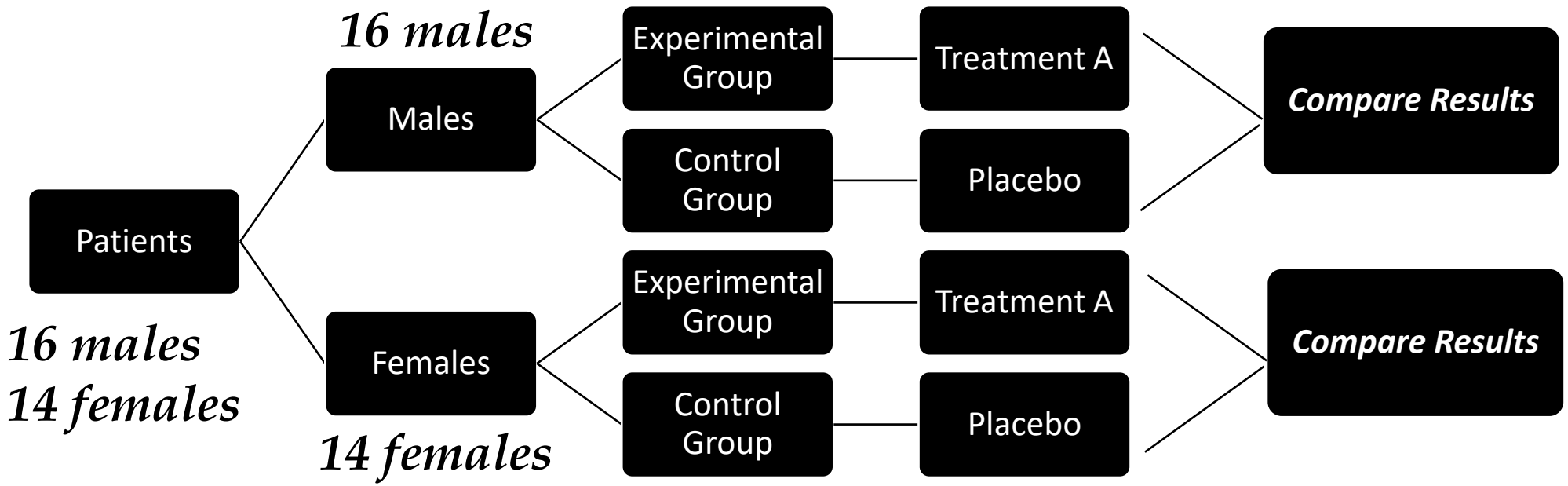
Errors

- **Two types of inputs**
  - Inputs in which we are interested to study the effect of these on the output or response. (Factors)
  - Inputs which are not of interest in the study. (Nuisance Factors or Noise)

Errors

- How to deal with nuisance factors?
  - Controllable
    - Blocking (e.g. city vs Highway drive, male/female)
  - Uncontrollable
    - Randomization (e.g. order of treatment)

Errors



Randomized Block Design

Run order	Treatment	# passengers	A/C	L/100 km
4	1	1	ON	13.8
5	2	1	OFF	13.6
6	3	2	ON	
1	4	2	OFF	
3	5	3	ON	
9	6	3	OFF	
	…	…	…	

Randomization

❖ Replication / Repetition

Performing the same treatment combination more than once.

Run order	Treatment	# passengers	A/C	L/100 km
4	1	1	ON	13.8
5	2	1	OFF	13.6
6	3	2	ON	
1	4	2	OFF	
3	5	3	ON	
9	6	3	OFF	
	…	…	…	

Replication and Repetition

- **Replication:** measurements are taken during identical but different experimental runs
- **Repetition:** measurements are taken during the same experimental run or consecutive runs.

Run order	Treatment	# passengers	A/C	L/100 km
4	1	1	ON	13.8
5	2	1	OFF	13.6
6	3	2	ON	
1	4	2	OFF	
3	5	3	ON	
9	6	3	OFF	
	…	…	…	

Replication and Repetition

5A2
DoE Graphs and Plots

01 Basic Terms

02 DoE graphs and plots

- **Coffee making process – 150cc**
- **Milk : 40** cc vs **80** cc
- **Sugar** : **10** gms vs **20** gms

DoE Graphs and Plots

- **Coffee making process – 150cc**
- **Milk : 40** cc (-) vs **80** cc (+)
- **Sugar** : **10** gms (-) vs **20** gms (+)

DoE Graphs and Plots

- **Coffee making process – 150cc**
- **Milk : 40** cc (-) vs **80** cc (+)
- **Sugar** : **10** gms (-) vs **20** gms (+)

#	Sugar	Milk
1	-	-
2	-	+
3	+	-
4	+	+

DoE Graphs and Plots

- **Coffee making process – 150cc**
- **Milk : 40** cc (-) vs **80** cc (+)
- **Sugar** : **10** gms (-) vs **20** gms (+)

#	Sugar	Milk	Sequence
1	-	-	2
2	-	+	4
3	+	-	1
4	+	+	3

Randomization

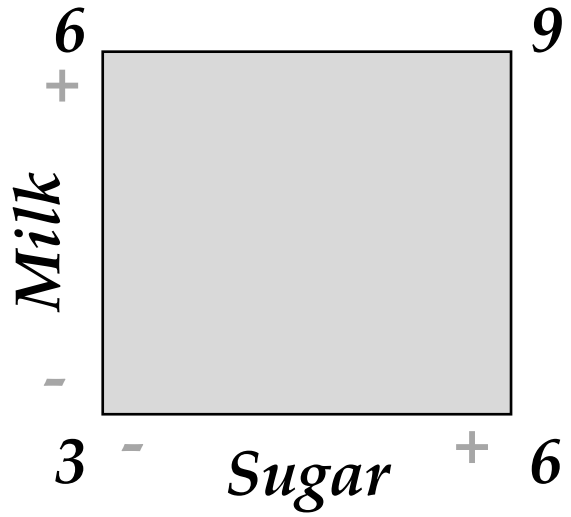
DoE Graphs and Plots

- **Coffee making process – 150cc**
- **Milk : 40** cc (-) vs **80** cc (+)
- **Sugar** : **10** gms (-) vs **20** gms (+)

#	Sugar	Milk	Rating	Sequence
1	-	-	3	2
2	-	+	6	4
3	+	-	6	1
4	+	+	9	3

DoE Graphs and Plots

#	Sugar	Milk	Rating	Sequence
1	-	-	3	2
2	-	+	6	4
3	+	-	6	1
4	+	+	9	3



DoE Graphs and Plots

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1	-	-	3	2
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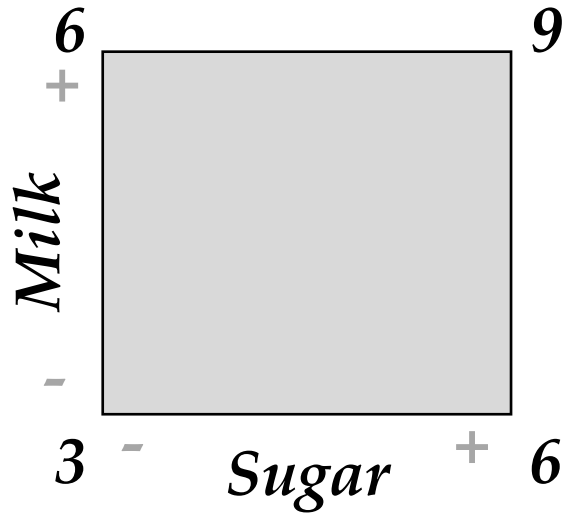

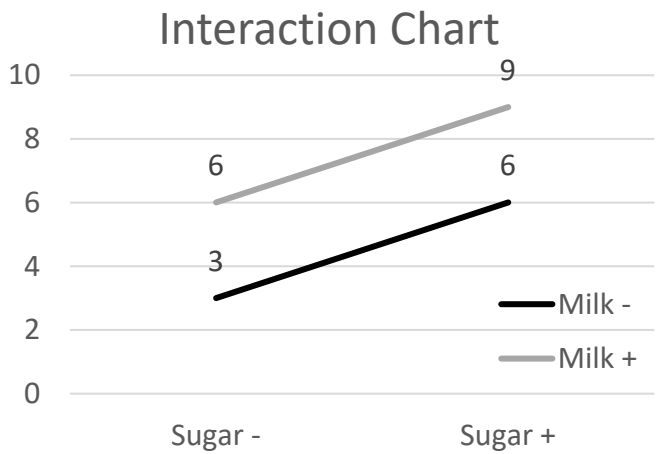

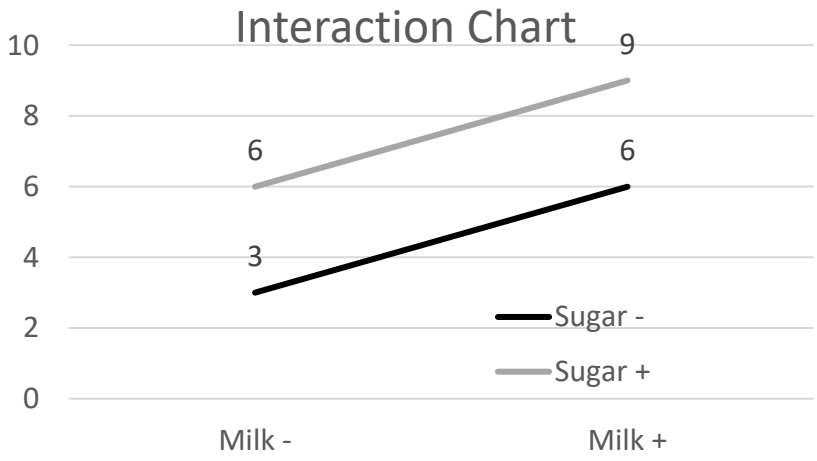

DoE Graphs and Plots

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1	-	-	3	2
2	-	+	6	4
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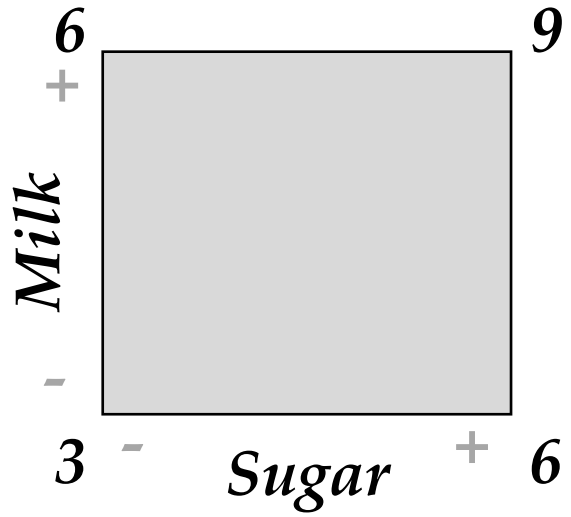
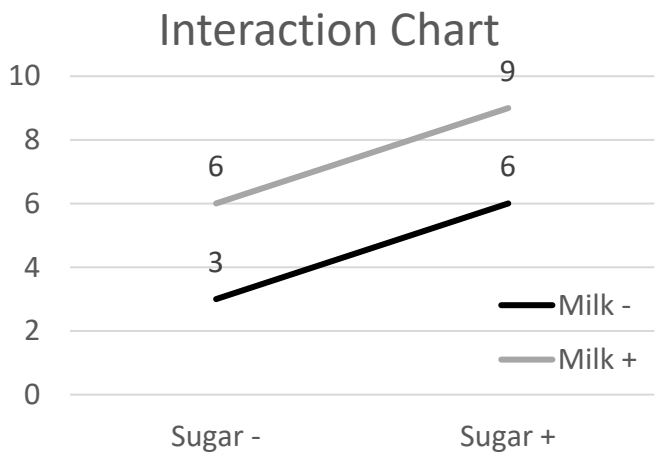
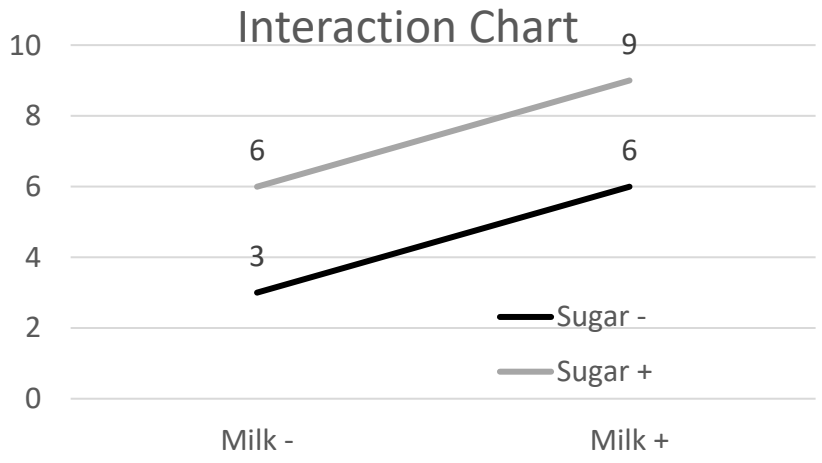
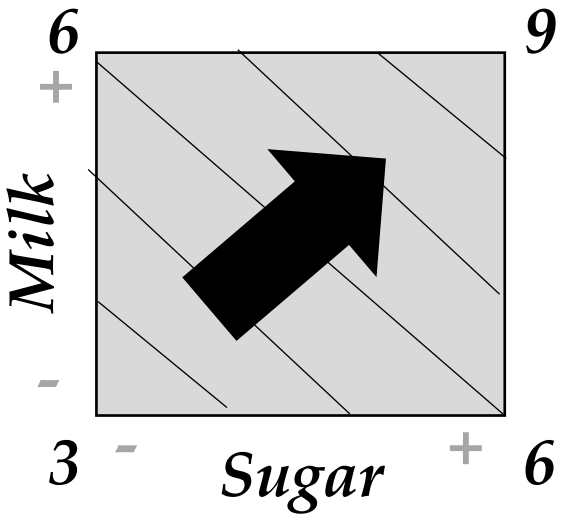
4	+	+	9	3









DoE Graphs and Plots

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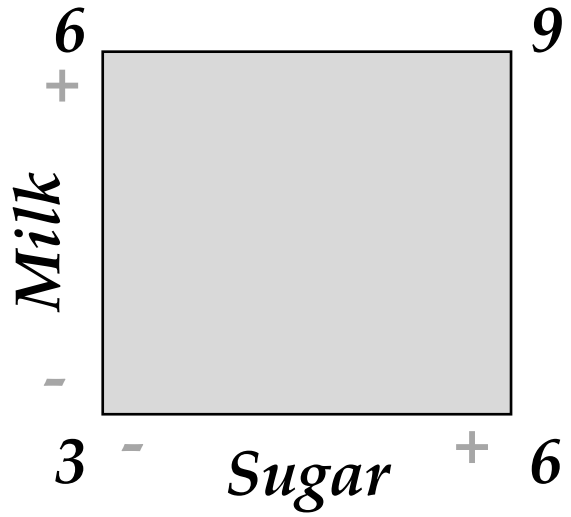
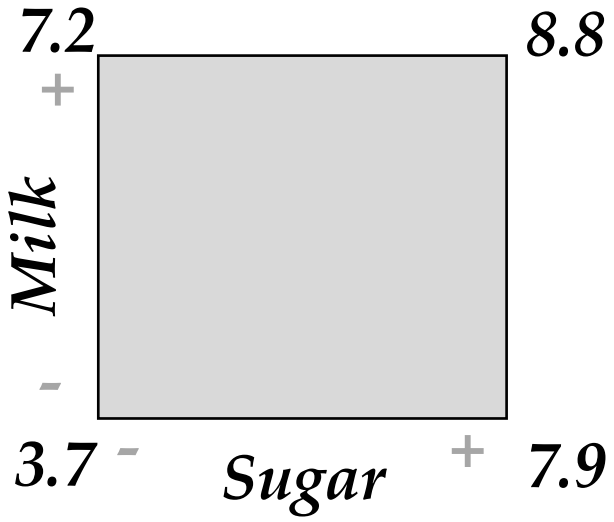


- $Y = B_0 + B_1X_1 + B_2X_2$
- $Y = B_0 + B_sX_s + B_mX_m$
- $Y = 6 + 1.5\ X_s + 1.5\ X_m$

DoE Graphs and Plots

#	Sugar	Milk	Rating	Sequence
1	-	-	3.7	2
2	-	+	7.2	4
3	+	-	7.9	1
4	+	+	8.8	3



DoE Graphs and Plots

#	Sugar	Milk	Rating	Sequence
1	-	-	3.7	2
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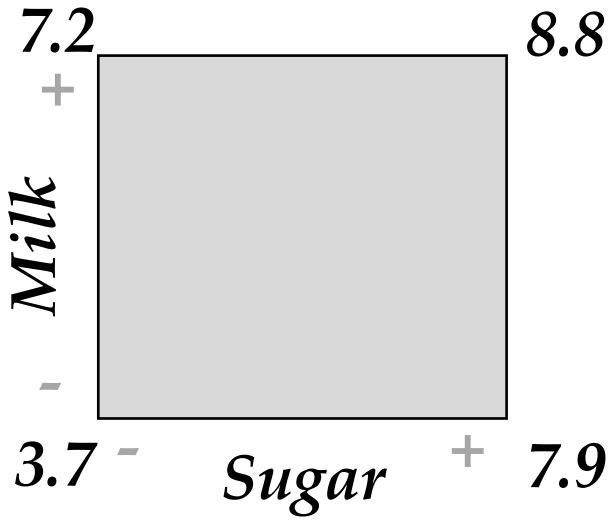
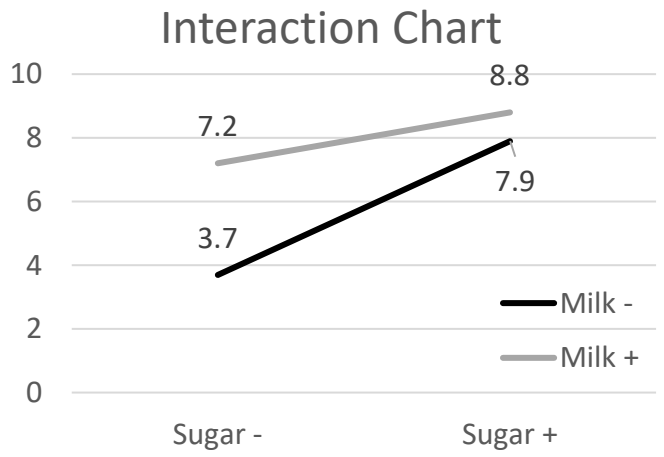
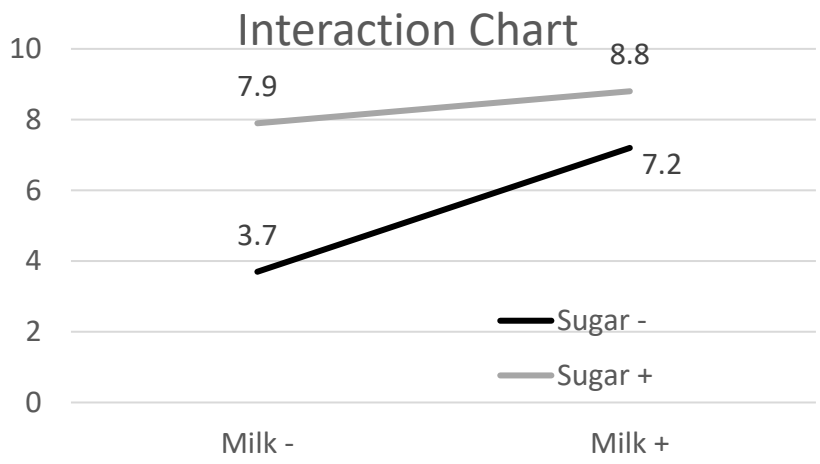
3	+	-	7.9	1
4	+	+	8.8	3







DoE Graphs and Plots

#	Sugar	Milk	Rating	Sequence
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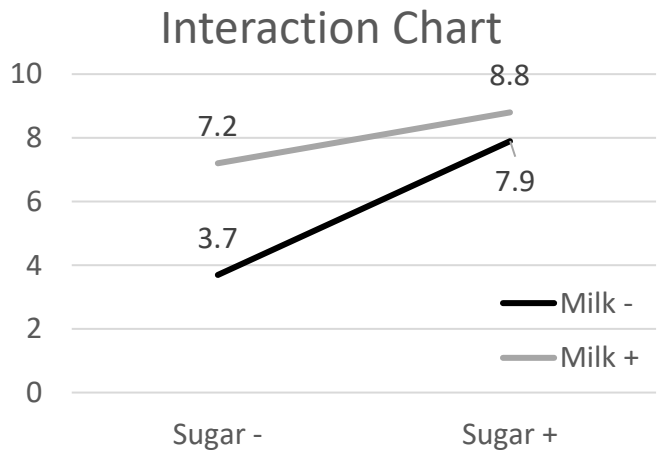
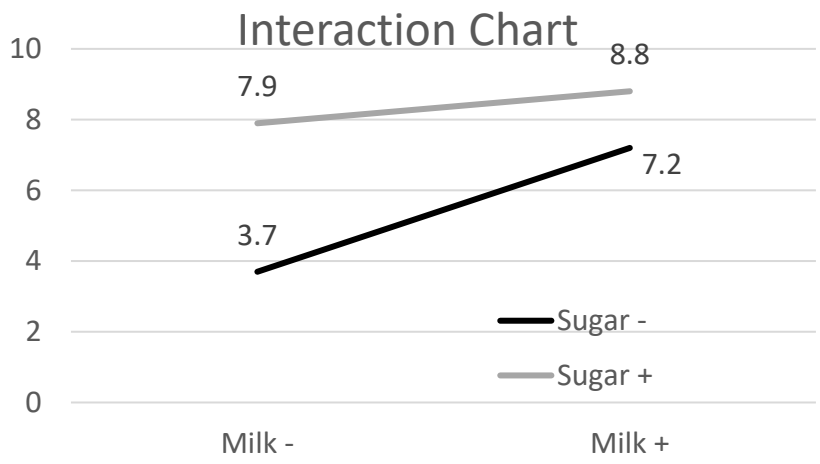
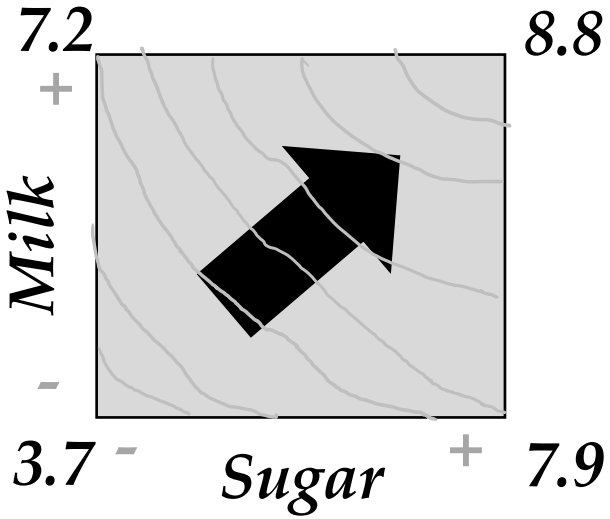
2	-	+	7.2	4
3	+	-	7.9	1
4	+	+	8.8	3

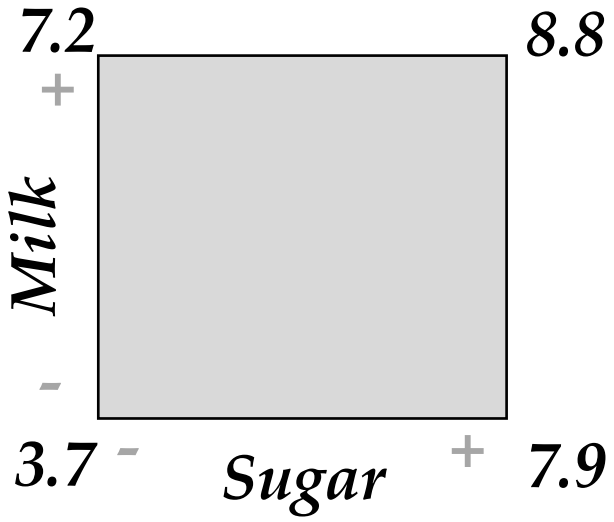






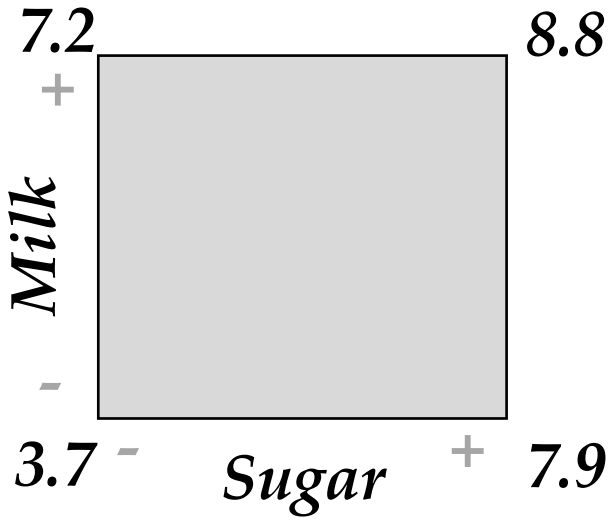
DoE Graphs and Plots

- Y = B0 + B1X1 + B2X2
- Y = B0 + BsXs + BmXm
- Y = 6.9 + 1.45 Xs + 1.1 Xm

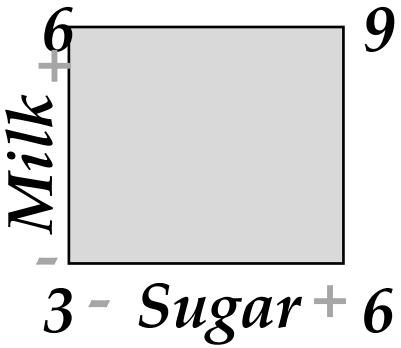


DoE Graphs and Plots

- Y = 6.9 + 1.45 Xs + 1.1 Xm
- For low milk, low sugar
  Y = 6.9 + 1.45 (-1) +1.1 (-1) = 4.35 (against 3.7)
  Hence something else is playing here … called interaction or Xs . Xm
- Interaction Xs . Xm = (8.8-7.2)-(7.9-3.7)/2

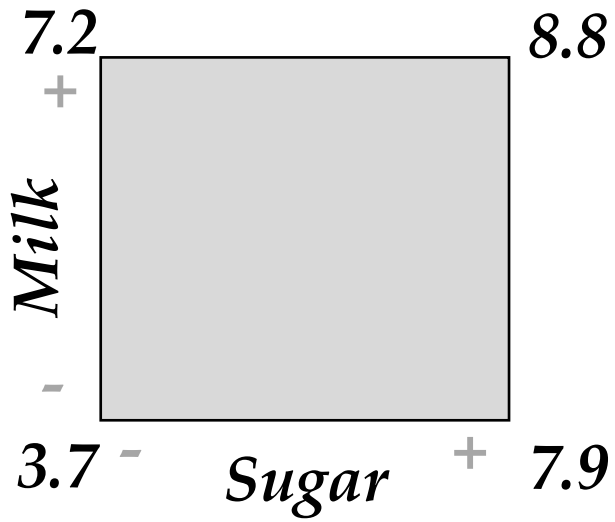


Zero Interaction



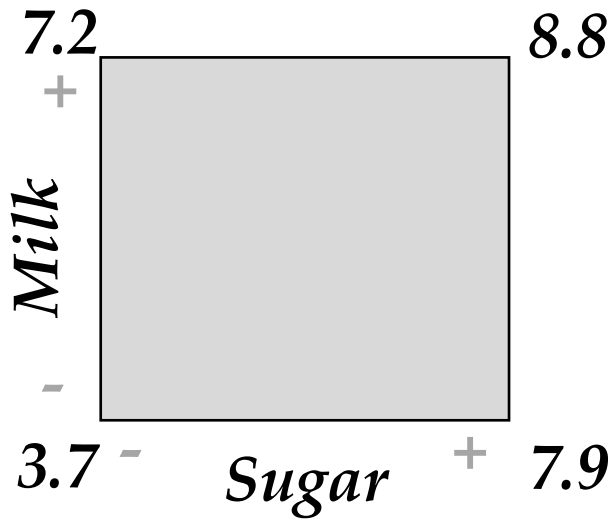
DoE Graphs and Plots

- $Y = B_0 + B_1X_1 + B_2X_2$
- $Y = B_0 + B_sX_s + B_mX_m$
- $Y = 6.9 + 1.45\ X_s + 1.1\ X_m$
- Interaction is half the difference in the effect of sugar when milk is high or low is = (8.8-7.2)-(7.9-3.7)/2 = -1.3
- Report of half of this in the equation as multiple of $X_s\ .\ X_m$ or -1.3/2 = -0.65
- $Y = 6.9 + 1.45\ X_s + 1.1\ X_m - 0.65\ X_s\ .\ X_m$



DoE Graphs and Plots

- $Y = 6.9 + 1.45\ X_s + 1.1\ X_m - 0.65\ X_s\ .\ X_m$
- For high (+) sugar high (+) milk
- $Y = 6.9 + 1.45\ (+1) + 1.1\ (+1) - 0.65\ (+1).(+1)$
- $Y = 6.9 + 1.45 + 1.1 - 0.65 = 8.8$



- For high (+) sugar low (-) milk
- $Y = 6.9 + 1.45\ (+1) + 1.1\ (-1) - 0.65\ (+1).(-1)$
- $Y = 6.9 + 1.45 - 1.1 + 0.65 = 7.9$

DoE Graphs and Plots

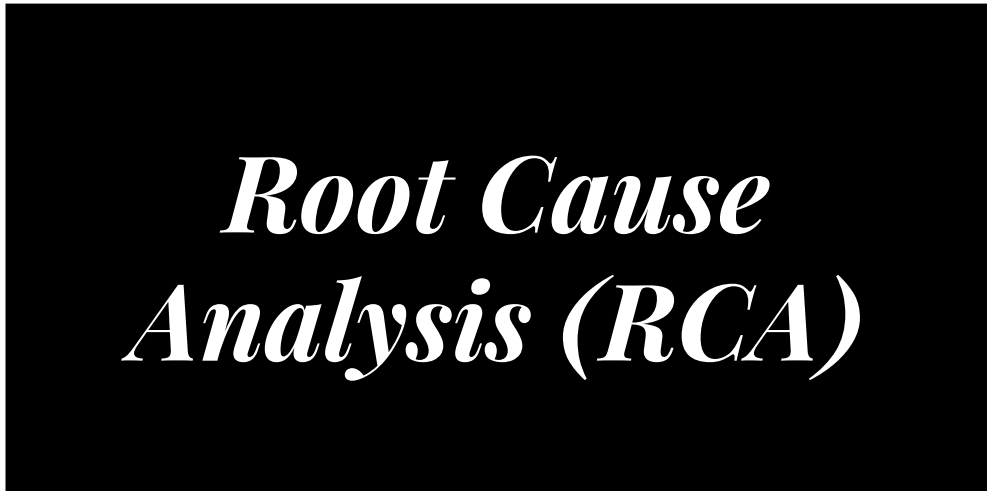
5B Root Cause Analysis

01 Definitions

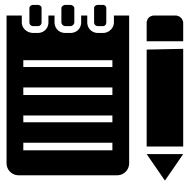
02 Commonly used Tools

Root Cause Analysis (RCA)

- RCA is a structured process to identify root causes of an event that resulted in an undesired outcome and develop corrective actions.

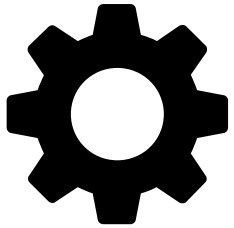


RCA - Commonly Used Tools

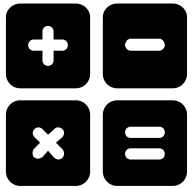


5 Whys

Cause and Effects Analysis



Process Mapping



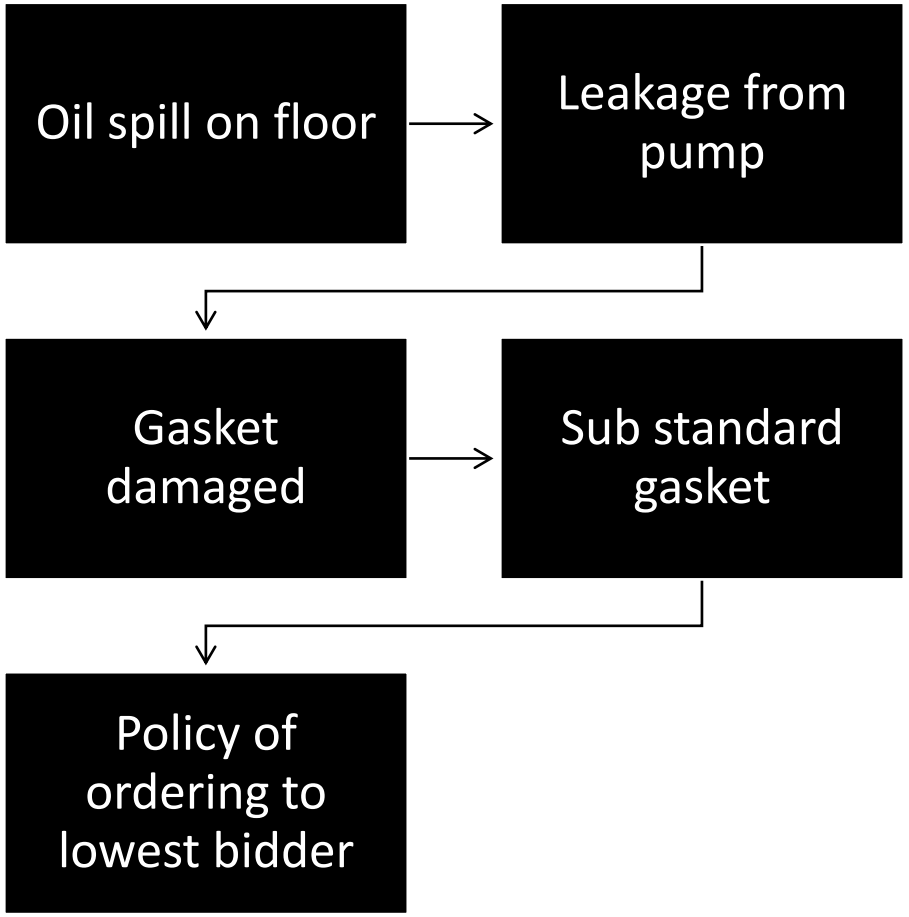
Prioritization Matrices

Root Cause Analysis (RCA)

5 Whys

- Ask “why” multiple times to reach to the root cause of the problem.

5 Whys

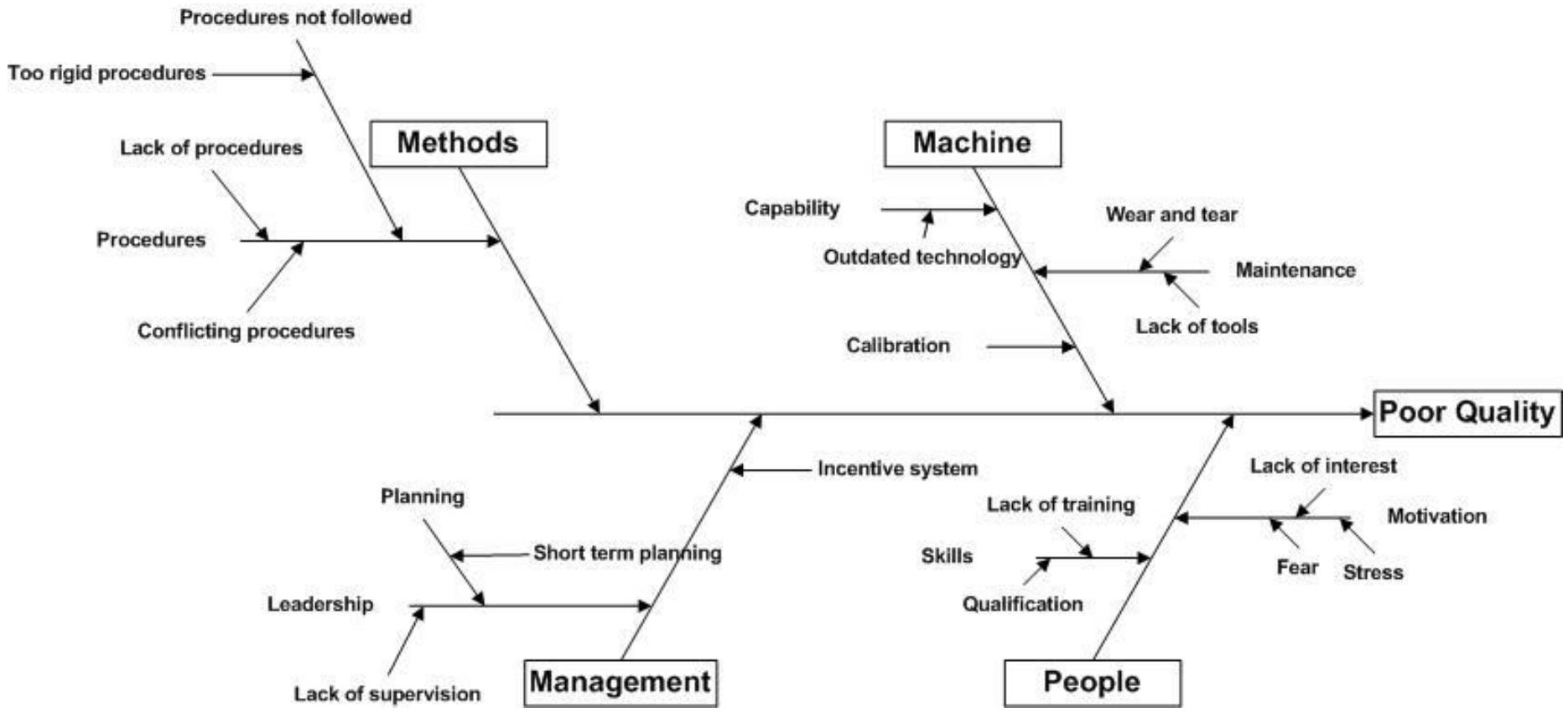

Oil spill on floor
Leakage from pump
Gasket damaged
Sub standard gasket
Policy of ordering to lowest bidder

5 Whys

Cause and Effects Diagram

- What?
  - A tool used to graphically display the relationship between an effect (e.g., a problem statement) and the its causes.
- Why?
  - To identify the various causes affecting a problem.
  - Helps a group reach a common understanding of a problem.

Cause and Effects Diagram



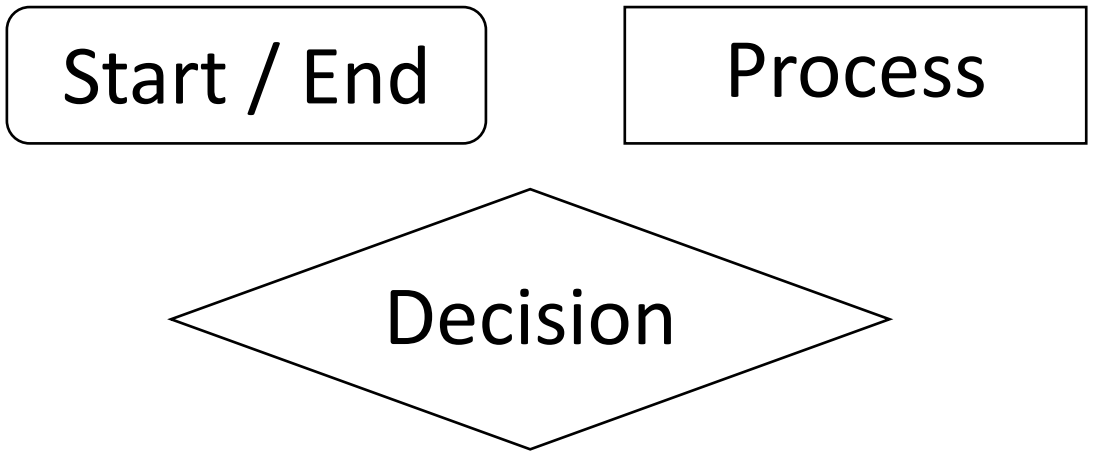
Cause and Effects Diagram

Process Mapping

- This helps in a clear understanding of the process.
- Shows the processes as boxes connected by arrows and decision boxes

Process Mapping

Process Mapping



Process Mapping

Prioritization Matrices

- It is used to compare choices
- Or to select a project

Prioritization Matrices

	IMPORTANCE	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5
Effective	0.3	2	3	5	2	1
Quick to implement	0.1	1	3	4	5	3
Less Costly	0.4	1	2	5	4	4
Mgmt support	0.2	2	1	4	2	3
Total	1.0	1.50	2.2	4.7	3.1	2.8

Prioritization Matrices

5C
Lean Tools

01 *Waste elimination*

02 *Cycle-time reduction*

03 *Kaizen and Kaizen Blitz*

5C1 Waste elimination

01 *Understanding types of wastes*

02 *Eliminating waste (techniques)*

- *Pull system*
- *Kanban*
- *5S*
- *Standard work*
- *Poka-yoke*

Waste - Philosophy

- Waste exist in all processes at all levels in the organization.
- Waste elimination is the key to successful implementation of lean.
- Waste reduction is an effective way to increase profitability.

Waste elimination

Muda

An activity that is wasteful and doesn't add value or is unproductive

Mura

Any variation leading to unbalanced situations.

Muri

Any activity asking unreasonable stress or effort from personnel, material or equipment.

3 Categories of Waste

Muda

- Muda is a traditional Japanese term for an activity that is wasteful and doesn't add value or is unproductive
  - Type I Muda: (Incidental Work)
    - Non-value-added tasks which seam to be essential. Business conditions need to be changed to eliminate this type of waste.
  - Type II Muda: (Non-Value-Added Work)
    - Non-value-added tasks which can be eliminated immediately.

3 Categories of Waste

Mura

- MURA: Any variation leading to unbalanced situations.
- Mura exists when
  - workflow is out of balance
  - workload is inconsistent

3 Categories of Waste

Muri

- MURI: Any activity asking unreasonable stress or effort from personnel, material or equipment.
  - For people, Muri means too heavy a mental or physical burden.
  - For machinery Muri means expecting a machine to do more than it is capable of or has been designed to do.

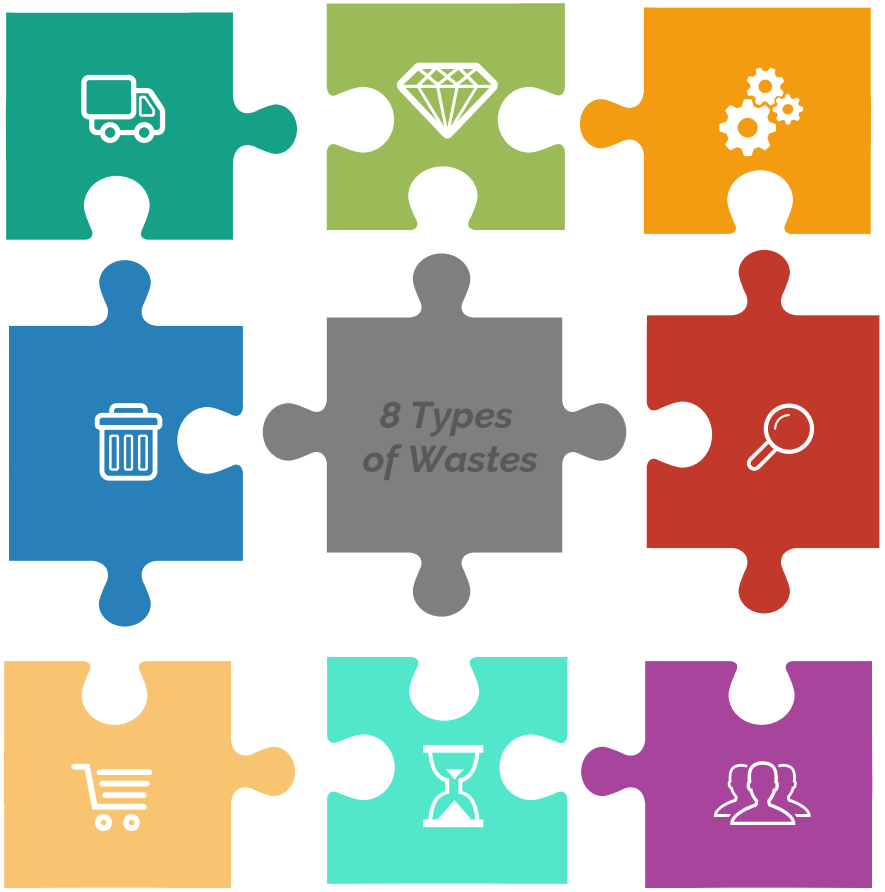
3 Categories of Waste

Transportation
Unnecessary movement of people or parts between processes.

Inventory
Materials parked and not having value added to them.

Motion
Unnecessary movement of people or parts within a process.

Wait Time
People or parts waiting for a work cycle to finish.



Over Processing
Processing beyond the demand from the customers.

Over Production
Producing too much, too early and/or too fast.

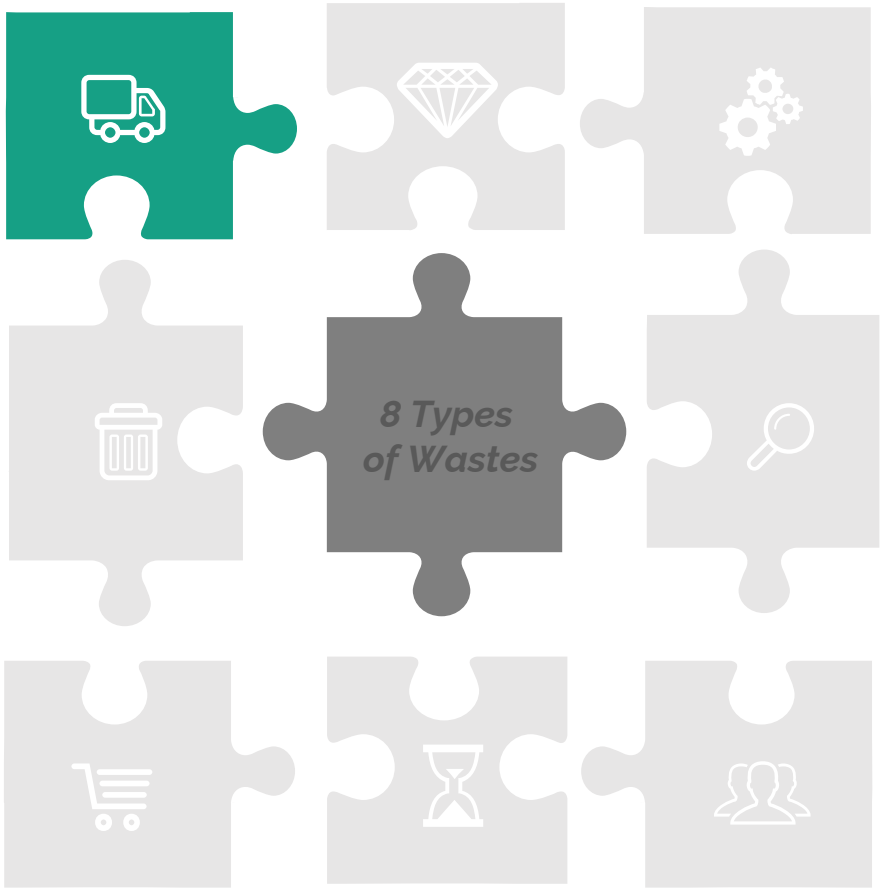
Defects
Sorting, repetition or making scrap

Under Utilized Staff
Failure when it comes to exploiting the knowledge and talent of the employees.

Eight Types of Muda

- ***Transportation***

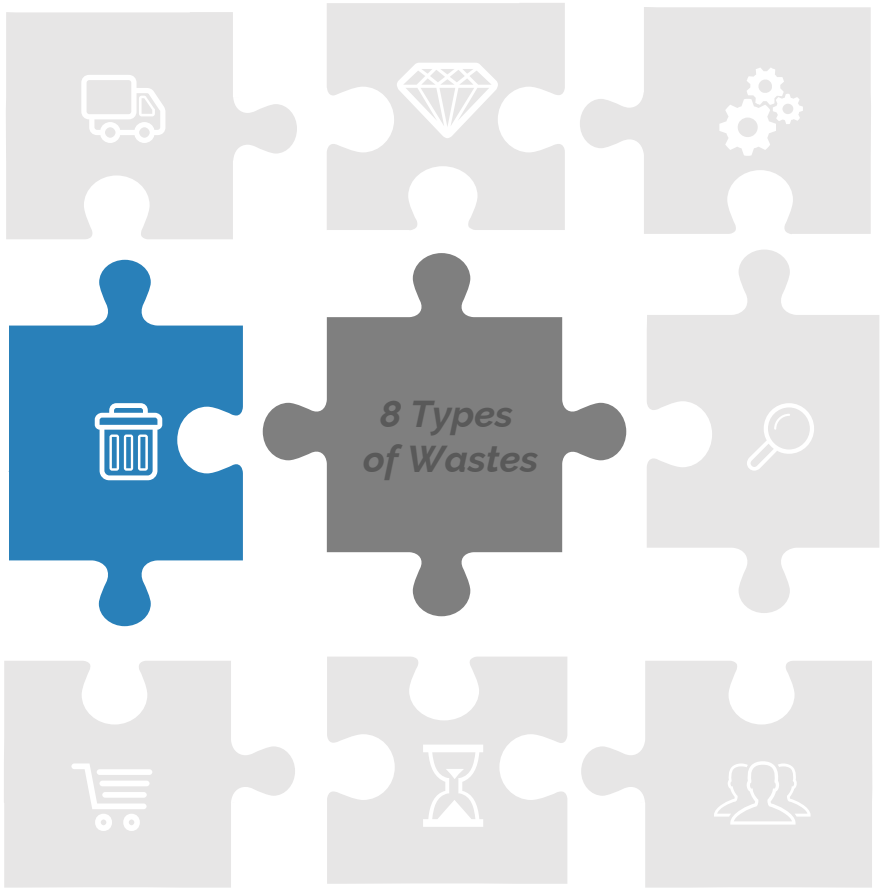
  Unnecessary movement of people or parts between processes.



Eight Types of Muda

- ***Inventory***

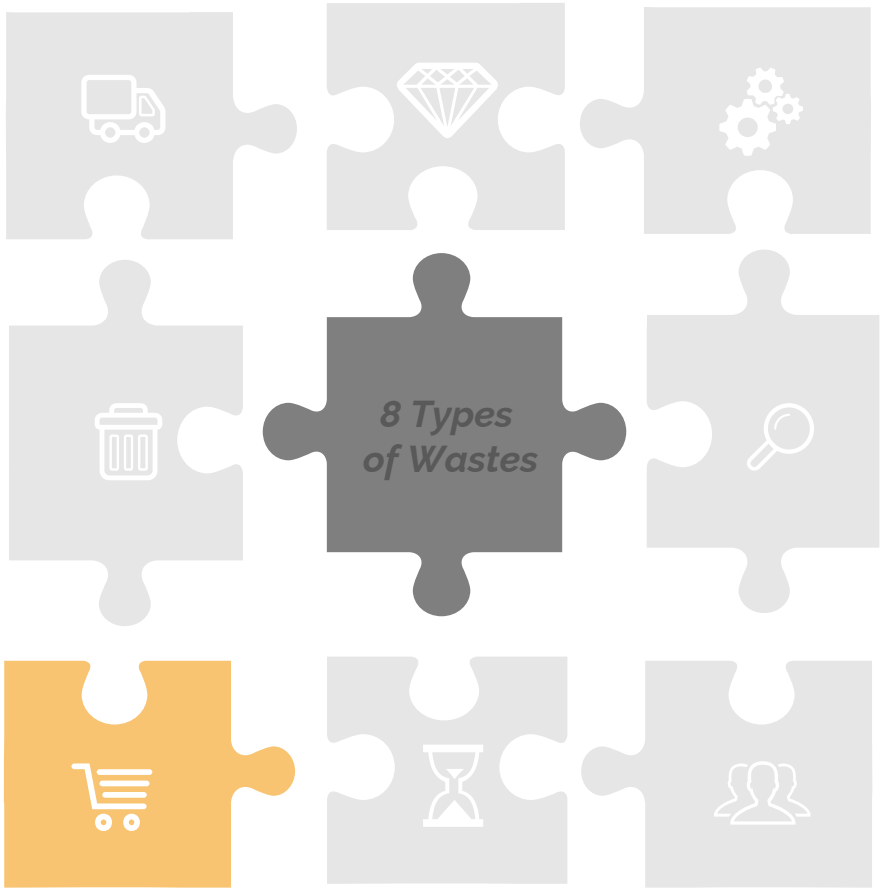
  Materials parked and not having value added to them.



Eight Types of Muda

Motion

Unnecessary movement of people or parts within a process.



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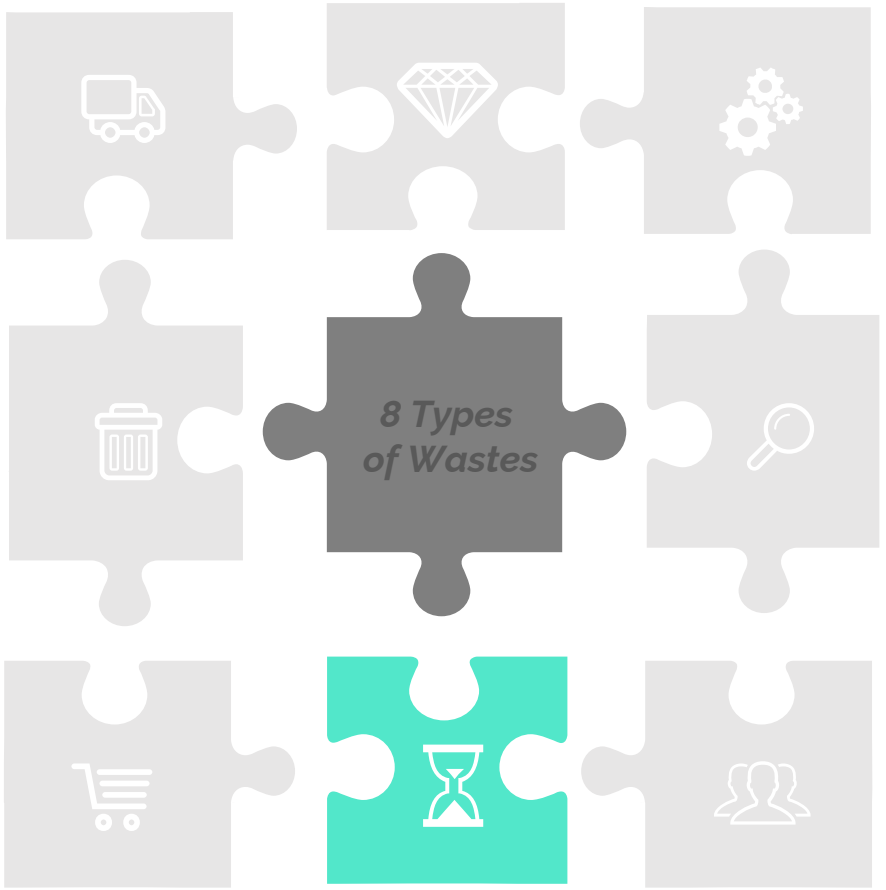

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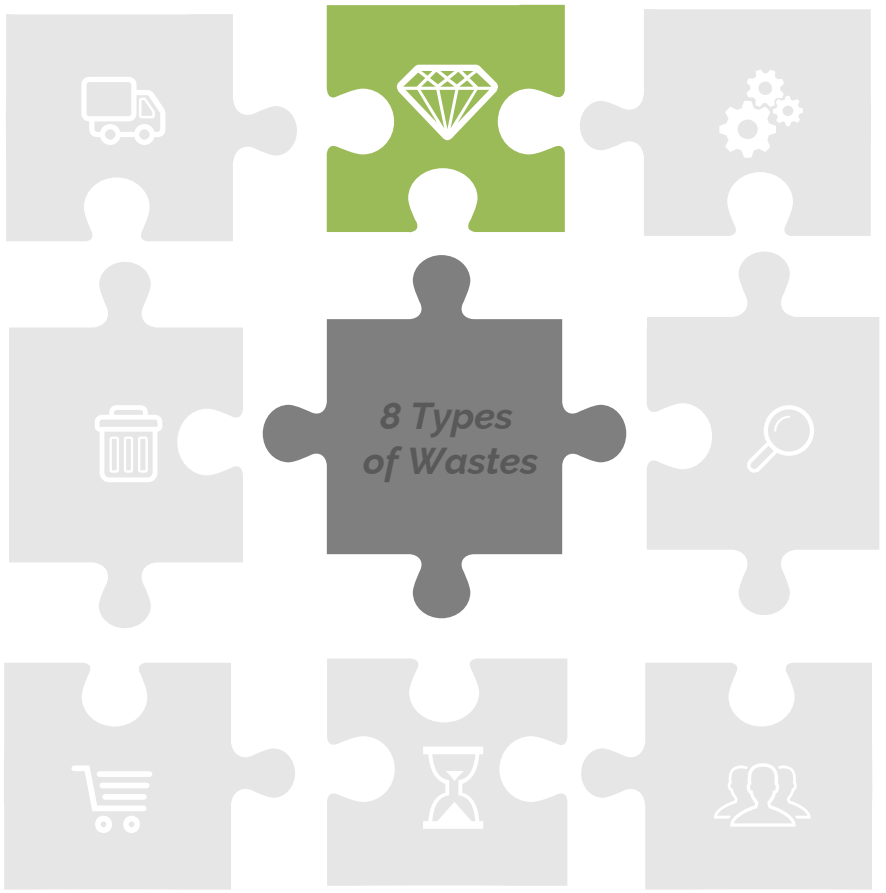

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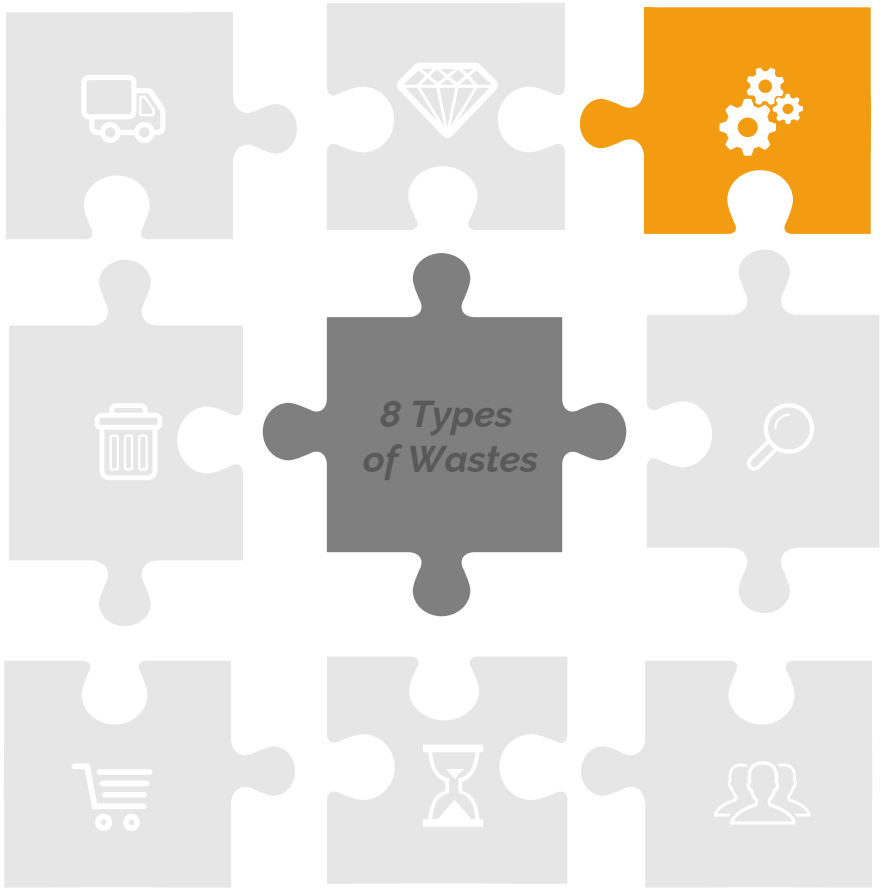
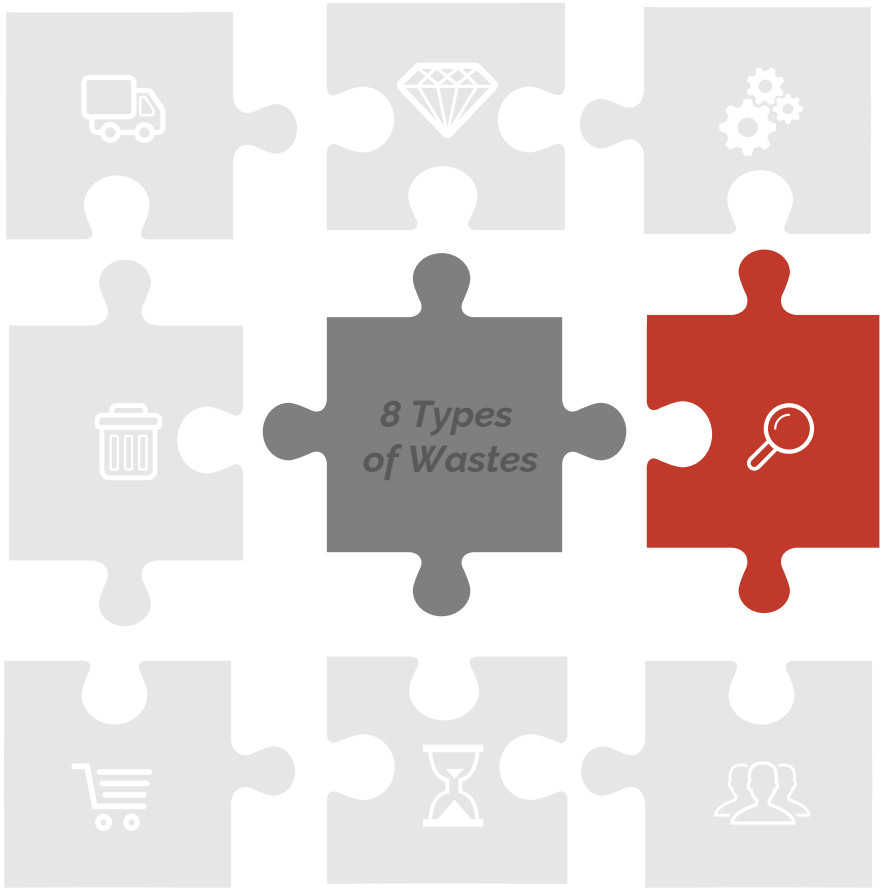


Eight Types of Muda

- ***Defects***

  Sorting, repetition or making scrap



Eight Types of Muda

- ***Under Utilized Staff***

  Failure when it comes
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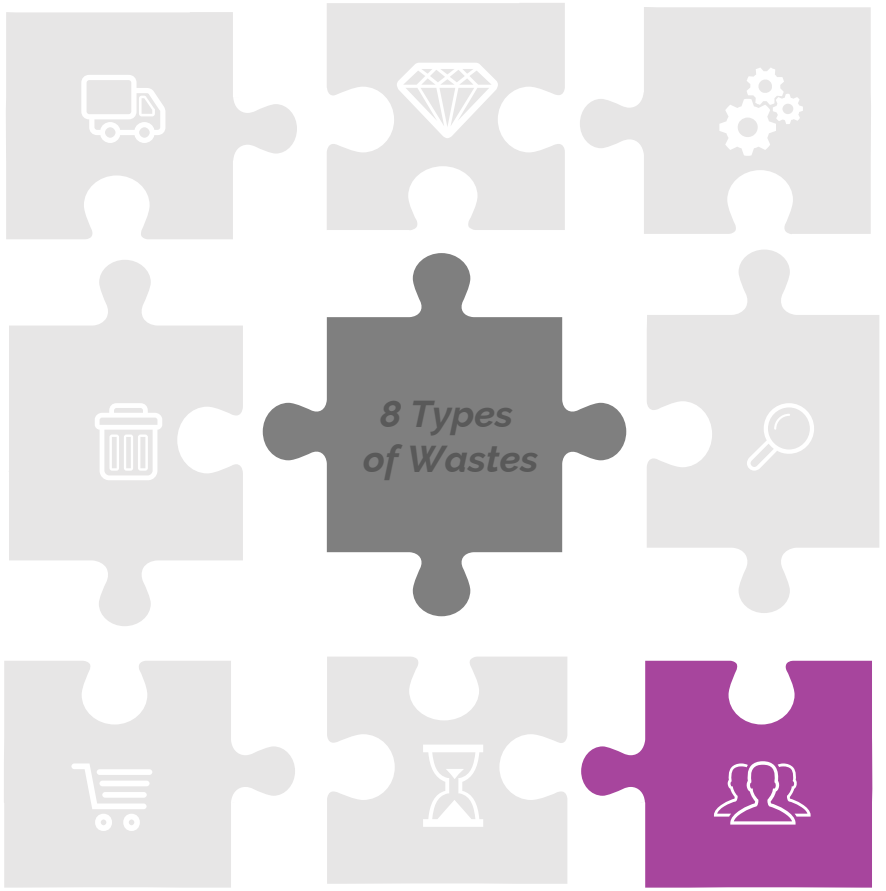
  and talent of the employees.



Eight Types of Muda

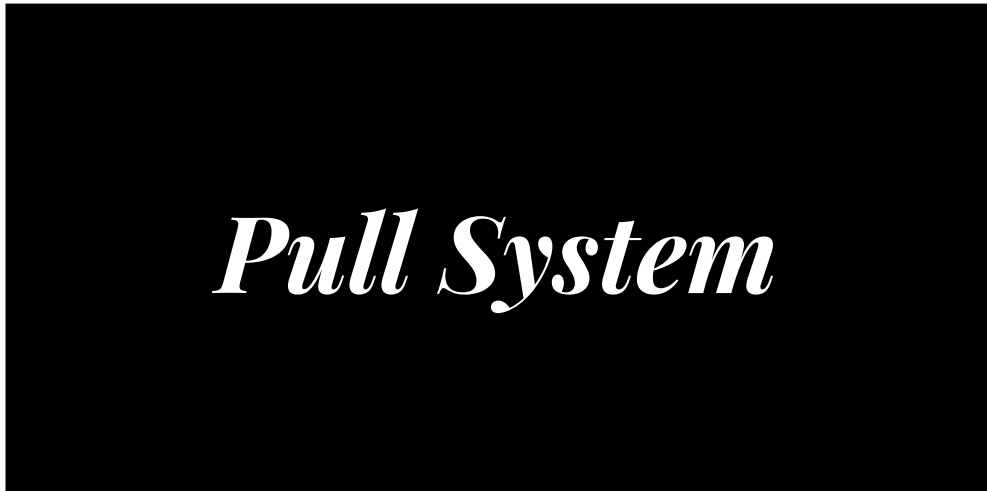
Eliminating waste (techniques)

- Pull system
- Kanban
- 5S
- Standard work
- Poka-yoke

Waste elimination

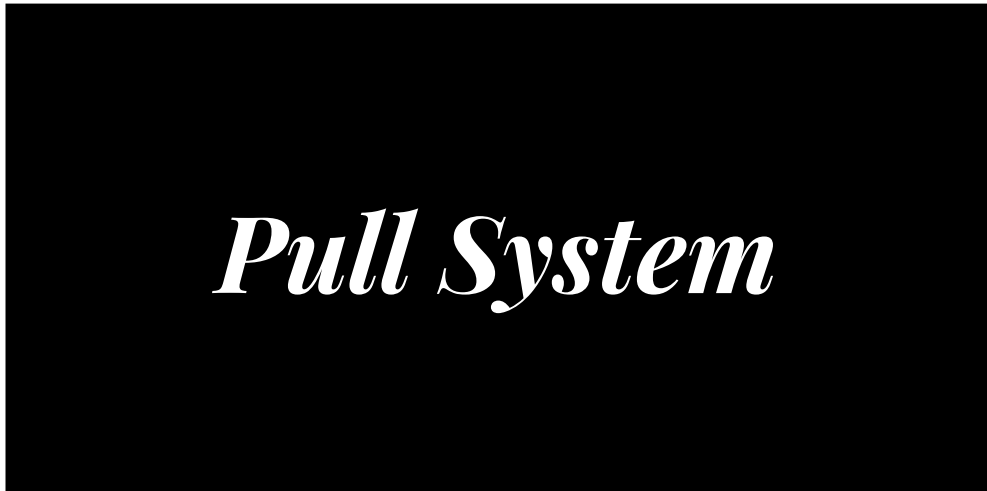
Pull Systems

- **Pull:**
- Produce based on demand
- Providing product or service when required by customer or the next process.
- **Push:**
- Produce to stock
- Based on demand forecast



Pull Systems

- **Pull:**
- Limits the Work In Progress and Inventory.
- Kanban cards



Kanban

- Kanban means Signboard (or billboard) in Japanese.
- Kanban is an inventory-control system
- Taiichi Ohno developed it as a part of JIT

Kanban

- Three bin system for supplied parts
  - One bin is on the factory floor (the initial demand point),
  - One bin is in the factory store (the inventory control point), and
  - One bin is at the supplier.
- The bins usually have a Kanban card.

5 S

- The 5S’s are simple but effective methods to organise the workplace.
- It however, goes beyond this simple concept, and is concerned with making orderly and standardized operations the norm, rather than the exception.

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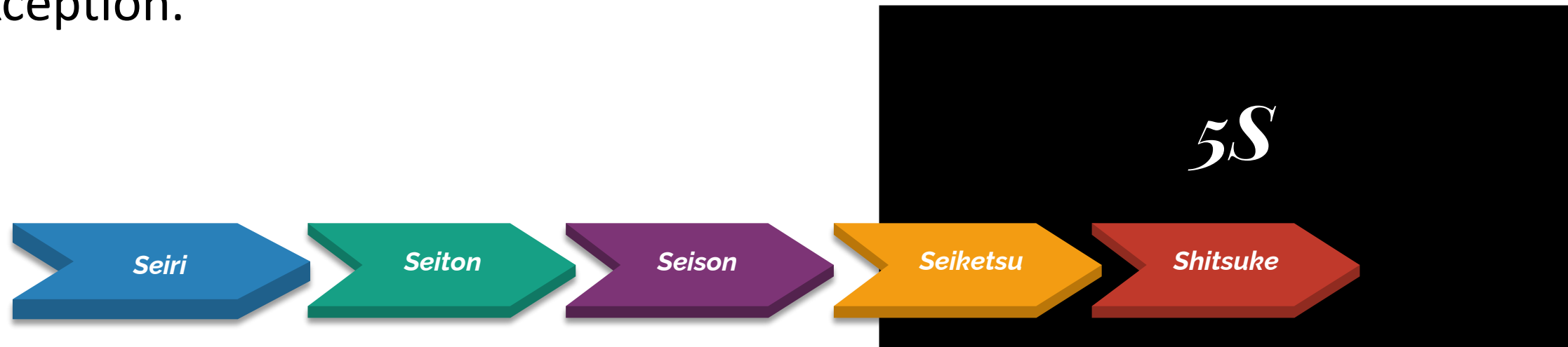
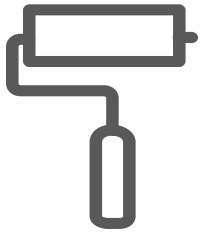
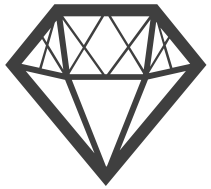


Seiri	Seiton	Seison	Seiketsu	Shitsuke
				
Sort	***Set in order***	***Shine***	***Standardize***	***Sustain***
Remove all of the clutter from the work place	Organize in an efficient and ergonomic manner.	Clean up the entire area removing all dirt	Ensure standard ways of working for the first three stages.	Ensure that 5S principles are part of the culture

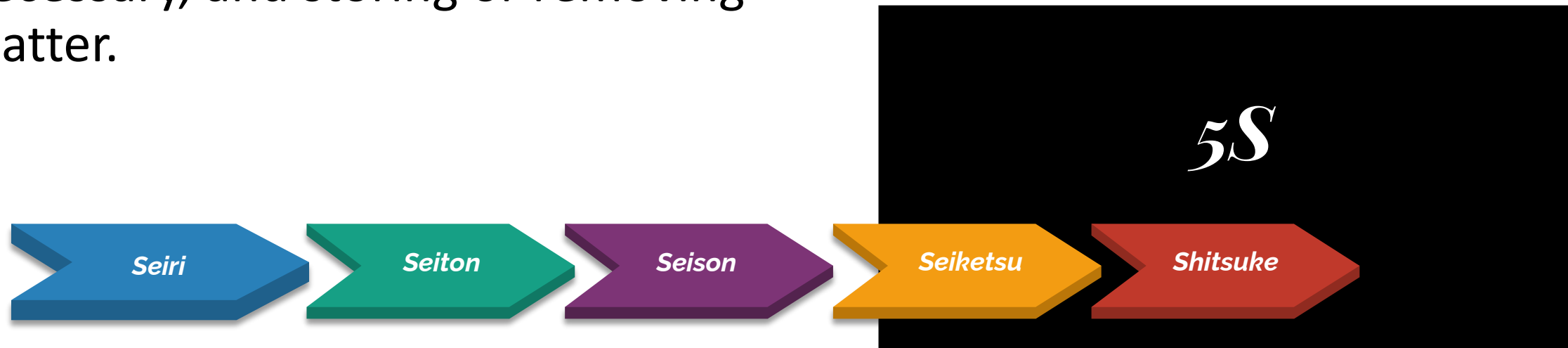
5S Summary

5 S

1. Seiri (Sort)

<u>Remove all of the clutter from the work place</u>

- This requires the classifying of items into two categories, necessary and unnecessary, and storing or removing the latter.



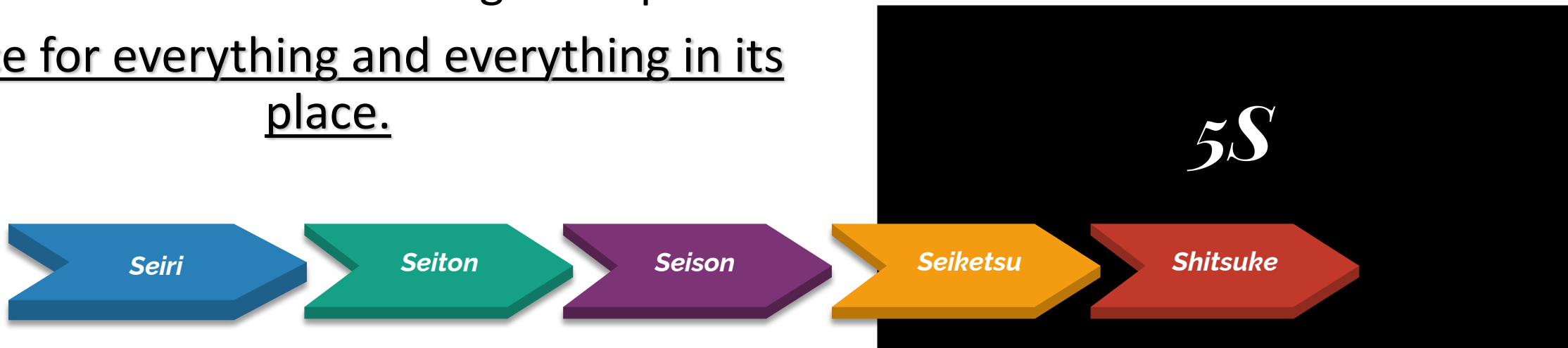
5 S

2. Seiton (Straighten)

<u>Organize in an efficient and ergonomic manner.</u>

- Arrange items to minimise search time and effort.
- Each item should have a designated place

<u>A place for everything and everything in its place.</u>

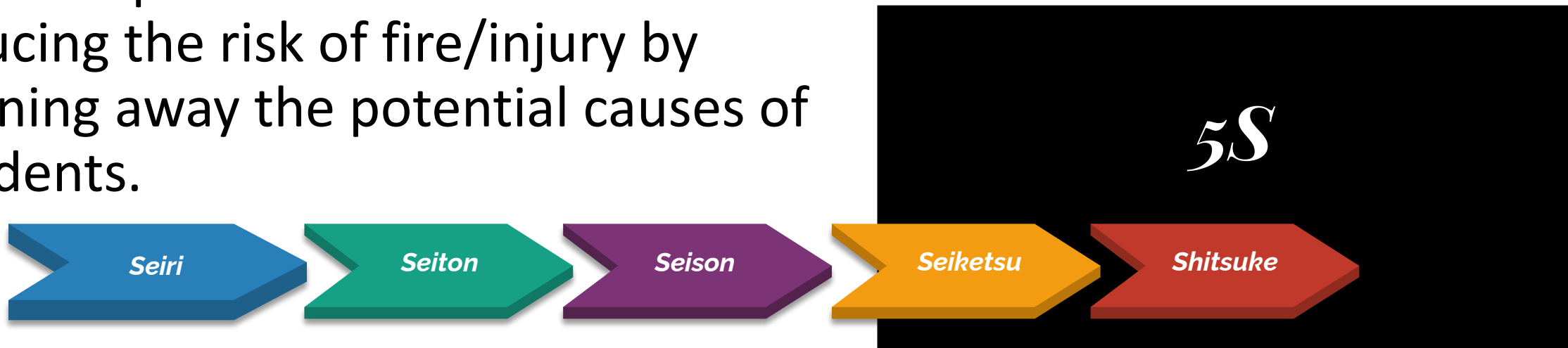


5 S

3. Seison (Shine)

Clean up the entire area removing all dirt

- Seison means cleaning the working environment.
- It can help in the spotting of potential problems as well as reducing the risk of fire/injury by cleaning away the potential causes of accidents.

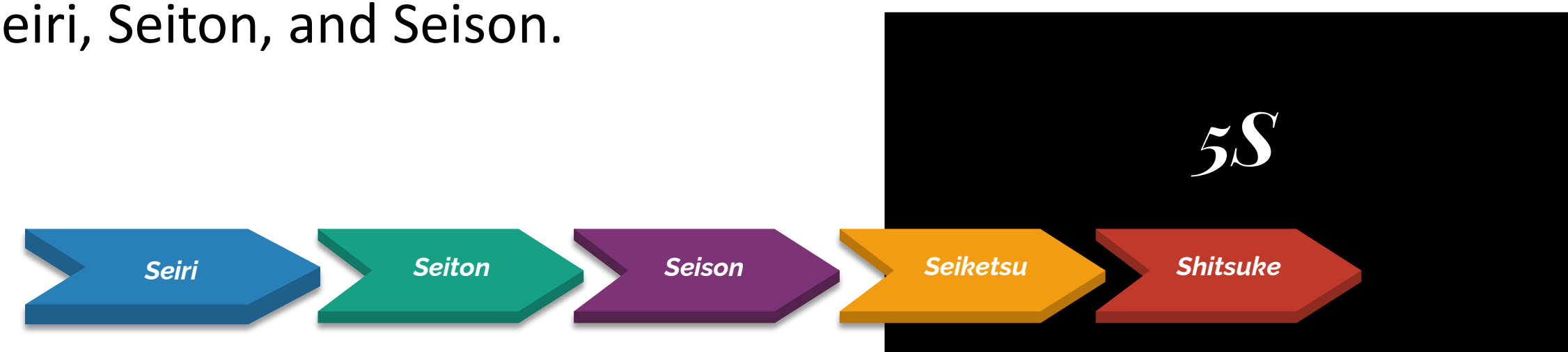


5 S

4. Seiketsu (Standardize)

<u>Ensure standard ways of working for the first three stages.</u>

- It can also be viewed as the continuation of the work carried out in Seiri, Seiton, and Seison.

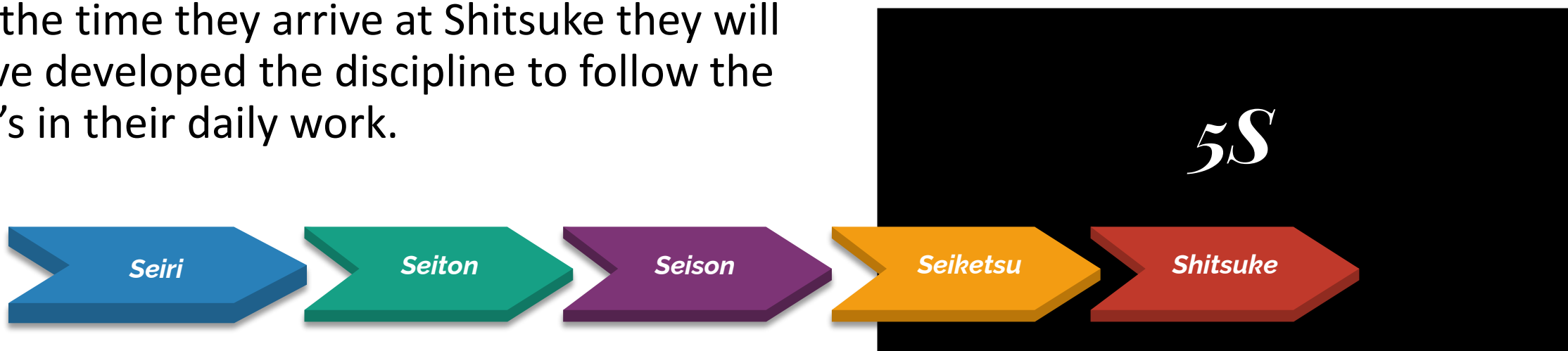


5 S

5. Shitsuke (Sustain)

Ensure that 5S principles are part of the culture

- Shitsuke means self-discipline.
  - The 5 S's may be viewed as a philosophy, with employees following established and agreed upon rules at each step.
  - By the time they arrive at Shitsuke they will have developed the discipline to follow the 5 S's in their daily work.



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		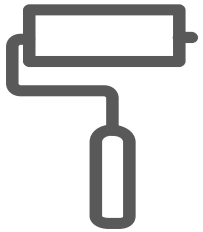		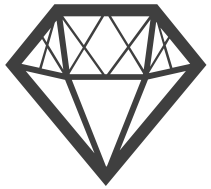
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Remove all of the clutter from the work place	Organize in an efficient and ergonomic manner.	Clean up the entire area removing all dirt	Ensure standard ways of working for the first three stages.	Ensure that 5S principles are part of the culture

5S Summary

Standard Work

- Doing work in a standard way
- All people do one work in one way only
- Improvement made in the process leads to revised standard work

Poka-yoke

- Poka-yoke (pronounced "POH-kah YOH-kay") was invented by Shigeo Shingo in the 1960s.

- The term "poka-yoke" comes from the Japanese words "poka" (inadvertent mistake) and "yoke" (prevent).

Types of Poka-yoke

- Eliminates the cause of an error at the source;
- Detects an error as it is being made;
- Detects an error soon after it has been made but before it reaches the next operation.

Waste elimination

Types of Poka-yoke

- Prevention.
  - engineers the process so that it is impossible to make a mistake.
  - remove the need of correction.

- Detection.
  - signals the user when a mistake has been made.
  - they do not enforce the correction.

5C
Lean Tools

01 *Waste elimination*

02 *Cycle-time reduction*

03 *Kaizen and Kaizen Blitz*

5C2 Cycle Time Reduction

01 Continuous flow

02 Setup reduction

Continuous Flow

- Moving products through a production system without separating them into lots or batches.
- Batches lead to increased inventory
- Ideally we attempt to achieve “1-piece flow” in which each product is moving along in the production line independently until it is completed and ready to be shipped to a waiting customer.

Continuous flow

Continuous Flow

Step 2

Step 1

Step 3

Continuous flow

Continuous Flow

- <u>Advantages:</u>
- Reducing inventory and transportation costs.
- Increases productivity
- Improves quality as errors get detected easier
- Reduces waste
- Meet customer needs more effectively

Setup Reduction
or
Single-Minute Exchange of Die - SMED

- For rapid and efficient way of converting a manufacturing process from running the current product to running the next product.
- Helps in reducing Mura by balancing line
- MURA: Any variation leading to unbalanced situations.

Setup Reduction

Setup Reduction
or
Single-Minute Exchange of Die - SMED

- Single-Minute here means less than 10 minutes (single digit), and not 1 minute
- Shigeo Shingo, created the SMED approach

Setup Reduction

Setup Reduction
or
Single-Minute Exchange of Die - SMED

Benefits:

- Reduced inventory
- Even with higher number of turnovers, the machine utilization increases
- Elimination of setup errors
- Reduces defect rates
- Lower setup expenses

Setup Reduction

Setup Reduction
or
Single-Minute Exchange of Die - SMED

- Techniques in implementing SMED.
  - Separate internal from external setup operations
  - Convert internal to external setup
  - Use functional clamps or eliminate fasteners altogether
  - Adopt parallel operations
  - Eliminate adjustments

Setup Reduction

5C
Lean Tools

01 *Waste elimination*

02 *Cycle-time reduction*

03 *Kaizen and Kaizen Blitz*

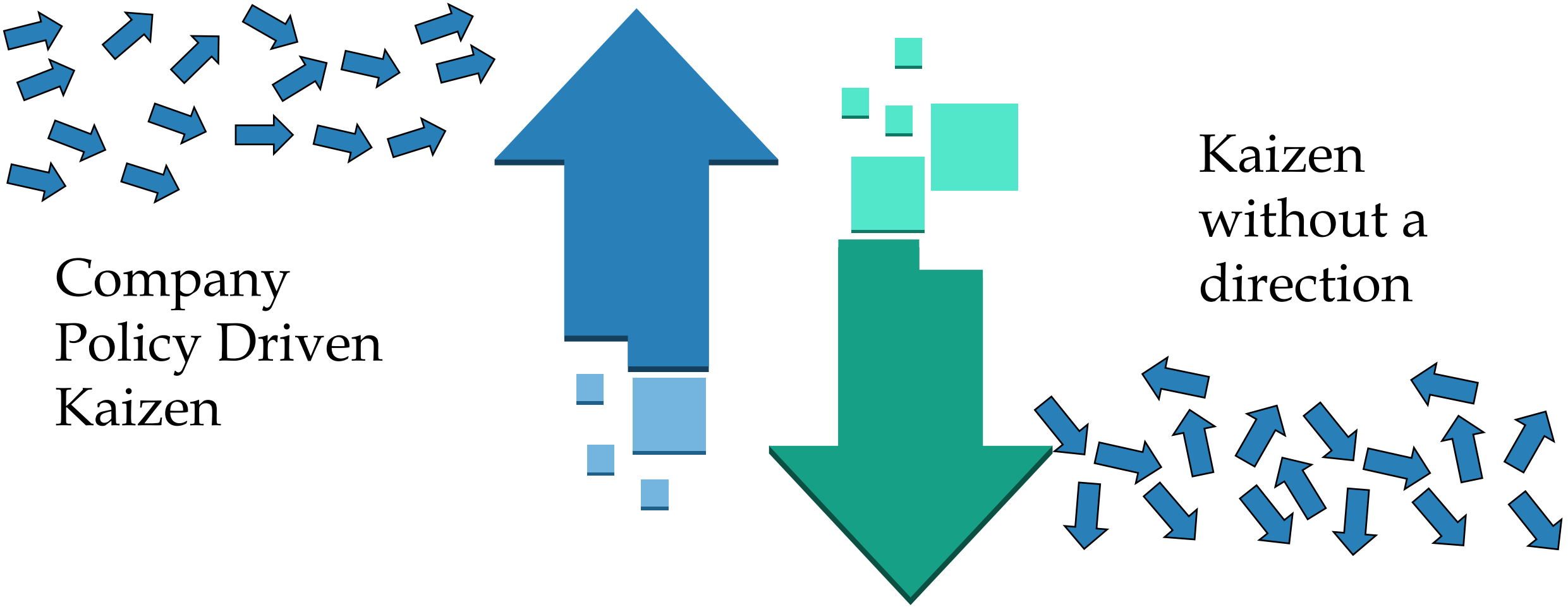
What is Kaizen

An approach for improvement of quality and productivity

KAI ZEN KAIZEN

1970s	**First made popular by Toyota as part of their production system (TPS or Lean Manufacturing) in the 1970s**
1980s	***"Discovered" and described in books in the West starting in the 1980s***

Kaizen Timeline



Kaizen

Business Case

Develop business case to define the discrepancy between customer's expectations and the current processes.

Kaizen

Waste

Reduce waste

Lead Time

Reduce lead time

Inventories

Reduce inventories

Capacity

Increase capacity

Delivery

Increase delivery performance

Bottleneck

Eliminate bottleneck

Down Time

Reduce machine down time

Quality

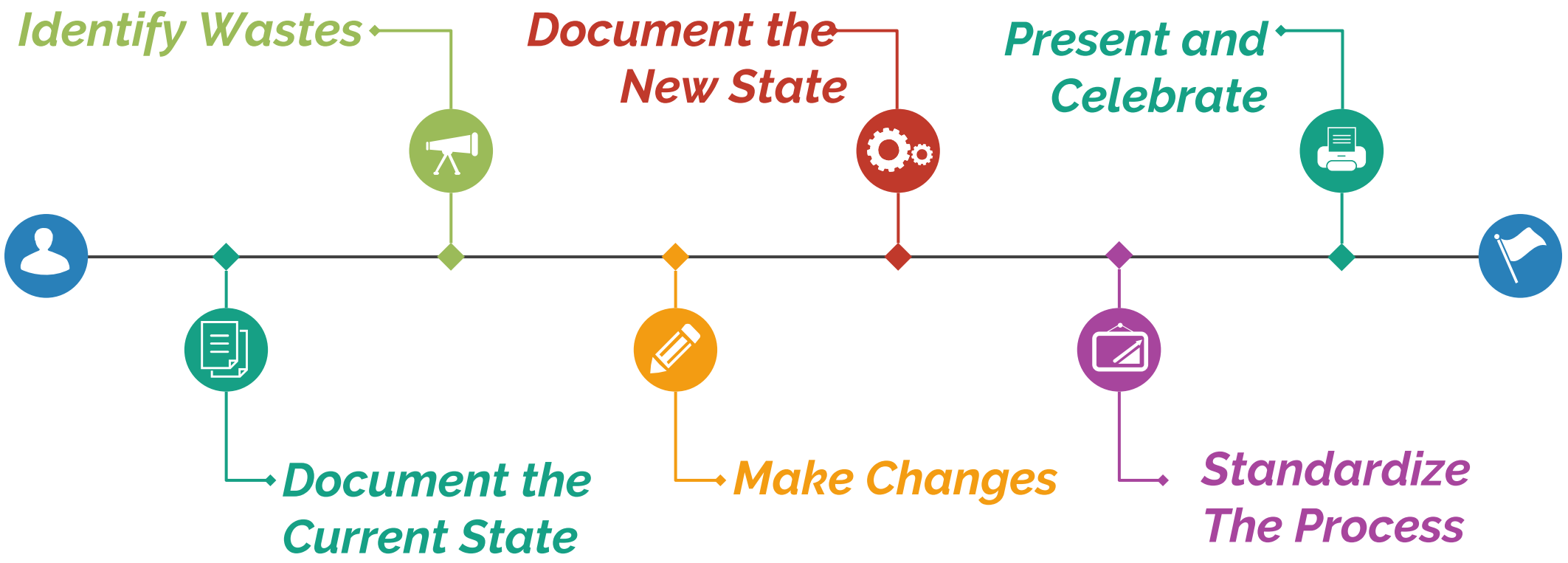
Improve quality

Kaizen – Business Case Examples

Selecting Team for Kaizen Event

- Team size should be based on the area(s) being improved.
- A trained Facilitator and a Team Leader for each Team
- Every team member should be chosen for a specific reason

Kaizen



Kaizen Steps

Kaizen – Key Success Factors

Kaizen Blitz

- A Kaizen Blitz, or rapid improvement, is a focused activity on a particular process or activity.
- The basic concept is to identify and quickly remove waste.

Kaizen Blitz

2022 – Changes in the BoK – 5C

	C. Lean tools	
V.C.1	1. Waste elimination Select and apply tools and techniques for eliminating or preventing waste, including pull systems, kanban, 5S, standard work, and poka-yoke. (Apply)	
V.C.2	2. Cycle-time reduction Use various techniques to reduce cycle time (continuous flow, setup reduction), single-minute exchange of dies (SMED). (Analyze)	Added SMED
V.C.3	3. Kaizen and kaizen blitz Define and distinguish between these two methods and apply them in various situations. (Apply)	

SMED

- For rapid and efficient way of converting a manufacturing process from running the current product to running the next product.
- Also called:
  - Quick Changeover
  - Setup Reduction

SMED

- Single-Minute here means less than 10 minutes (single digit), and not 1 minute
- Shigeo Shingo, created the SMED approach

SMED

- Benefits:
  - Reduced inventory
  - Even with higher number of turnovers, the machine utilization increases
  - Elimination of setup errors
  - Reduces defect rates
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SMED

- Techniques in implementing SMED.
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