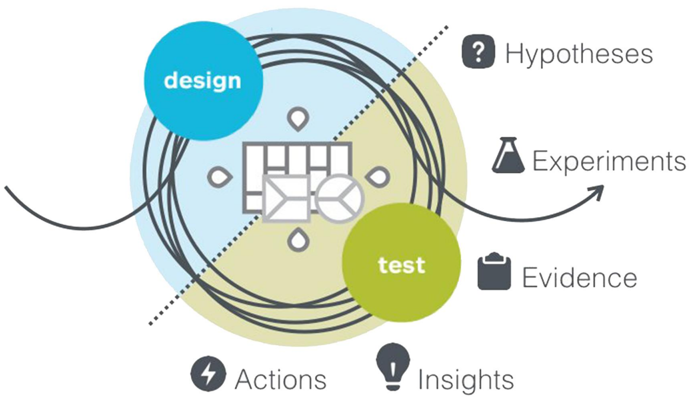


3 Days Online Workshop on

Design of Experiments- An Engineering Perspective

22, 23 & 24th April 2020

jaeronline.com/doeworkshop

ORGANISED BY

JAER

HEXACUBE

DESIGN OF EXPERIMENTS

(DOE)

INTRODUCTION

1. Design of Experiments (DOE) is a statistical technique introduced by Sir R.A. Fisher in England in the early 1920s.
2. His primary goal was to determine the optimum water, rain, sunshine, fertilizer and soil conditions needed to produce the best crop.
3. Using the DOE technique, Fisher was able to lay out all possible combinations, created using a matrix.

INTRODUCTION

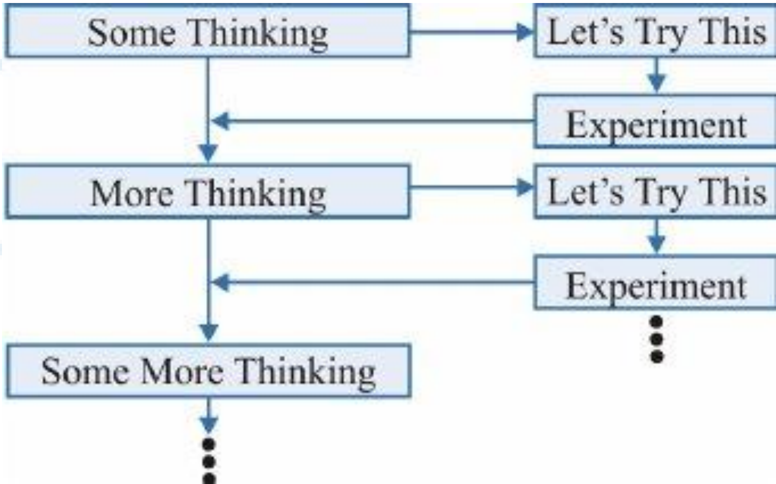
1. DOE is a method of experimenting with complex processes with the objective of optimizing the process.
2. DOE refers to the process of planning, designing and analyzing the experiment so that valid and objective conclusions can be drawn effectively and efficiently.
3. Statistical design of experiments refers to the process of planning the experiment so that appropriate data that can be analyzed by statistical methods will be collected, resulting in valid and objective conclusions.

METHODS of EXPERIMENTATION

1. Trial and Error
2. Single Factor Experiment
    1. One factor to be changed at a time
3. Factorial Experiment Design
    1. Fractional Factorial Experiment
        - change many things at a time with reduced experiments
    2. Full Factorial Experiment
        - change many things at a time
4. Other Designs (Taguchi, RSM, Box-Jenkins etc.)

TRIAL AND ERROR

1. Trial and Error is the most basic form of learning.
2. In some cases, it is as efficient or applicable as any other detailed statistical strategy.
3. Example: Finding the combination of a lock, where previous trials provide no insight in to subsequent trails.



TRIAL AND ERROR

1. Trial and Error Experiments
   1. Lack direction and focus
   2. Guesswork
2. Trial and Error Experiment
   1. How many different permutations exist?
   2. What would happen if we added more variables?

SINGLE FACTOR EXPERIMENT

1. A single factor experiment allows for the manipulation of only one factor during an experiment.
   1. Select one factor and vary it, while holding all other factors constant.
2. The assumption in a single factor experiment is to isolate the changes in the response variable as they relate to the single factor.
3. These types of experiments are:
4. Simple to Analyze

SINGLE FACTOR EXPERIMENT

5. Only one thing changes at a time and you can see what affect that change has on the system.
6. Time Consuming
   1. Changing only one thing at a time can result in dozens of repeated experiments.
   2. Interaction effects between the variables can not be analyzed

Exp. No	Speed	Temperature	Tire Pressure	Chassis Design
1	65	75	32	A
2	70	75	32	A
3	65	75	32	B
4	70	75	32	B
5	65	85	32	A
6	70	85	32	A
7	65	85	32	B
8	70	85	32	B
9	65	75	27	A
10	70	75	27	A
11	65	75	27	B
12	70	75	27	B
13	65	85	27	A
14	70	85	27	A
15	65	85	27	B
16	70	85	27	B

FACTORIAL EXPERIMENT

1. Factorial design involves having more than one independent variable, or factor, in a study.
2. It is widely accepted that the most commonly used experimental designs in manufacturing companies are full and fractional factorial designs at 2-levels and 3-levels.
3. Factorial experiments with two-level factors are used widely because they are easy to design, efficient to run, straight forward to analyze and full of information.

FACTORIAL EXPERIMENT

4. Factorial designs would enable an experimenter to study the joint effect of the factors (or process/design parameters) on a response.
5. A factorial design can be either full or fractional factorial.
6. Studies only a fraction or subset of all the possible combinations.
7. A selected and controlled multiple number of factors are adjusted simultaneously.
   1. This reduces the total number of experiments.
   2. This reveals complex interactions between the factors.
   3. This will reveal which factors are more important than others.

FACTORIAL EXPERIMENT

Runs

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
4	2^{2}	2^{3-1}_{III}																		
8		2^{3}	2^{4-1}_{IV}	2^{5-2}_{III}	2^{6-3}_{III}	2^{7-4}_{III}														
16			2^{4}	2^{5-1}_{V}	2^{6-2}_{IV}	2^{7-3}_{IV}	2^{8-4}_{IV}	2^{9-5}_{III}	2^{10-6}_{III}	2^{11-7}_{III}	2^{12-8}_{III}	2^{13-9}_{III}	2^{14-10}_{III}	2^{15-11}_{III}						
32				2^{5}	2^{6-1}_{VI}	2^{7-2}_{IV}	2^{8-3}_{IV}	2^{9-4}_{IV}	2^{10-5}_{IV}	2^{11-6}_{IV}	2^{12-7}_{IV}	2^{13-8}_{IV}	2^{14-9}_{IV}	2^{15-10}_{IV}	2^{16-11}_{IV}	2^{17-12}_{III}	2^{18-13}_{III}	2^{19-14}_{III}	2^{20-15}_{III}	2^{21-16}_{III}
64					2^{6}	2^{7-1}_{VII}	2^{8-2}_{V}	2^{9-3}_{IV}	2^{10-4}_{IV}	2^{11-5}_{IV}	2^{12-6}_{IV}	2^{13-7}_{IV}	2^{14-8}_{IV}	2^{15-9}_{IV}	2^{16-10}_{IV}	2^{17-11}_{IV}	2^{18-12}_{IV}	2^{19-13}_{IV}	2^{20-14}_{IV}	2^{21-15}_{IV}
128						2^{7}	2^{8-1}_{VIII}	2^{9-2}_{VI}	2^{10-3}_{V}	2^{11-4}_{V}	2^{12-5}_{IV}	2^{13-6}_{IV}	2^{14-7}_{IV}	2^{15-8}_{IV}	2^{16-9}_{IV}	2^{17-10}_{IV}	2^{18-11}_{IV}	2^{19-12}_{IV}	2^{20-13}_{IV}	2^{21-14}_{IV}
256							2^{8}	2^{9-1}_{IX}	2^{10-2}_{VI}	2^{11-3}_{VI}	2^{12-4}_{VI}	2^{13-5}_{V}	2^{14-6}_{V}	2^{15-7}_{V}	2^{16-8}_{V}	2^{17-9}_{V}	2^{18-10}_{IV}	2^{19-11}_{IV}	2^{20-12}_{IV}	2^{21-13}_{IV}
512								2^{9}	2^{10-1}_{X}	2^{11-2}_{VII}	2^{12-3}_{VI}	2^{13-4}_{VI}	2^{14-5}_{VI}	2^{15-6}_{VI}	2^{16-7}_{VI}	2^{17-8}_{VI}	2^{18-9}_{VI}	2^{19-10}_{V}	2^{20-11}_{V}	2^{21-12}_{V}

2 Level Design

FACTORIAL EXPERIMENT

Create Factorial Design: Display Available Designs

Available Factorial Designs (with Resolution)

	Factors													
Run	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
4	Full	III												
8		Full	IV	III	III	III								
16			Full	V	IV	IV	IV	III	III	III	III	III	III	III
32				Full	VI	IV	IV	IV	IV	IV	IV	IV	IV	IV
64					Full	VII	V	IV	IV	IV	IV	IV	IV	IV
128						Full	VIII	VI	V	V	IV	IV	IV	IV

Available Resolution III Plackett-Burman Designs

Factors	Runs	Factors	Runs	Factors	Runs
2-7	12,20,24,28,...,48	20-23	24,28,32,36,...,48	36-39	40,44,48
8-11	12,20,24,28,...,48	24-27	28,32,36,40,44,48	40-43	44,48
12-15	20,24,28,36,...,48	28-31	32,36,40,44,48	44-47	48
16-19	20,24,28,32,...,48	32-35	36,40,44,48		

Help   OK

FULL FACTORIAL EXPERIMENT

1. A full-factorial experiment (FFE) design consists of all possible combinations of all selected levels of the factors to be investigated.
2. A full factorial experiment consists of every combination of the levels of factors in the experiment.
3. Thus, if we have *k* factors, each at two levels, the full factorial consists of

$$\underbrace{2 \times 2 \times \cdots \times 2}_{k} = 2^k$$

FULL FACTORIAL EXPERIMENT

1. Benefits of full factorial design
    1. FFE reveal whether the effect of each factor depends on the levels of other factors in the experiment, showing the interaction effects.
    2. FFE provide excellent precision for the regression model parameter estimates that summarize the combined effects of the factors.
2. Time consuming

FULL FACTORIAL EXPERIMENT

Standard Order	Run Order	A: Brand	B: Time (minutes)	C: Power (percent)	Y_1: Taste (rating)	Y_2: "bullets" (ounces)
2	1	Costly (+)	4 (–)	75 (–)	75	3.5
3	2	Cheap (–)	6 (+)	75 (–)	71	1.6
5	3	Cheap (–)	4 (–)	100 (+)	81	0.7
4	4	Costly (+)	6 (+)	75 (–)	80	1.2
6	5	Costly (+)	4 (–)	100 (+)	77	0.7
8	6	Costly (+)	6 (+)	100 (+)	32	0.3
7	7	Cheap (–)	6 (+)	100 (+)	42	0.5
1	8	Cheap (–)	4 (–)	75 (–)	74	3.1

Run	Score Depth	Speed	Temperature	Belt Tension	Dry Crush Mean
1	High	18	75	65	311.5
2	High	22	145	65	312.4
3	High	18	145	65	271.2
4	Low	22	145	65	365.6
5	Low	18	145	65	335.2
6	Low	18	75	65	315.1
7	Low	18	145	65	329.4
8	Low	22	75	65	353.8
9	High	22	75	65	286.4
10	Low	18	75	65	295.1
11	Low	22	145	65	352.4
12	High	18	75	65	299.5
13	High	18	145	65	280.6
14	High	22	75	65	261.6
15	High	22	145	65	353.2
16	Low	22	75	65	319.0

FRACTIONAL FACTORIAL EXPERIMENT

1. Fractional factorial designs permit investigation of the effects of many factors in fewer runs than a full factorial design.

Factors and levels for electroplating experiment

Factors		Levels −1	Levels 1
A	Temperature (°C)	20	50
B	Current density (A/m^2)	500	2500
C	pH	1	4
D	NaH_2PO_2 concentration (M)	0.5	1
E	Stirring rate (rev/min)	200	400

t.c.	A	B	C	D	E	%P
1	−1	−1	−1	−1	1	0.51
2	1	−1	−1	−1	−1	1.54
3	−1	1	−1	−1	−1	2.38
4	1	1	−1	−1	1	12.20
5	−1	−1	1	−1	−1	5.93
6	1	−1	1	−1	1	5.83
7	−1	1	1	−1	1	2.90
8	1	1	1	−1	−1	4.73
9	−1	−1	−1	1	−1	0.49
10	1	−1	−1	1	1	1.02
11	−1	1	−1	1	1	10.59
12	1	1	−1	1	−1	12.00
13	−1	−1	1	1	1	6.50
14	1	−1	1	1	−1	4.87
15	−1	1	1	1	−1	1.86
16	1	1	1	1	1	4.49

$$2^k = 2^5$$
$$= 2 \times 2 \times 2 \times 2 \times 2$$
$$= 32$$

FRACTIONAL FACTORIAL EXPERIMENT

Std	Run	A: Seat	B: Tires psi	C: Handle Bars	D: Helmet Brand	E: Gear	F: Wheel covers	G: Gener-ator	Time 1/4 mile secs
1	2	Up	40	Up	Windy	Low	Off	Off	77
2	1	Down	40	Up	Atlas	High	Off	On	74
3	4	Up	50	Up	Atlas	Low	On	On	82
4	7	Down	50	Up	Windy	High	On	Off	47
5	6	Up	40	Down	Windy	High	On	On	72
6	3	Down	40	Down	Atlas	Low	On	Off	77
7	8	Up	50	Down	Atlas	High	Off	Off	48
8	5	Down	50	Down	Windy	Low	Off	On	83

EXPERIMENTAL DESIGN

1. The (statistical) design of experiments (DOE) is an efficient procedure for planning experiments so that the data obtained can be analyzed to yield valid and objective conclusions.
2. When performing an experiment, varying the levels of the factors simultaneously rather than one at a time is efficient in terms of time and cost, and also allows for the study of interactions between the factors.
3. Factorial designs allow for the simultaneous study of the effects that several factors may have on a process.

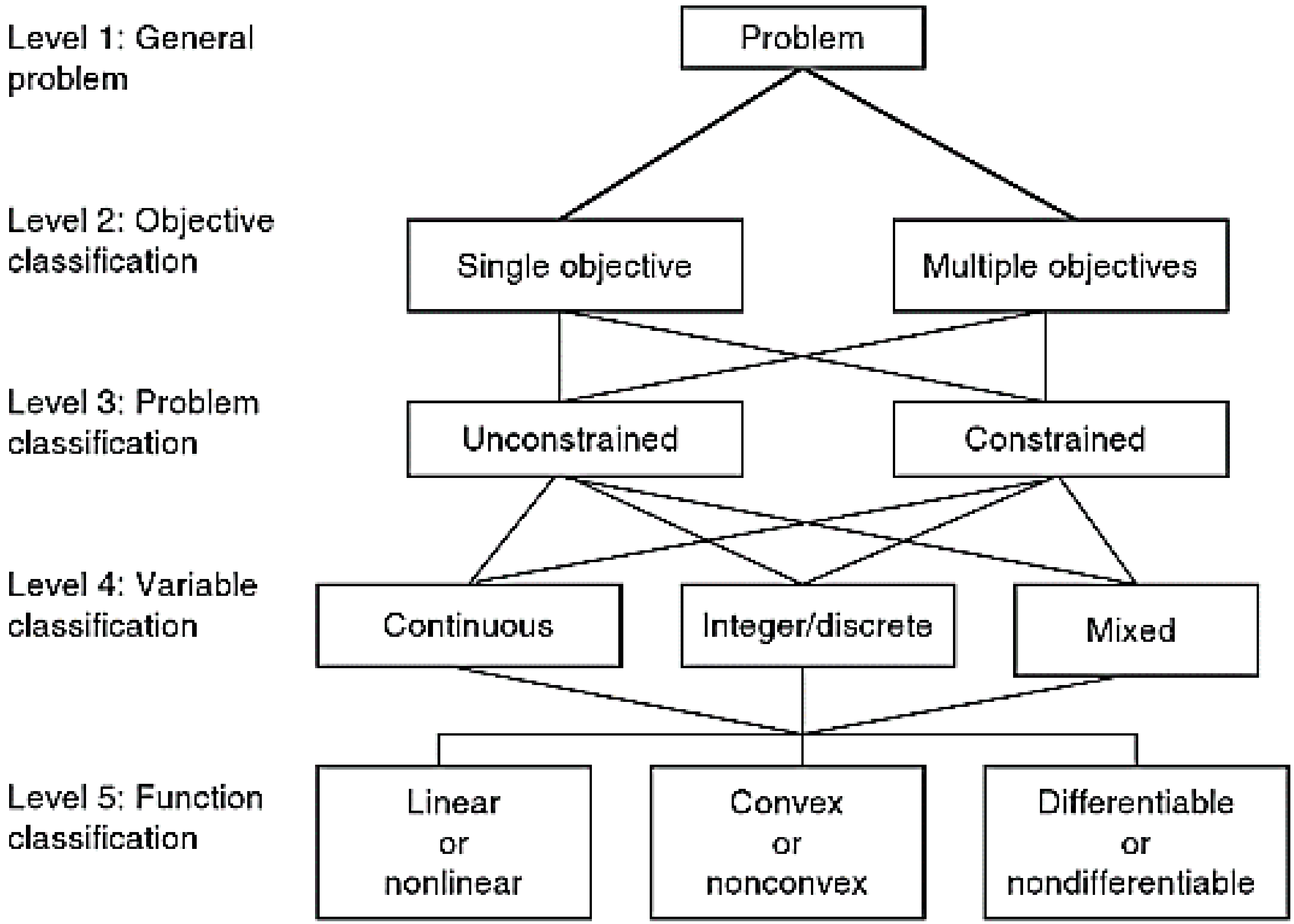
EXPERIMENTAL DESIGN

1. Interactions are the driving force in many processes. Without the use of factorial experiments, important interactions may remain undetected.
2. Experimental Design (or DOE)economically maximizes information

DESIGN OF EXPERIMENTS

1. In order to properly understand a designed experiment, it is essential to have a good understanding of the process.
2. A process is the transformation of inputs into outputs.
3. In the context of manufacturing, inputs are factors or process variables such as people, materials, methods, environment, machines, procedures, etc.
4. The outputs can be performance characteristics or quality characteristics of a product

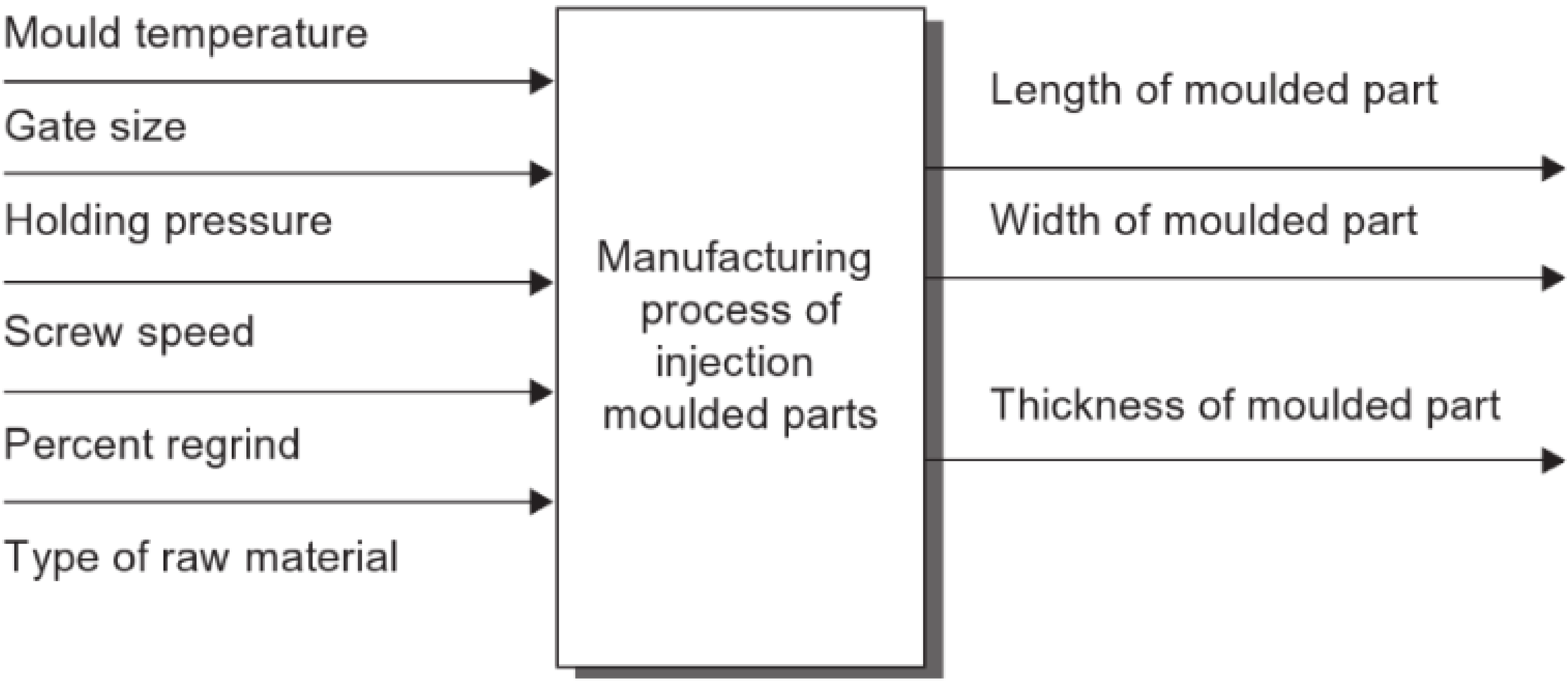
DESIGN OF EXPERIMENTS



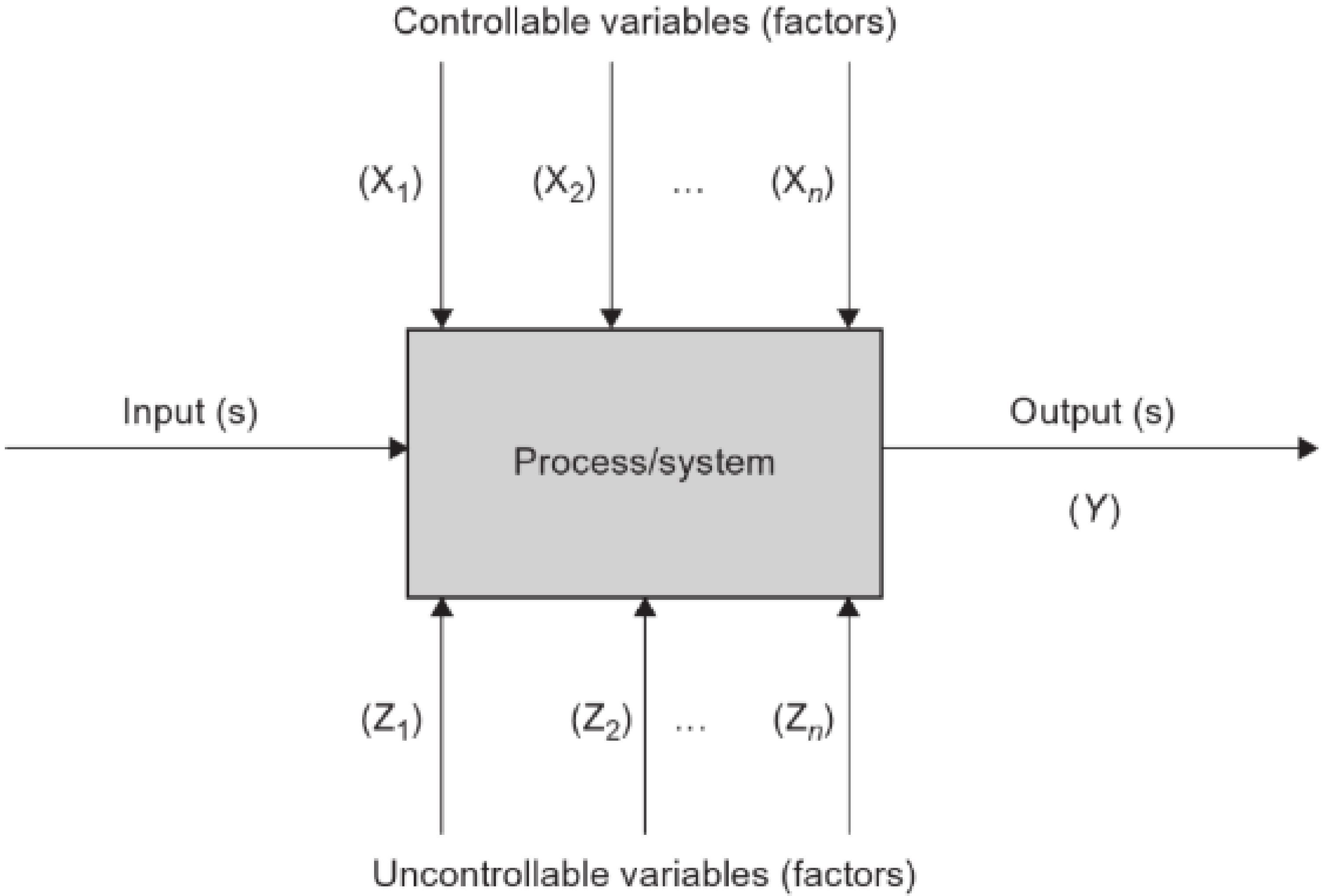
FORMULATION OF PROBLEM

1. Model plays important part in optimization since they provide economic description and clarification of the real system.
2. To develop an optimization model, the process is divided into five major parts.
    1. Data collection
    2. Definition of formulated problem
    3. Development of model
    4. Validation of model and performance evaluation
    5. Application and interpretation of model

FORMULATION OF PROBLEM



FORMULATION OF PROBLEM



FORMULATION OF PROBLEM

1. Controllable variables (represented by X's) can be varied easily during an experiment and such variables have a key role to play in the process characterisation.
2. Uncontrollable variables (represented by Z's) are difficult to control during an experiment.
3. These variables or factors are responsible for variability in product performance or product performance inconsistency

PRINCIPLES OF EXPERIMENTAL DESIGN

1. The three principles of experimental design, used to improve the efficiency of experimentation are:
   1. Randomisation
   2. Replication
   3. Blocking
2. These principles of experimental design are applied to reduce or to remove experimental bias, a larger experimental bias could result in wrong optimal settings.

RANDOMISATION

1. We all live in a non-stationary world, a world in which noise factors (or external disturbances) will never stay still.
2. Randomisation is one of the methods experimenters often rely on to reduce the effect of experimental bias.
3. The purpose of randomisation is to remove all sources of extraneous variation which are not controllable in real-life settings.
4. For instance, the manufacture of a metal part is an operation involving people, where the attitudes of the people who operate the machines vary from time to time.

REPLICATIONS

1. In all industrial designed experiments, some variation is introduced because of the fact that the experimental units such as people, batches of materials, machines, etc. cannot be physically identical.
2. Replication means repetitions of an entire experiment or a portion of it, under more than one condition.
3. Replication has three important properties.
4. The first property is that it allows the experimenter to obtain a more accurate estimate of the experimental error.

REPLICATIONS

1. The second property is that it permits the experimenter to obtain a more precise estimate of the factor/interaction effect.
2. The third property is that replication can decrease the experimental error and thereby increase precision.
3. Replication can result in a substantial increase in the time needed to conduct an experiment.
4. Moreover, if the material is expensive, replication may lead to exorbitant material costs.
5. Many researchers use ‘repetition’ and ‘replication’ interchangeably.

BLOCKING

1. Blocking is a method of eliminating the effects of extraneous variation due to noise factors and thereby improving the efficiency of experimental design.
2. The main objective is to eliminate unwanted sources of variability such as batch-to-batch, day-to-day, shift-to-shift, etc..
3. The idea is to arrange similar or homogenous experimental runs into blocks (or groups).
4. Observations collected under the same experimental conditions (i.e. same day, same shift, etc.) are said to be in the same block.

PROCESS VARIABLE SELECTION

1. Process variables include both inputs and outputs - i.e., factors and responses.
2. The selection of these variables is best done as a team effort.
3. The team should include all important factors (based on engineering judgment).
4. Be bold, but not foolish, in choosing the low and high factor levels.
5. Check the factor settings for impractical or impossible combinations - i.e., very low pressure and very high gas flows.
6. Include all relevant responses.

QUERIES

THANK YOU