IE301 Product Design and innovation
Exercise (7) [Robust Design]

Selected Statistical Revision problem

1- *A company has a filling machine for low-pressure oxygen shells. Data collected over two months show an average weight after filling of 1.433g with standard deviation of 0.033g. The specification for weight is 1.460±0.085g. Weight is normally distributed.*
   a) *What percentage will not meet specification?*
   b) *Would you suggest a shift in the aim of the filling machine? Why or why not?*

2- *A cylindrical grinding machine is used to produce precision shafts from bars. The produced shaft diameters are normally distributed around the mean with σ = 0.005 in.*
   a) *What symmetrical tolerance limits are necessary to have no more than 2% of the bars outside tolerance?*
   b) *If the tolerances on a ground bar are* $3.000^{+0.005}_{-0.010}$ *in, what percentage of the bars will be accepted?*

3- *The yield of a new pilot plant process has a mean of 92.3% and standard deviation of 1.2% based on 10 trial runs.*
   a) *What are 95% confidence limits on this mean?*
   b) *If the mean and standard deviation are the result of many trials (n>100), what are the 95% confidence limits?*
   c) *For the original 10 trial runs, what is the tolerance interval that contains at least 95% of the population with 95% confidence?*
   d) *What is the prediction interval to contain all 10 future observations with 95% probability?*

4- *A manufacturer of needles has a new method of controlling a diameter dimension. From many measurements of the present method, the average diameter is 0.076 cm with a standard deviation of 0.010 cm. A sample of 25 needles from new process shows that the average was 0.071. if smaller diameter is desirable, should the new method be adapted? (Assume the standard deviation of the new method is the same as that for the present method).*

5- *A statistical study was made on the influence of weather conditions (temperature T, wind velocity V) and rail size S on the strength of welded steel rail joints. A* 2^3 *factorial design was conducted at the test conditions given in table (5-1). Duplicate specimens were tested for weld strength at each of these test conditions as shown in the table.*
   a) *Calculate the main effects and the two factors interaction effects.*
   b) *Determine the standard error.*
   c) *Conduct an analysis of variance (ANOVA) table and determine which factors are significant.*
   d) *Establish a regression equation, using response surface methodology.*

Table (5-1)

Std order	*Treatment conditions*			*Weld strength, ksi*	
	T	*V*	*S*	*Specimen 1*	*Specimen 2*
1	*0*	*0*	*0.364*	*84.0*	*91.0*
a	*70*	*0*	0.364	*95.5*	*84.0*
b	*0*	*20*	0.364	*69.6*	*86.0*
ab	*70*	*20*	0.364	*76.0*	*98.0*
c	*0*	*0*	*1.000*	*77.7*	*80.5*
ac	*70*	*0*	*1.000*	*99.7*	*95.4*
bc	*0*	*20*	*1.000*	*82.7*	*74.5*
abc	*70*	*20*	*1.000*	*93.7*	*81.7*

Robust design problems

A) Function loss problems

6- *A cylinder block (width $200^{+0.04}_{-0.00}$ x length $200^{+0.04}_{-0.00}$ x height$250^{+0.00}_{-0.01}$) mm is machined by high speed CNC milling machine. The standard deviation for CNC machine is known from previous production runs to be σ=0.10mm.*

   a) *Assuming that the CNC machine setting for height machining is perfectly between upper and lower tolerance limits to give a mean μ= 249.95, what is the probability of making a part with an out-of-tolerance? Is the tolerance specification within the capability of the CNC machine?*
   b) *Using 6σ approach, what is the percent defect?*
   c) *Determine the ideal process capability index C_p to establish the relation between the tolerance specified for component and the standard deviation for the process.*
   d) *Determine actual process capability index C_{pk}. What is the effect of shift in process mean on defect rate?*

7- *A product has specification limits 120±10MN and a target value of 120MN. The standard deviation of the products coming off the process line is 3MN. The mean value of the strength is initially 118MN, but it shifts to 122MN and then 125MN without any change in variability. Determine the process capability C_p, and C_{pk}.*

8- *A grinding machine is grinding the root of gas turbine blades where they attach to the disk. The critical dimension at the root must be 0.450±0.006 in. thus, a blade falls out of specs in the range 0.444 to 0.456 and has to be scrapped at a cost of $120.*

   a) *What is the Taguchi loss equation for this situation?*
   b) *Samples taken from grinder had the following dimensions: (0.451; 0.446; 0.449;0.456; 0.450, 0.452; 0.449; 0.447; 0.454; 0.453; 0.450; 0.451), what is the average loss function for the parts made on the machine?*

9- *The weather strip that seals the door of an automobile has a specification on width of 20±4mm. Three suppliers of weather strip produced the results shown in table (9-1).*

Table (9-1)

Suppliers	Mean width $\bar{x}$	Variance s^2	C_{pk}
A	20.0	1.778	1.0
B	18.0	0.444	1.0
C	17.2	0.160	1.0

Field experience showed that when the width of the weather is 5mm below the target the seal begin to leak and 50% of the customers will complain and insist that it be replaced at a cost of $60. When the strip width exceeds 25mm door closure becomes difficult and customer will ask to have the weather strip replaced. Historically the three suppliers had the following number of parts out of spec in deliveries of 250,000 parts: (supplier A: 0.27%; supplier B: 0.135%; supplier C: 0.135%)

   a) *Compare the three suppliers on the basis of loss function.*
   b) *Compare the three suppliers in the basis of cost of defective units.*

B) Robust design of experiments

10- *Robust design of experiment is conducted for air cooling system to select the controlling parameters (output temperatures T1, T2, T3) minimizing the cost. The air cooling system is shown in figure (1) and gives the flow of air and water and critical temperatures. The air is cooled first in a pre-cooler, then in a refrigeration unit. Water passes through the condenser of the refrigeration unit then into the pre-cooler and finally to the cooling tower where heat is rejected to the atmosphere.*

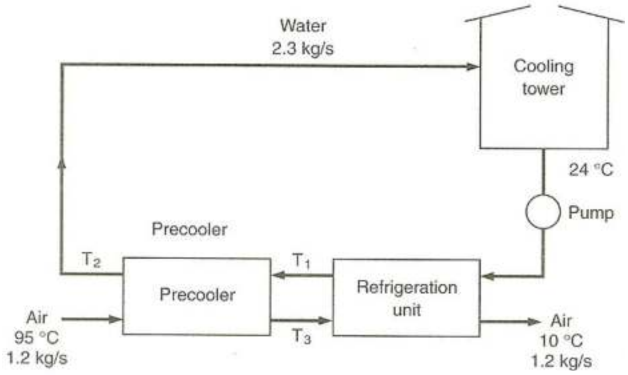

Figure 1 Air Cooling System

The quality characteristic to be observed is the total cost C_T

$$C_T = X_1 + X_2 + X_3$$

Where costs equations are established for design as follow;

$$X_1 = Cost\ of\ refrigeration = 1.2a(T_3 - 10)$$

$$X_2 = Cost\ of\ pre-cooler = 1.2b\frac{(95 - T_3)}{T_3 - T_1}$$

$$X_3 = Cost\ of\ cooling\ tower = 9.637c(T_2 - 24)$$

$$a = 48; b = 50; c = 25$$

Hence, the objective function is to set of design parameters that minimize the total cost C_T subject to the constraints of the mass and energy balances.

The critical noise factors that cannot control or are too expensive to control, are as follow:
N1 = cost parameter for refrigeration unit
N2 = output temperature of water from cooling tower
N3 = input temperature of air into pre-cooler

Therefore, three levels of control parameters and two levels for noise are considered. The choice of test conditions is given in table (10-1).

A) *Select the appropriate orthogonal array for inner and outer arrays.*
B) *If responses of the experiments are given in table (10-2) find:*
   a. *S/N ratio*
   b. *ANOVA*
   c. *The significance of the factors*
   d. *The optimum selection for the control parameters*

Table (10-1)

Control factor levels				Noise factor levels		
	1	2	3		1	2
T_1	25	28	31	N_1	48	56
T_2	36	39	42	N_2	24	27
T_3	35	38	41	N_3	95	100

Table (10-2) Responses y_{ij}

1	4691	3998	4961	4208
2	5489	4790	5782	5036
3	6325	5621	6641	5899
4	4926	4226	5247	4501
5	5568	4888	5851	5086
6	6291	5598	6590	5838

11- *Part of the pollution control system of an automobile engine consists of a nylon tube inserted in a flexible elastomeric connector. The tubes had been coming loose, so an experimental program was undertaken to improve the robustness of the design. The effectiveness of the design was measured by the pounds of forces needed to pull the nylon tube out of the connector. The control factors of this design were:*

A_ interference between the nylon tube and the elastomeric connector
B_ wall thickness of the elastomeric connector
C_ depth of insertion of the tube in the connector
D_ the percent, by volume, of adhesive in the connector predip

The environmental noise factors that conceivably could affect the strength of the bond had to do with the conditions of the predip that the end of the connector was immersed in before the tube was inserted, there were three:

X_ time the predip was in the pot	*24h*	*120hr*
Y_ temperature of the predip	*72F^0*	*150F^0*
Z_ relative humidity	*25%*	*75%*

(a) Set up orthogonal arrays for the inner and the outer array. How many runs will be required to complete the tests?

(b) The S/N ratio for the nine experimental conditions of the control matrix are, in order:

(1) 24.02; (2) 25.52; (3) 25.33; (4) 25.90; (5) 26.90; (6) 25.32; (7) 25.71; (8) 24.83; (9) 26.15

What type of S/N ratio should be used? What do you learn from these results?

12- *A microprocessor company is having difficulty with its current yields. Silicon processors are made on a large die, cut into pieces, and each one is tested to match specifications. The company has requested that you run experiments to increase processor yield. The factors that affect processor yields are temperature, pressure, doping amount, and deposition rate.*

a) Determine the Taguchi experimental design orthogonal array. The operating conditions for each parameter and level are listed in table (12-1):

Table (12-1) Control factor levels

	1	2 (current value)	3
(A)Temperature, ^{0}C	100	150	200
(B) Pressure, psi	2	5	8
(C)Doping Amount,%	35	38	41
(D) Deposition Rate, mg/s	0.1	0.2	0.3

b) Conducting three trials for each experiment, the data given in table (12-2) was collected. Compute the SN ratio for each experiment for the target value case, create a response chart, and determine the parameters that have the highest and lowest effect on the processor yield.

Table (12-2)

Experiment Number	Temperature	Pressure	Doping Amount	Deposition Rate	Trial 1	Trial 2	Trial 3	Mean
1	100	2	4	0.1	87.3	82.3	70.7	80.1
2	100	5	6	0.2	74.8	70.7	63.2	69.6
3	100	8	8	0.3	56.5	54.9	45.7	52.1
4	150	2	6	0.3	79.8	78.2	62.3	73.4
5	150	5	8	0.1	77.3	76.5	54.9	69.3
6	150	8	4	0.2	89	87.3	83.2	86.5
7	200	2	8	0.2	64.8	62.3	55.7	60.9
8	200	5	4	0.3	99	93.2	87.3	93.2
9	200	8	6	0.1	75.7	74	63.2	71