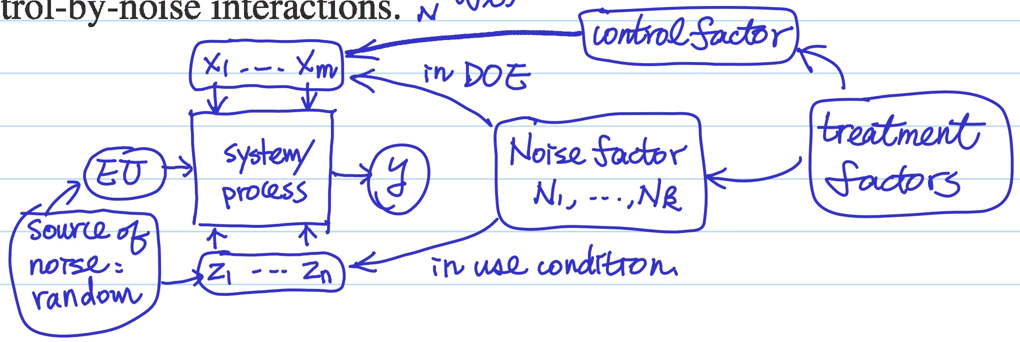
Robust Parameter Design

- Statistical/engineering method for product/process improvement (G. Taguchi).
- Two types of factors in a system (product/process):
  - control factors: once chosen, values remain fixed.
  - noise factors: hard-to-control during normal process or usage.
- **Robust Parameter design** (**RPD** or **PD**): choose control factor settings to make response less sensitive (i.e.more robust) to noise variation; exploiting control-by-noise interactions.



A Robust Design Perspective of Layer-growth and Leaf Spring Experiments

- The original AT & T layer growth experiment had 8 control factors, 2 noise factors (location and facet). Goal was to achieve *uniform* thickness around 14.5 μm over the noise factors. See Tables 1 and 2.
- The original leaf spring experiment had 4 control factors, 1 noise factor (quench oil temperature). The quench oil temperature is not controllable; with efforts it can be set in two ranges of values 130-150, 150-170. Goal is to achieve *uniform* free height around 8 inches over the range of quench oil temperature. See Tables 3 and 4.
- Must understand the role of *noise factors* in achieveing *robustness*.

Layer Growth Experiment: Factors and Levels

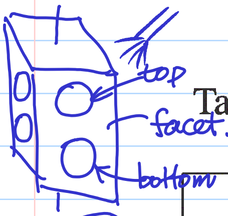


Table 1: Factors and Levels, Layer Growth Experiment

Control Factor		Level −	Level +
A.	susceptor-rotation method	continuous	oscillating
B.	code of wafers	668G4	678D4
C.	deposition temperature(°C)	1210	1220
D.	deposition time	short	long
E.	arsenic flow rate(%)	55	59
F.	hydrochloric acid etch temperature(°C)	1180	1215
G.	hydrochloric acid flow rate(%)	10	14
H.	nozzle position	2	6
Noise Factor		**Level −**	**Level +**
L.	location	bottom	top
M.	facet	1 2	3 4

treatment factors
4 factors discussed in CH4
C.f
all 2 level
Q: Why should they be treated as noise factors?
1 2 level
1 4 level

Layer Growth Experiment: Thickness Data

treated as pure replicates in CH4 & 5

Table 2: Cross Array and Thickness Data, Layer Growth Experiment

a design matrix d_N for noise factor
2×4 full factorial

Control Factor								Noise Factor L-Bottom				L-Top			
A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*M*-1	*M*-2	*M*-3	*M*-4	*M*-1	*M*-2	*M*-3	*M*-4
−	−	−	+	−	−	−	−	14.2908	14.1924	14.2714	14.1876	15.3182	15.4279	15.2657	15.4056
−	−	−	+	+	+	+	+	14.8030	14.7193	14.6960	14.7635	14.9306	14.8954	14.9210	15.1349
−	−	+	−	−	−	+	+	13.8793	13.9213	13.8532	14.0849	14.0121	13.9386	14.2118	14.0789
−	−	+	−	+	+	−	−	13.4054	13.4788	13.5878	13.5167	14.2444	14.2573	14.3951	14.3724
−	+	−	−	−	+	−	+	14.1736	14.0306	14.1398	14.0796	14.1492	14.1654	14.1487	14.2765
−	+	−	−	+	−	+	−	13.2539	13.3338	13.1920	13.4430	14.2204	14.3028	14.2689	14.4104
−	+	+	+	−	+	+	−	14.0623	14.0888	14.1766	14.0528	15.2969	15.5209	15.4200	15.2077
−	+	+	+	+	−	−	+	14.3068	14.4055	14.6780	14.5811	15.0100	15.0618	15.5724	15.4668
+	−	−	−	−	+	+	−	13.7259	13.2934	12.6502	13.2666	14.9039	14.7952	14.1886	14.6254
+	−	−	−	+	−	−	+	13.8953	14.5597	14.4492	13.7064	13.7546	14.3229	14.2224	13.8209
+	−	+	+	−	+	−	+	14.2201	14.3974	15.2757	15.0363	14.1936	14.4295	15.5537	15.2200
+	−	+	+	+	−	+	−	13.5228	13.5828	14.2822	13.8449	14.5640	14.4670	15.2293	15.1099
+	+	−	+	−	−	+	+	14.5335	14.2492	14.6701	15.2799	14.7437	14.1827	14.9695	15.5484
+	+	−	+	+	+	−	−	14.5676	14.0310	13.7099	14.6375	15.8717	15.2239	14.9700	16.0001
+	+	+	−	−	−	−	−	12.9012	12.7071	13.1484	13.8940	14.2537	13.8368	14.1332	15.1681
+	+	+	−	+	+	+	+	13.9532	14.0830	14.1119	13.5963	13.8136	14.0745	14.4813	13.6862

no replicates.

2^{8-4}_{IV} FFD ← a design matrix d_C for control factor

$D=-ABC, F=ABE, G=ACE, H=BCE.$

For A–H, L, M, design matrix $d_C \times d_N$

A — H, L, M

− ⋯ − d_N) 8 run

− ⋯ + d_N) 8 run

16×8 = 128

Leaf Spring Experiment

Table 3: Factors and Levels, Leaf Spring Experiment

	Control Factor	Level −	Level +
B.	high heat temperature (°F)	1840	1880
C.	heating time (seconds)	23	25
D.	transfer time (seconds)	10	12
E.	hold down time (seconds)	2	3
	Noise Factor	**Level −**	**Level +**
Q.	quench oil temperature (°F)	130-150	150-170

Table 4: Cross Array and Height Data, Leaf Spring Experiment

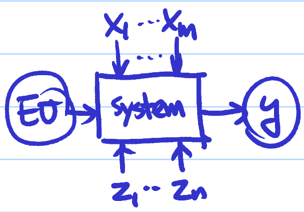
B	C	D	E	Q^-	Q^-	Q^-	Q^+	Q^+	Q^+
−	+	+	−	7.78	7.78	7.81	7.50	7.25	7.12
+	+	+	+	8.15	8.18	7.88	7.88	7.88	7.44
−	−	+	+	7.50	7.56	7.50	7.50	7.56	7.50
+	−	+	−	7.59	7.56	7.75	7.63	7.75	7.56
−	+	−	+	7.94	8.00	7.88	7.32	7.44	7.44
+	+	−	−	7.69	8.09	8.06	7.56	7.69	7.62
−	−	−	−	7.56	7.62	7.44	7.18	7.18	7.25
+	−	−	+	7.56	7.81	7.69	7.81	7.50	7.59

(Control Factor: B, C, D, E; Noise Factor: Q)

- **Reading**: textbook, 11.1

Strategies for Variation Reduction

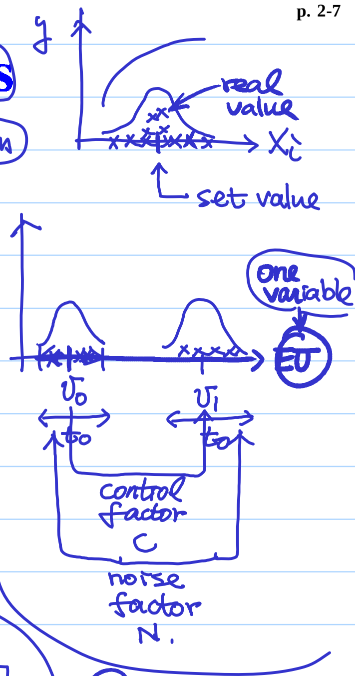
- ***Sampling inspection***: passive, sometimes last resort.
- ***Control charting and process monitoring***: can remove special causes. If the process is stable, it can be *followed* by using a *designed experiment*.
- ***Blocking, covariate adjustment***: passive measures but useful in reducing variability, not for removing root causes.
- ***Reducing variation in noise factors***: effective as it may reduce variation in the response but can be expensive. Better approach is to change control factor settings (*cheaper* and *easier* to do) by exploiting control-by-noise interactions, i.e., use robust parameter design!

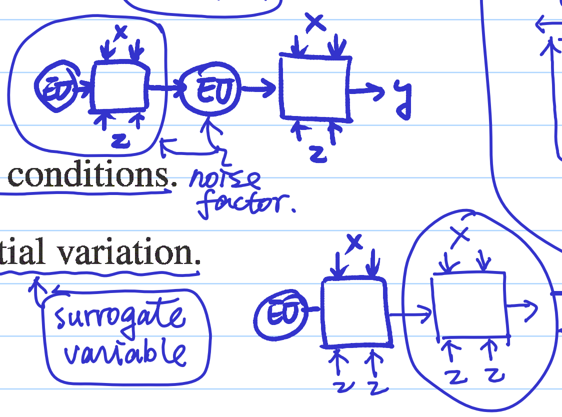


- **Reading**: textbook, 11.2

Types of Noise Factors

1. Variation in process parameters.
2. Variation in product parameters.
3. Environmental variation.
4. Load Factors.
5. Upstream variation.
6. Downstream or user conditions.
7. Unit-to-unit and spatial variation.
8. Variation over time.
9. Degradation.





- **Traditional design uses 7 and 8.**

v Reading: textbook, 11.3

Variation Reduction Through RPD

- Suppose $y = f(x,z)$, x control factors and z noise factors. If x and z interact in their effects on y, then the $var(y)$ can be reduced either by reducing $var(z)$ (i.e. method 4 on p.2-6) or by changing the x values (i.e., RPD).

- An example:

$$
\begin{aligned}
y &= \mu + \alpha x_1 + \beta z + \gamma x_2 z + \varepsilon, \\
  &= \mu + \alpha x_1 + (\beta + \gamma x_2) z + \varepsilon.
\end{aligned}
$$

By choosing an appropriate value of x to reduce the coefficient $\beta + \gamma x_2$, the impact of z on y can be reduced. Since β and γ are unknown, this can be achieved by using the control-by-noise interaction plots or other methods to be presented later.