The inspection report for the SN-ratio optimum prediction accuracy of Taguchi two step design. Is its D grade?

Teruo Mori

The 3rd Pacific Rim Statistical Conference for production Engineering
Dec 13/14 2018 at Taipei Taiwan: National Tsing Hua University

1. Introduction

Robust design has been widely adopted during product design to reduce variation and improve quality. It was proposed by prof Gen-ichi Taguchi [memo] as the optimizing methodology at the1980, and it was composited two steps process. First step is to reduce variation with SN-ratio. Second step is to tune to target. Initially, this methodology was introduced to engineer just following only the procedure like How-to -approach.

It was informed that engineers were supposed to be not required the any statistic knowledge for applying it to their own subjects on design and experiment site.

Therefore, it had been almost spent 30 years without to inspect its accuracy performance grade with case studies on site. Engineers had expecting at least the predicted optimum confirming trail value(b) should be better than the best one(a) of original datasets as the optimizing to tool.

We had surveyed the prediction accuracy performance of Taguchi two step design at engineering design sites. Data bases were the case studies reports of Japanese quality engineering association of 2003-2012. We had collected originally 171 published case studies using the mainly L_{18} orthogonal array with SN ratio from them. We reselected 159 from original dataset of 171 cases to analysis prediction accuracy for Taguchi two step design.

61% optimum trial values(b) could not exceed the best value(a)of SN ratio of the original dataset. So, it might be D grade.

2.Taguchi: two step design process[1]

Taguchi way was two step design to reduce the variation for the researching subject. Engineer will layout to cross array with the control factors to inner array and noise factors to outer array. Let μ and σ^2 are mean and variance of the response. So, SN ratio η will be defined the following

$$\text{SN ratio: } \eta=10\times\log(\mu^2/\sigma^2).$$

We will apply μ and σ^2 for average (y) and sample variance s^2.

$$\text{SN ratio: } \eta=10\times\log(y^2/s^2) \text{ dB}$$

Also, tune will be adapted sensitivity S

$$\text{Sensitivity } S=10\times\log(y^2) \text{ dB}$$

To optimize the engineer subject will be followed under two steps.

Step 1: Select the highest levels of the control factors in the SN ratio main effect chart to maximize η.

Inner array, usually $L_{18}(2^1 3^7)$ will be applied, and outer array noise factor will be compound error N_1,N_2 or orthogonal array . Response were converted for SN ratio (η) and Sensitivity (S) with dB unit.

Then level-average of SN ratio will be plotted as main effect chart. Taguchi was sure that the optimum condition with combination of the highest levels of SN ratio for each control factors at main effect chart will be shown the maximized SN ratio η.

Step 2: Select the level of the tune factor to target with sensitivity S without increasing variation σ^2.

3. Problems at step 1 on Taguchi process

If it was the right/correct which Taguchi described the optimum SN ratio value(b) which were consisted with the highest-level set for the layout factors was better than the highest one (a) of the original datasets.

However, we saw so many the optimum SN ratio value (b) which were lower than the highest one(a) of the original data set.

So, we will show there are the typical two type case at Step 1. Type 1 is a<b, Type 2 is a>b. Table-1 shows the typical case two in data-base 2007 No80 and No47 of the Table 2.

So, we collected to survey the relationship (a) and (b) at the real case studies. Orthogonal arrays were applied for L_{18} with the full layout ABCDEFGH with SN ratio (dB) and sensitivity (dB) as basic condition.

Fig-1 shows the factor effect charts were made with level average of SN ratio. We put round-mark(●) the highest level for each factor. We combined the round -mark(●) level as Taguchi step 1 to be the optimum condition(b). Both outputs of the optimum conditions were shown the lowest column at Table 1.

The optimum output 35.04 of Type 1 was the higher than the highest value 27.90 (No7). However, type2 optimum output 12.65 was the 6th in descending order. There are higher ones: No1,2,9,16,17 with bold letter. The highest of the original dataset is square mark ■ at Fig-2.

Table 1 Two type of Taguchi problems at step 1

Taguchi cases									Type 1		Type 2	
Layout $L_{18}(2^1 3^7)$									a<b[2007-80]*		a>b[2007-47]	
No	A	B	C	D	E	F	G	H	SN	S	SN	S
1	1	1	1	1	1	1	1	1	26.01	**25.01**	**15.66**	-15.09
2	1	1	2	2	2	2	2	2	26.25	27.58	**16.41**	-15.10
3	1	1	3	3	3	3	3	3	10.56	20.64	7.53	-15.10
4	1	2	1	1	2	2	3	3	26.38	27.00	-24.65	-15.34
5	1	2	2	2	3	3	1	1	26.24	27.24	-22.59	-15.27
6	1	2	3	3	1	1	2	2	26.04	26.33	7.44	-15.10
7	1	3	1	2	1	3	2	3	27.90	28.44	-24.00	-15.05
8	1	3	2	3	2	1	3	1	22.76	25.58	11.42	-15.06
9	1	3	3	1	3	2	1	2	25.41	26.19	**14.47**	-15.10
10	2	1	1	3	3	2	2	1	26.19	26.07	10.42	-15.08
11	2	1	2	1	1	3	3	2	25.93	25.93	9.93	-15.00
12	2	1	3	2	2	1	1	3	2.15	9.85	8.67	-15.13
13	2	2	1	2	3	1	3	2	26.37	26.85	7.39	-15.10
14	2	2	2	3	1	2	1	3	25.88	27.02	9.06	-15.12
15	2	2	3	1	2	3	2	1	26.58	26.15	9.80	-15.03
16	2	3	1	3	2	3	1	2	25.91	28.53	**17.34**	-15.12
17	2	3	2	1	3	1	2	3	24.30	26.83	**15.05**	-15.11
18	2	3	3	2	1	2	3	1	24.59	25.39	8.77	-15.09
Optimum Condition									**35.04**	**28.85**	**12.65**	**-15.06**

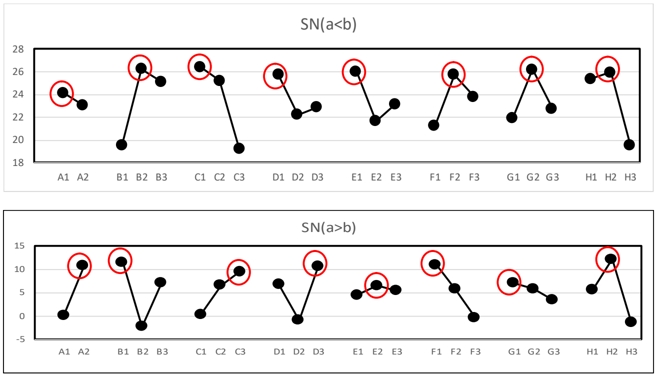


Fig-1 SN ratio to Type-1(upper) and Type-2(lower)

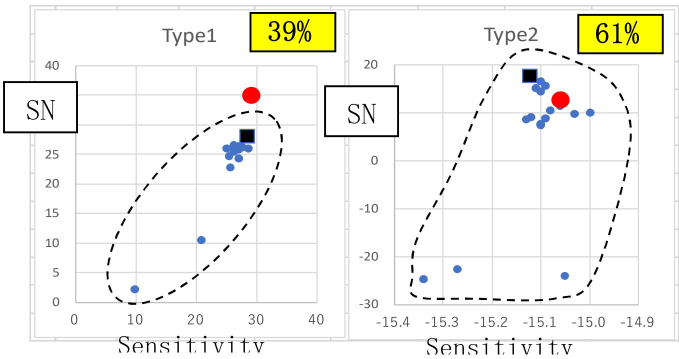


Fig-2 Correlation: Type-1(left), Type-2(right)

Fig-2 shows the correlation charts between the optimum condition output(b)● and the highest one(a)■ in the L_{18} dataset of the dotted circle.

If Taguchi suggestion was right on step 1 at his two-step design, all of optimum condition was upper side of the dotted circled line. Clearly, type 2 was against it, it is a contradiction in Taguchi. Type 1 is 39%, Type 2 is 61% on sites.

4.Data-base for step 1 problems

We have seen a lot of case studies Type2 that the optimum outputs(b) were inside the dotted line at the design and experiment sites at 1980s-2018s.

Taguchi selected and introduced the formal case studies to outside after screening to follow the success cases to support his way which were done at the organization like institute or company or academia until 1980s. People was sure there are potential bias by Taguchi for the content of cases. There were no inconvenient cases as public ones for him.

So, we selected the cases of almost open voluntary applications of the Japanese Quality Engineering association (JQEA) which was established at 1993 to eliminate bias. We selected 10 years cases until 2003 to 2012 for data-base.

Selection criteria are satisfied with

1: The optimum condition
 Select the highest SN ratio
2: Characteristic
 Target, Dynamic, Minimum
3: Orthogonal array
 L_9, L_{18}, L_{27}, L_{36}
4. Missing data
 Out of cases.

Originally 171 case studies were selected as 62% problems[2]. This report just used 159 with eliminating some cases to follow for survey criteria. We will list all of the database[9] to Table 2 for this report.

Table 2 Database 2003-2012

QES2003						a(db)	b(db)	b-a	b-Oder
Conditions						SNratio	SNratio	Differen	
No	Group	Experiment	OA	Data	Analysis	Ex-Best	Optmize	ce	*=a<b
14	Ricoh	Developing	18	Current	Dynamic	-15.32	-19.70	-4.38	5
18	Ricoh	Sensitive paper	18	gray-scale	Dynamic	42.25	43.87	1.62	*
24	Orient	Motor	18	shift-time	Dynamic	128.55	128.36	-0.19	4
25	Takano	pp-resin	18	push-displace	Dynamic	-12.57	-10.32	2.25	*
			18		Dynamic	1.67	5.58	3.91	*
26	Alps	CAE-Switch	18	force-angle	Dynamic	23.20	23.48	0.28	*
28	Takano	Gate System	18	Angle-shift	Dynamic	14.56	15.08	0.52	*
31	Fuji	CAE-Handlig	18	position-curve	Dynamic	21.08	14.07	-7.01	10
34	Ricoh	CAE-Handlig	18	shift-quantity	Target	11.84	11.84	0.00	1
41	Shindengen	Semi-Conductor	18	current-voltage	Dynamic	26.99	29.94	2.95	*
48	Aishin	sintering	18	depth-density	Standard	9.04	8.53	-0.51	3
50	Ricoh	Resin-Extension	18	Angle-shift	Dynamic	11.98	9.01	-2.97	5
67	Orient	Motor	18	voltage-Current	Dynamic	-5.55	-11.83	-6.28	8
69	Mazda	Welging	18	fource-angle	Dynamic	20.96	30.54	9.58	*
78	Isuzu	Holing	18	kw-hour	Dynamic	15.11	17.89	2.78	*
			18		Dynamic	33.10	32.01	-1.09	2
83	Isuzu	Metalfinishing	18	power	Dynamic	31.71	29.99	-1.72	3
84	Epspn	Cutting	18	cutwight-time	Dynamic	9.85	7.91	-1.94	2
87	MORI-seiki	CAE-air	18	flowspeed-quantity	Dynamic	-18.16	-18.23	-0.07	3
88	Mitsuba	Static paint	18	Air pressure-speed	Dynamic	51.28	51.43	0.14	*
102	Matsuura	imageing	18	Positionning	Dynamic	19.67	20.56	0.89	*

No is the register number. Group is the experiment organization. Experiment is the main subject field. OA is orthogonal array size. Data is the analysis for characteristics. * is the case of Type 1. b-Oder is the ranking order to dataset including optimum.

QES2004						a(db)	b(db)	b-a	b-Oder
Conditions						SNratio	SNratio	Differen	
No	Group	Experiment	OA	Data	Analysis	Ex-Best	Optmize	ce	*=a<b
4	Ricoh	Painting	18	floespeed	Standard	66.30	66.30	0.00	1
6	Mitsuba	painting	18	pressure	Standard	43.30	39.05	-4.25	8
13	IHI	Plating	18	plate wight	Dynamic	28.66	24.21	-4.45	2
15	TokaiRika	Painting	18	Coat weight	Dynamic	16.20	16.00	-0.20	2
16	Mitsuba	Static-painting	18	Thickness	Dynamic	28.10	27.70	-0.40	2
18	テラル	powder painting	18	voltage-time	Dynamic	25.20	17.00	-8.20	6
19	Alps	Soldering	18	Deffect	Dynamic	76.34	74.46	-1.88	6
24	Mori	Clamp	18	Binding	Target	11.45	11.45	0.00	1
25	MORI	Structure(*]	18	Distance	Dynamic	58.99	61.00	**2.01**	*
33	TokaiRika	Drilling	18	Power-cutting	Dynamic	28.05	26.28	-1.77	4
			18		Dynamic	21.87	17.90	-3.97	9
34	Ryobi	Cutting	18	Power-cutting	Dynamic	-9.92	-12.22	-2.30	5
			18		Dynamic	9.90	9.86	-0.04	2
37	Toyama	Cutting	18	Power-time	Dynamic	38.03	36.18	-1.85	2
60	Nissan	Steering	18	Speed-torque	Dynamic	39.95	38.01	-1.94	7
61	Sekisui	Molding	18	stable-time	Dynamic	-1.88	0.00	**1.88**	*
			18		Dynamic	-0.86	-0.58	**0.29**	*
62	Ryobi	Casting	18	Transform	Dynamic	25.79	20.45	-5.34	2
70	Sanaroi	Forging	18	Chemical reaction	Dynamic	43.99	40.44	-3.55	10
73	Xerox	Develping	18	Voltage-tonner	Standard	41.65	42.37	**0.72**	*

QES2005						a(db)	b(db)	b-a	b-Oder
Conditions						SNratio	SNratio	Differen	
No	Group	Experiment	OA	Data	Analysis	Ex-Best	Optmize	ce	*=a<b
12	Alps	CMOS	18	Ope-amp	Dynamic	71.17	71.74	**0.57**	*
16	Alps	High-frequency	18	part	Dynamic	63.3	59.17	-4.13	3
20	Sekisui	Production	18	dia	Dynamic	54.37	54.94	**0.57**	*
			18		Dynamic	28.5	28.85	**0.35**	*
21	Toa-chem	painting	18	Weight-Curve	Dynamic	56.3	56.6	**0.3**	*
22	Sekisui	Molding	18	Thick-time	Dynamic	33.52	23.64	-9.88	16
23	Mitsuba	Metalfinishing	18	Vent-position	Dynamic	8.08	9.64	**1.56**	*
24	Toukairika	Mgfinishing	18	die-cast	Min	-18.56	-17.66	**0.9**	*
26	Nissei	Molding	18	tighitning	Target	21.54	21.01	-0.53	3
27	Asahkasei	Dyalyzer	18	Housing	Target	21.39	18.44	-2.95	7
			18			28.85	28.86	**0.01**	*
			18			36.66	38.86	**2.2**	*
31	Nissei	Molding	18	weight-taime	Dynamic	24.76	17.6	-7.16	10
65	Sekisui	Addhessive	18	time-viscosity	Dynamic	3.8	0.79	-3.01	3
67	Toacemi	Concreate	18	Square-power	Dynamic	-3.8	-3.2	**0.6**	*
86	Mitsubishi	Motor	18	Noise	Target	50.75	51.84	**1.09**	*
93	Ryoubi	Bearing	18	Press	Standard	19.94	23.4	**3.46**	*
95	Ryobi	Cut	18	Power-cutwight	Dynamic	11.6	1.23	-10.37	7
			18		Dynamic	38.17	34.27	-3.9	2
97	Gunma	Casing	18	dimension	Dynamic	27.73	26.57	-1.16	3
99	Noritake	Cut	18	Power-cutwight	Dynamic	4.651	4.885	**0.234**	*
			18		Dynamic	4.903	4.797	-0.106	2
101	Mazda	Cleaning	18	Brushing	Dynamic	24.37	24.21	-0.16	2
109	Ricoh	powder paint	18	dimension-time	Dynamic	41.38	43.65	**2.27**	*

QES2006						a(db)	b(db)	b-a	b-Oder
Conditions						SNratio	SNratio	Differen	
No	Group	Experiment	OA	Data	Analysis	Ex-Best	Optmize	ce	*=a<b
14	Mitsubishi	Gear	18	Gear	Standard	40.12	39.36	-0.76	2
15	Gunma	Vibration	18	vibration	Dynamic	9.54	9.3	-0.24	2
17	Nissei	Tie-bar nut	18	Curve	Dynamic	-26.36	-28.99	-2.63	6
18	Maruyama	Brower	18	Airspeed	Target	12.5	11.3	-1.20	4
19	Mitsubishi	Espak-finish	18	dimension	Standard	80.3	79.8	-0.50	3
23	Isuzu	Blowspeed	18	condensor	Standard	11.74	9.95	-1.79	4
24	Alps	Lazer -add	18	welding	Dynamic	-33.66	-35.87	-2.21	7
25	Sekisui	tubewelding	18	Arc-weld	Dynamic	-19.47	-20.18	-0.71	3
29	Shizuoka	Add-almi	18	Epoxy	Dynamic	15.76	7.9	-7.86	3
30	Shizuoka	Add-copper	18	Epoxy	Dynamic	7.09	5	-2.09	3
31	Shizuoka	Supersonic	18	Welding	Dynamic	4.52	0.74	-3.78	3
33	NEC	Heat-add	18	forse-dim	Dynamic	21.9	21.2	-0.70	2
			18	forse-dim	Average	9.82	9.78	-0.04	2
40	Nissei	sliding	18	power-gap	Dynamic	6.6	5.38	-1.22	2
51	Alpine	Surbo-mech	18	res-wave	Standard	100.21	100.54	**0.33**	*
			27	res-wave	Standard	103.77	103.93	**0.16**	*
58	Mazda	Spline	18	package qty	Standard	4.67	-2.69	-7.36	6
59	Isuzu	Welding	18	welght-dimenssion	Dynamic	-5.26	-8.1	-2.84	2
85	Sunalloy	Ally-finish	18	wight-abrasion	Dynamic	32.35	31.4	-0.95	2
			18	weight-trace	Dynamic	36.4	35.3	-1.10	4
88	Ryoubi	Spraying	18	Volume-dimension	Dynamic	47.87	45.5	-2.37	2
89	Alpine	Screw	18	torqu-angle	Dynamic	32.46	22.34	-10.12	14
91	MORI	vibration	18	dimension	Target	-28.717	-27.616	**1.10**	*
92	Isuzu	Collision	18	accelarate	Standard	42.83	42.95	**0.12**	*
			18			22.84	18.78	-4.06	3
94	Denki-Uni	Cutting	18	power-cut	Dynamic	46.2	46.9	0.70	*
95	Mitsubishi	Lamp-vib	18	Integ-Vib	Dynamic	47.4	51.4	4.00	*
114	Kao	Sullary	18	separation	Dynamic	8.29	25.59	17.30	*
119	Nisan	Compo	18	colure	Dynamic	-13	-14.69	-1.69	2
121	Isuzu	Material	18	forse-expand	Standard	79.94	71.91	-8.03	2
122	Isuzu	Material	18	forse-expand	Dynamic	-0.81	-9.27	-8.46	7
124	Alps	Semi-con	18	Etching	Dynamic	61.78	61.98	**0.20**	*
125	Sanpo	Touhu	18	viscosity-time	Dynamic	-0.334	-0.449	-0.12	2

QES2007						a(db)	b(db)	b-a	b-Oder
Conditions						SNratio	SNratio	Differen	
No	Group	Experiment	OA	Data	Analysis	Ex-Best	Optmize	ce	*=a<b
11	Shizuoka	Sonic connect	18	weight	Dynamic	4.19	2.05	-2.14	2
15	Ryobi	Drilling	18	Drilweight-power	Dynamic	12.76	12.26	-0.5	2
			18		Dynamic	-12.65	-15.29	-2.64	6
43	Toa	light-adhesive	18	dim-Temp	Standard	35.6	35.6	0	1
45	Mazda	Die design	18	weight	Dynamic	-37.47	-43.12	-5.65	4
47	imetal	Die design	18	Uniformity	Dynamic	15.66	12.65	-3.01	6
48	Toa	Resin	18	colore	Standard	58.38	60.11	**1.73**	*
51	e-Charging	e-photo	9	charging	Standard	23.12	23.67	**0.55**	*
80	IwateUniv	Reduc-effice	18	Reduc-device	Dynamic	27.902	35.04	**7.138**	*
84	Toyama	Lubricant	18	Fretting	Dynamic	57.79	61.2	**3.41**	*
99	Gunma	Molding	18	dimmension	Dynamic	34.31	30.27	-4.04	8
102	Hitachi	Powder metal	18	molding	Dynamic	24.89	24.08	-0.81	6

QES2008						a(db)	b(db)	b-a	b-Oder
Conditions						SNratio	SNratio	Differen	
No	Group	Experiment	OA	Data	Analysis	Ex-Best	Optmize	ce	*=a<b
3	Alps	Welding	36	dimmension	Dynamic	77.19	78.18	**0.99**	*
7	Alps	Handling	18	Distance	Dynamic	0.00	0.00	0.00	2
12	Alpine	Measure	18	Press-change	Dynamic	29.43	32	**2.57**	*
13	Konica	Measure	18	Length	Dynamic	9.59	8.8	-0.79	3
19	Toyama	Machine	18	Speed	Dynamic	66.02	66.85	**0.83**	*
31	kagoshima	Lazer	18	Melting	Dynamic	10.45	17.57	**7.12**	*
37	Gunma	CAD mold	18	Molding	Target	3.8128	2.79	-1.023	4
44	Shizuoka	Sonic connect	18	Strength	Dynamic	7.242	6.345	-0.897	4
45	Alpine	Soldering	18	Resistance	Dynamic	2.58	-10.73	-13.31	19
46	Shizuoka	Connect	18	Strength	Dynamic	11.59	11.63	**0.04**	*
48	Alps	die-bond	18	Strength	Dynamic	13.4	15.34	**1.94**	*
50	Konica	handling	18	Speed	Target	29.09	27.68	-1.41	3
51	Fijinon	CAE-handle	36	Accuracy	Dynamic	34.59	31.76	-2.83	18
80	Kagoshima	Water-heli	18	Time	Dynamic	19.3	22.81	**3.51**	*
90	Kao	Measure	18	Uniformity	Dynamic	23.48	24.53	**1.05**	*
93	Shizuoka	AntiWet	18	Water Qty	Dynamic	7.33	8.77	**1.44**	*
147	Nikon	Coolong	18	Speed	Dynamic	13.29	11.48	-1.81	2

QES2009						a(db)	b(db)	b-a	b-Oder
Conditions						SNratio	SNratio	Differen	
No	Group	Experiment	OA	Data	Analysis	Ex-Best	Optmize	ce	*=a<b
11	Shizuoka	Conneting	18	Strength	Dynamic	2.17	12.08	9.91	*
20	Toa	Compound	18	Emission	Dynamic	30.28	26.4	-3.88	2
24	Nitsubishi	Wiper	18	Speed	Dynamic	17.75	14.97	-2.78	13
64	Aishin	Compuressor	18	Out Qty	Dynamic	15.3	14.55	-0.75	4
87	Toa	Semicom	18	Change	Dynamic	-19.9	-23.5	-3.60	2
92	Gunma	Molding	18	Dimension	Dynamic	13.13	12.92	-0.21	2
93	Ichiko	Molding	18	Dimension	Dynamic	19.03	19.03	0.00	1

QES2010						a(db)	b(db)	b-a	b-Oder
Conditions						SNratio	SNratio	Differen	
No	Group	Experiment	OA	Data	Analysis	Ex-Best	Optmize	ce	*=a<b
8	Mzda	Welding	18	Current	Dynamic	41.84	42.06	**0.22**	*
16	Mitsubishi	Control	18	quntity	Dynamic	48.82	49.75	**0.93**	*
			18		Dynamic	38.41	39.34	**0.93**	*
			18		Dynamic	25.26	25.81	**0.55**	*
31	Shizuoka	Adhesive	18	Strength	Dynamic	22.279	21.25	-1.03	2
32	Shizuoka	Adhesive	18	Strength	Dynamic	17.59	2.87	-14.72	5
33	Shizuoka	Adhesive	18	Strength	Dynamic	9.33	4.7	-4.63	3
42	Sunalloy	Poder	18	Time	Dynamic	36.67	35.87	-0.80	2
50	Gunma	Molding	18	Thickness	Target	18.74	18.74	0.00	1
55	Mazda	Assenmbly	18	Change	Dynamic	-8.71	-6.74	**1.97**	*
58	Toyama	Light	18	Iluminant	Dynamic	82.1	81.76	-0.34	2
67	Alps	Bracket	18	Strength	Dynamic	-27.1	-26.89	**0.21**	*
79	Alps	Jig	18	Torque	Dynamic	-12.3	-14.4	-2.10	2
90	Toyama	light	18	Iluminant	Dynamic	47.88	48.56	**0.68**	*

QES2011						a(db)	b(db)	b-a	b-Oder
Conditions						SNratio	SNratio	Differen	
No	Group	Experiment	OA	Data	Analysis	Ex-Best	Optmize	ce	*=a<b
21	Cannon	Paper handle	18	Time-length	Dynamic	57.5	57.16	-0.34	3
29	Konica	Blast	18	Surface squre	Target	23.3	22.44	-0.86	6
77	Toyama	Flow system	18	Gel ratio	Dynamic	40.6	41.697	**1.10**	*
84	Konica	Measure	18	Surface squre	Dynamic	9.68	14.43	**4.75**	*
87	Toa	Paint	18	Diffusion qty	Dynamic	25.4	25.2	-0.20	2
88	Maruyama	Pump	18	Output	Dynamic	17.3	16.97	-0.33	3
96	Rikoh	Paint	18	Thicness	Dynamic	10.01	0.59	-9.42	9

QES2012						a(db)	b(db)	b-a	b-Oder
Conditions						SNratio	SNratio	Differen	
No	Group	Experiment	OA	Data	Analysis	Ex-Best	Optmize	ce	*=a<b
34	Canon	Paper handling	18	Time	Target	26.68	16.16	-10.52	18
			18		Standard	35.75	36.03	**0.28**	*
46	Toyama	Illuminant	18	lightness	Dynamic	30.77	33.7	**2.93**	*
88	Konica	Processing	18	light-strength	Dynamic	-28.17	-25.75	**2.42**	*

Table 3 shows the totaling results, type1 was 39%, Type2 was 61%. There was just 1% difference compared to original [14]. It will be reached the same conclusion.

Table 3 Totaling result

QES	全体	Type1	Type2
2003	21	10	11
2004	20	4	16
2005	24	13	11
2006	33	9	24
2007	12	4	8
2008	17	9	8
2009	7	1	6
2010	14	7	7
2011	7	2	5
2012	4	3	1
計	159	62	97
%	100%	39.0	61.0

If Taguchi suggestion is right on step 1 at his two steps design, type 1 at Table 3 should be 100%. So, Taguchi two step design using SN ratio and sensitivity, it might be D grade. Engineers are very difficult to use it at design and experiment site. Because it is too poor prediction accuracy as optimizing tool for engineers to apply for their subjects.

5. The three reasons for D grade

Taguchi two step design had been introduced in USA that engineer will not need to ask/think "why reason" for optimizing mechanism", just do it.

We realized the something wrong at Taguchi two step design at 2008[3], because there were so many cases that optimum outputs(b) were lower than the highest value(a) of L_{18} dataset.

We identified the some of reasons for it. We will introduce the main three reasons.

5.1. Problem on layout alternate columns to L_{18}

We will show the problem with OTL Circuit (Fig3) which was introduced at chapter 11 by Subir Ghosh[4]. Its purpose is to reduce variation.

Fig-3 was eliminated outside DC power and input alternative current and $Vbe_1=Vbe_3=0.65V$, $Vbe_2=0.74V$, $Ec=12V$ was fixed. We will use CAE simulation and target Vm=6.

5.1.1. Formula of OTL circuit and factors [8]

Formula of Fig3: OTL circuit was the following with target Vm=6V.

$$V_m = (V_{b1}+V_{be1})\frac{\beta R_0}{\beta R_0 + R_f} + (E_c - V_{be3})\frac{R_f}{\beta R_0 + R_f} + \frac{V_{be2} R_f \beta R_0}{(\beta R_0 + R_f)R_{c1}} \quad (2)$$

$Rb_1, Rb_2, Rf, Rc_1, Rc_2$ were resistance and β is current gain. Constants are following.

$V_{b1}=E_C \cdot R_{b2}/(R_{b1}+R_{b2}):R_c=R_{c2}+R_L$

$V_{be1}=V_{be3}=0.65V$, $Vbe_2=0.74V$, $Ec=12V$

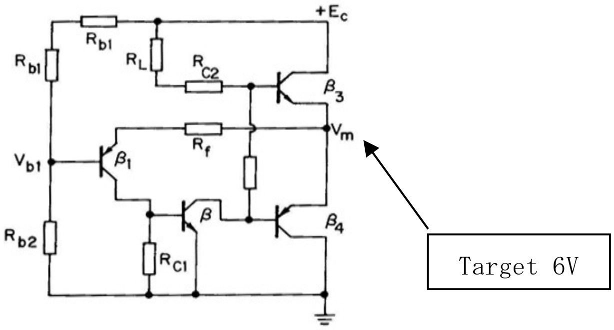


Fig-3 OTL circuit and Target 6V

Table 4 Factors and Levels

Factor	A:ˆRb2 ／Rb1		B:Rf		C:Rc2		D:Rc1		E:β	
Level	1	0.215	1	120.00	1	42.00	1	170.0	1	14
	2	0.600	2	1200.00	2	420.00	2	1700.0	2	140
	3	1.000	3	12000.00	3	4200.00	3	17000.0	3	1400

5.1.2. 6 types Layout ABCDE to L_{18}

L_{18} has 7 factors with three levels. Table 4 has 5 factors, so We selected 6 type layout to L_{18}. 5 factors ABCDE were arranged like the following:①②③④⑤⑥.

① : 23456 ② : 24567 ③ : 25678
④ : 34567 ⑤ : 35678 ⑥ : 45678
[Number is column position in L_{18}]

Table 5 shows the layout and SN ratio.

Table 5 ABCDE arrange column

No	Layout ABCDE to L_{18}					
	23456	24567	25678	34567	35678	45678
	①	②	③	④	⑤	⑥
1	26.60	26.60	26.60	26.60	26.60	26.59
2	26.58	26.58	26.58	27.54	27.54	27.54
3	26.33	26.33	26.33	28.81	28.81	28.81
4	27.11	26.83	26.86	25.68	25.73	25.73
5	26.86	27.16	20.13	27.16	20.13	20.13
6	20.13	22.57	27.11	22.69	28.68	28.68
7	28.79	30.05	28.45	26.44	25.67	26.83
8	29.01	19.59	34.76	19.37	32.46	34.76
9	35.08	28.48	20.34	28.48	20.34	19.75
10	25.54	22.10	31.30	22.10	31.30	34.34
11	22.07	25.59	25.54	26.78	26.75	25.54
12	31.30	23.61	22.07	26.47	25.04	23.95
13	27.09	23.81	32.79	21.91	29.63	32.79
14	23.83	48.69	27.29	48.69	27.29	28.79
15	25.17	26.79	27.55	28.42	29.01	26.58
16	28.45	35.56	24.92	30.03	21.93	24.92
17	34.76	28.79	26.25	27.29	25.17	23.37
18	20.34	28.97	28.67	28.97	28.67	27.09

Fig 4 showed factor effect chart of ①-⑥.Factor C, E are almost same, but A, B, D are different pattern. Optimum condition will be combined the highest levels of each factors. So, the optimum conditions are dependent upon the layout position to L_{18}.

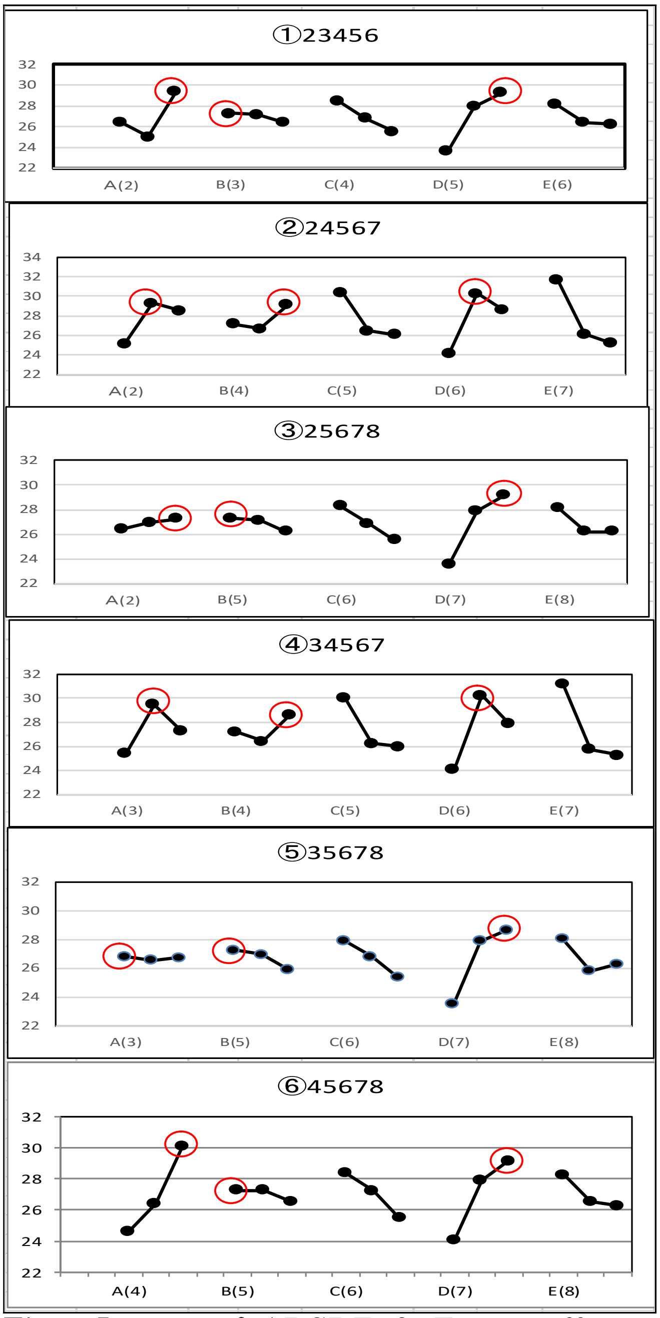


Fig-4 Layout of ABCDE & Factor effect

The optimum conditions were combined for each the highest levels for SN ratio. So, the different 4 kinds optimum conditions were conducted with just different layout to L_{18}.

These differences are caused by Confounding effects by other columns. The level of main effects is mixed with the different number of interactions between columns. Table 6 shows typical one.

Table 6.1 c complete to full interaction ab

a\b	1			2			3		
1	1	2	3	2	3	1	3	1	2
2	2	3	1	3	1	2	1	2	3
3	3	1	2	1	2	3	2	3	1
c									

Columns a,b interaction affects to c column.

Table 6.2 Confounding: partial interaction with Empty space

2\4	1			2			3		
1	11			22			33		
2	22			33			11		
3	33			11			22		
5									

2\5	1			2			3		
1	11			22			33		
2		33			11			22	
3			22			33			11
4									

2\3	1			2			3		
1	1	2		2	3		3	1	
2	2		1	3		2	1		3
3	33			11			22		
6									

8\2	1			2			3		
1	1	2		2		1	33		
2	2	3		3		2	11		
3	3	1		1		3	22		
7									

2\5	1			2			3		
1	1	2		2	3		3	1	
2	2	3		3	1		1	2	
3	3	1		1	2		2	3	
3									

8\6	1			2			3		
1	1		3	2	3			1	2
2	2	3			1	2	1		3
3		1	2	1	2		2	3	
7									

Full interaction is $27(3^3)$. L_{18} is partial and it is less max 18 to minus 9 empty spaces.

5.2. Noise type and different optimum condition

Noise factors have two kinds. One is the compound noise (N_1,N_2) and the others is orthogonal table noise. There was one explanation that compound noise factor N_1, N_2, will reduce the experiment numbers and maintain the same optimum condition.

But it was a wrong information.

5.2.1. Validation Case for Thermostat Circuit[6]

Fig-5 on x Thermostat circuit[8] with R_1,R_2,R_3, R_5,R_{12},Ez,E_0.

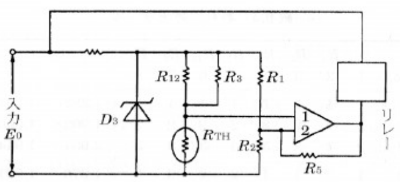


Fig-5 Thermostat circuit

$$x = \frac{\frac{R_3R_{12}}{R_3+R_{12}}R_2(E_zR_5+E_0R_1)}{E_z(R_1R_2+R_1R_5+R_2R_5)-R_2(E_zR_5+E_0R_1)} \qquad (1)$$

The current constant is :3.9kΩ, R_2:7.5kΩ, R_3:1.0kΩ, R_5:360kΩ, R_{12}:3.3kΩ, Ez:5.3V, E_0:10.1V, R+/-10% Ez+/-0.3V, E_0+/-0.5V is noise.

First level is half of R, Third level is double of R. We layout to the 4-8 columns as inner orthogonal array. Noise R is 4-8 columns, noise E_0 and Ez were layout to second and third columns. They were layout to outer Orthogonal array.

Experiment was done with inner and outer product type. Table 7 shown the results.

Table 7　Orthogonal array results

In\out	1	2	3	4	5	6	7	8	9
1	0.691	0.770	0.850	0.864	0.889	0.580	0.756	0.627	0.946
2	1.382	1.541	1.700	1.729	1.778	1.161	1.513	1.254	1.891
3	2.765	3.082	3.401	3.457	3.556	2.322	3.026	2.508	3.782
4	3.051	3.394	3.739	3.800	3.995	2.531	3.348	2.771	4.157
5	3.530	3.967	4.413	4.472	4.322	3.068	3.809	3.181	4.937
6	0.198	0.220	0.243	0.244	0.260	0.165	0.216	0.179	0.270
7	1.369	1.524	1.680	1.715	1.757	1.150	1.501	1.243	1.867
8	0.342	0.381	0.420	0.429	0.439	0.287	0.375	0.311	0.467
9	5.874	6.593	7.327	7.254	7.654	4.926	6.345	5.293	8.208
10	1.167	1.305	1.445	1.467	1.466	0.997	1.271	1.056	1.609
11	2.177	2.421	2.665	2.777	2.704	1.852	2.392	1.978	2.962
12	0.871	0.974	1.079	1.064	1.168	0.721	0.948	0.789	1.201
13	1.548	1.725	1.903	1.923	2.033	1.285	1.695	1.405	2.117
4	0.415	0.464	0.513	0.507	0.549	0.348	0.453	0.376	0.569
15	3.224	3.592	3.961	4.163	3.883	2.794	3.530	2.925	4.408
16	1.214	1.360	1.509	1.513	1.530	1.043	1.319	1.098	1.676
17	3.381	3.775	4.173	4.158	4.517	2.788	3.686	3.060	4.654
18	0.547	0.608	0.670	0.697	0.680	0.466	0.601	0.497	0.744
BM	1.382	1.541	1.700	1.729	1.778	1.161	1.513	1.254	1.891
In\out	10	11	12	13	4	15	16	17	18
1	0.752	0.822	0.730	0.774	0.645	0.893	0.753	0.882	0.672
2	1.503	1.644	1.460	1.549	1.289	1.786	1.505	1.763	1.343
3	3.007	3.287	2.920	3.097	2.578	3.572	3.010	3.526	2.686
4	3.346	3.675	3.140	3.394	2.810	4.028	3.348	3.821	3.003
5	3.743	4.037	4.076	4.046	3.402	4.294	3.735	4.805	3.291
6	0.217	0.237	0.205	0.219	0.183	0.260	0.218	0.247	0.194
7	1.487	1.629	1.441	1.536	1.277	1.767	1.491	1.745	1.332
8	0.372	0.407	0.360	0.384	0.319	0.442	0.373	0.436	0.333
9	6.429	6.943	6.347	6.532	5.472	7.630	6.387	7.532	5.668
10	1.255	1.362	1.283	1.320	1.107	1.464	1.256	1.530	1.113
11	2.324	2.561	2.344	2.485	2.051	2.728	2.332	2.856	2.088
12	0.968	1.048	0.903	0.955	0.803	1.166	0.966	1.078	0.859
13	1.701	1.862	1.601	1.719	1.427	2.045	1.700	1.940	1.522
4	0.459	0.494	0.436	0.456	0.388	0.546	0.460	0.516	0.406
15	3.387	3.724	3.614	3.738	3.090	3.907	3.400	4.379	3.031
16	1.310	1.409	1.345	1.366	1.161	1.519	1.314	1.585	1.155
17	3.746	4.082	3.482	3.722	3.098	4.533	3.733	4.195	3.338
18	0.584	0.643	0.590	0.624	0.516	0.685	0.587	0.717	0.524
BM	1.503	1.644	1.460	1.549	1.289	1.786	1.505	1.763	1.343

5.2.2. Compound noise factors

To center value of the combination Factor R,Ez,E0 were changed by just one factor at the same time, to the down tendency is N_1, the upper one is N_2. Table 8 shown compound noise factor. Table 9 shows SNratio.

Table 8 compound noise factor

Level ratio 2 one factor	x(ON)	
	N1(-)	N2(+)
R_1	3	1
R_2	1	3
R_3	1	3
R_5	3	1
R_{12}	1	3
Ez	3	1
E_0	1	3

Table-9 Noise type and SN ratio

Control factors						Compound noise			OA noise
No	R1	R2	R3	R5	R12	N1	N2	SN	SN
1	1	1	1	1	1	0.560	1.045	6.981	17.487
2	2	2	2	2	2	1.121	2.089	6.981	17.487
3	3	3	3	3	3	2.241	4.179	6.981	17.487
4	1	2	2	3	3	2.486	4.582	7.149	17.268
5	2	3	3	1	1	2.792	5.519	6.172	17.420
6	3	1	1	2	2	0.160	0.298	7.042	17.361
7	2	1	3	2	3	1.114	2.059	7.103	17.525
8	3	2	1	3	1	0.278	0.515	7.103	17.525
9	1	3	2	1	2	4.654	9.165	6.226	17.214
10	3	3	2	2	1	0.937	1.786	6.676	17.631
11	1	1	3	3	2	1.777	3.261	7.210	17.660
12	2	2	1	1	3	0.700	1.333	6.676	17.069
13	2	3	1	3	2	1.256	2.338	7.011	17.245
14	3	1	2	1	3	0.334	0.631	6.810	17.407
15	1	2	3	2	1	2.616	4.868	7.011	17.593
16	3	2	3	1	2	0.971	1.864	6.568	17.728
17	1	3	1	2	3	2.723	5.156	6.763	17.004
18	2	1	2	3	1	0.446	0.820	7.195	17.678
BM	2	2	2	2	2	1.121	2.089	6.981	17.487

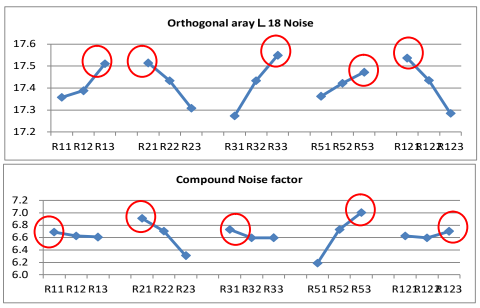


Fig 5　Orthogonal array and compound noise

Fig 5　shows Factor effect chart x on two type. There are some differences. Table 10 shows the highest levels to type noise.

Table 10　Highest level to two types

Factor	Noise style		Consistency
	OA	Compound	
R_1	3	1	×
R_2	1	1	O
R_3	3	1	×
R_5	3	3	O
R_{12}	1	3	×

There are three difference factors R_1, R_3, R_{12}. So, we will show at Table 11 correlation coefficient

Table 11 correlation coefficient

noise	R_1	R_2	R_3	R_5	R_{12}
Orthgonal array	0.31	-0.379	0.585	0.183	-0.535
Compound	-0.037	-0.574	-0.012	0.735	0.079

If The difference of plus and minus on the orthogonal array and compound noise array are inverse, Optimum levels of Table 9 are difference in them.

5.3. Reverse data for compound noise factor[6].

Compound error factor is usually consisted with $N_1(y_1)$ <$N_2(y_2)$ at the standard condition. Robust design will use interaction. So, it will give y_1 and y_2 intercept like Fig 7.

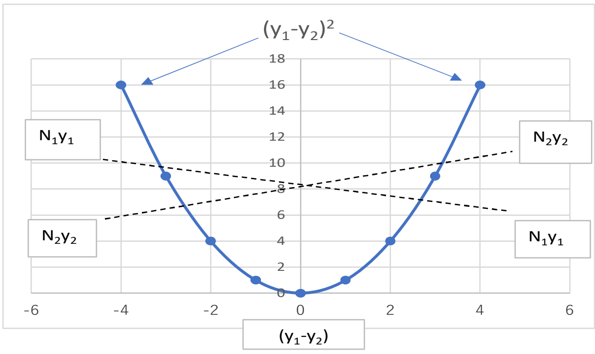


Fig-6 $(y_1\text{-}y_2)$ & $(y_1\text{-}y_2)^2$

To do robust design, there is premise that is interaction between factors. So, frequently, y_1, y_2 will take reverse position like $N_1(y_1)>N_2(y_2)$. Taguchi Robust design using decomposition of sum of square could calculate it but could not design by it. If try to reduce variation for y_1, y_2 on Fig 6, it is ok just with $y_1=y_2$. For Example, if $(y_1\text{-}y_2)$ is -4, engineer will shift the factor tune from minus side to 0. If $(y_1\text{-}y_2)$ is +4, engineer will shift the other factor tune from plus side to 0.

If $(y_1\text{-}y_2)^2$ is 16(square = $(-4)^2$, or = $(4)^2$) on Fig 6, there are two points at right and left to center. It cannot detect the factor to tune at the Taguchi. We will show the real mixture data on Table 12. Table 12 shows the reverse data of Molten cast

Table 12 Molten cast : Reverse data（Red Bold）

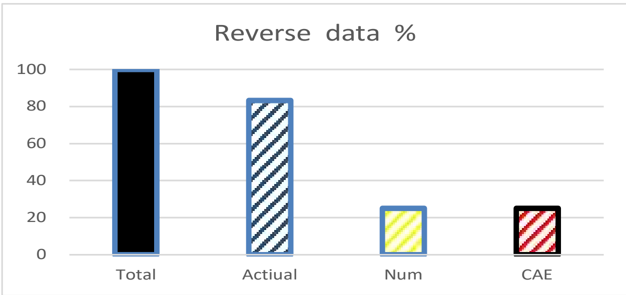
Ex No	A	B	C	D	N_1 y_1	N_2 y_2	SN ratio	Sens itvity
1	3	3	3	1	**14.0**	**11.6**	17.7	22.1
2	6	2	2	1	**17.7**	**17.0**	30.9	24.8
3	6	3	1	2	9.1	12.0	14.0	20.4
4	1	3	1	1	**13.0**	**11.0**	18.8	21.5
5	1	1	3	2	14.7	17.6	17.9	24.1
6	2	1	3	3	12.2	12.6	32.8	21.8
7	2	2	2	2	15.2	20.2	14.0	24.9
8	3	1	1	3	**11.5**	**11.4**	44.2	21.2
9	4	2	3	3	10.6	19.2	7.5	23.1
10	5	2	1	1	**15.3**	**12.3**	16.2	22.8
11	4	1	2	1	9.8	15.6	9.7	21.8
12	5	3	2	3	12.0	15.8	14.3	22.8

No1(SN:17.7), No5(SN:17.9) are almost same to SN ratio. However, raw data are reverse No1(y_1,y_2: 14.0,11.6) and No5(y_1,y_2:14.7,17.6). So, tunes are different directions. SN ratio can not optimize the mixture of forward and reverse data like Table 12.

We show the statistical data 107 case to 1993-2017. 83% Actual trials, 25% numeric trails, 25% CAE trail are concluded with the mixture data to Table 23..

Table 13 Mixture data in case studies

Cases	Total	Actiual	Num	CAE
Total	107	83	12	12
Reverse	107	69	3	3
Reverse %	100	83	25	25



6.Summar and Conclusion

Taguchi two step design was started at 1980's. We inspected using the judgement level on focusing on design-experiment site that optimum condition(b) detected with factor effect chart should be higher than the highest(a) of the L_{18} data set for case studies for 2003-2012 Japan quality Engineering Association. So, it should be a<b for all of cases, but it was just 39%, actually a>b is 61% on Table 3. It meant it is just D grade.

We introduced the three reasons for D grade.
1: Optimum dependent on layout columns in L_{18}
2: Optimum are different with noise format between compound and orthogonal array.
3: Reverse data for noise: SN ratio can be calculated, but cannot design for it.

7: Discussions

There was the different fact that Taguchi campaign introduced us that if we used SN ratio (average^2 /diversion=$y^2/6^2$) at design and experiment site, it means the same thing to reduce the social loss 6^2 on loss function $k(y-t)^2$. (See Fig7)

Engineers were affected with SN-ratio concept on Taguchi two step design contributing to reduce variation also at the same time to reducing society loss. However, it was not fact. Orthogonal array noise will be presented for the social variation, also compound noise factor N was supposed to be compacted size of orthogonal array noise. Actually, they will give the different optimum.

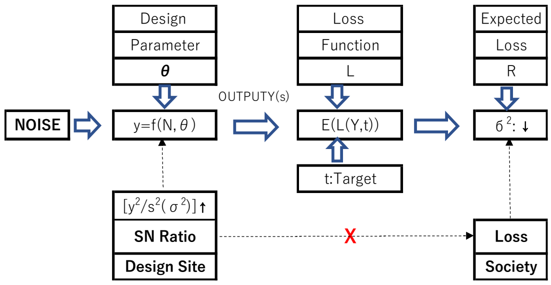


Fig-7 Taguchi campaign at 1980's

1980's Taguchi case studies for outside were introduced after screening which were done at the organization. So, there were no worse cases to outside.

SLK[7] detected the problems of tuning process after minimized variation for Taguchi as PerMIA (1987).

PerMIA was the biggest concern at the statistic in USA, however it did not continue to discuss because there were not enough the case studies to judge to it. People did not know there were many prediction trouble cases on design sites.

The next problem of Taguchi after PerMIA was inconsistency to make the compound noise. Hou[8] (2002) pointed the cases that compound noise factor did not replace for orthogonal array. Also, Matsuura (2014)[9] suggested the output of order $N_1(y_1)$ and $N_2(y_2)$ to compound noise will be possibility reverse/replace cause by the interaction between inner array and outer of noise. It was actually confirmed at cases.

We as engineer at the first time realized the cause of prediction troubles were the causes in Taguchi process itself at 2008[3]. They have been happened in design /experiment site to confirm with the detail difference the prediction and optimum run results.

. So, we/engineers started to survey as database[10] the proceeding volunteer actual case studies on 2003-2012 of JQEA. Because we are sure almost no bias.

8. Near Future Research

Our target is "the smaller trials with higher accuracy for researching" . It will be the new statistics area. We are looking for the new compact matrix for it.

Reference

[1] Taguchi,G and Wu, Y (1980), Introduction to off-line Quality Control, Japan Quality Control association.
[2] Teruo MORI (2018): "The 62% Problems of SN Ratio and New Conference Matrix for Optimization", Proceeding of the pacific Rim Statistical Conference in Korea for Production Engineering 15-20 (Springer)
[3] Teruo, Mori (2008) "Survey for Optimum the difference prediction and actual value" (Taguchi is OK??) No113 Proceeding 16th Quality Engineering Association.
[4] Jeff: Sober Ghosh (1990): [Statistical Design and Analysis of industrial Experiment Marcel Dekker, NC (USA)
[5]Teruo MORI,Izuru Sadamatsu,Akira Tomishima, Shun Matsuura (2018) "Comparison of the behaviors and difference of the optimum between compound and orthogonal arrays 48(1),pp105-111.
[6]Teruo MORI (2018) " Survey and analysis for Reverse data to compound noise factors" No2-1 117th JSQC Nagoya
[7]Leon, Shoemaker, Kacker (1987) "Performance Independent of Adjustment: An explanation and Extension of Taguchi's Signal-to-Noise Ratio. Technimetrics Aug p253-285
[8]X.Shirley Hou(2002) "On the use of compound noise factor in parameter design experiment" Appl.Stochstic Models Bus. Ind 18.225-243
[9]Shun Matsuura(2014) "Precision of the Estimation of the Response Mean and the Response variance in Compound Noise Experiments', Japanese society for Quality control 44(19,pp123-134)
[10] Data base (Excel) for 62% problems. http://www02.jet.ne.jp/~i-sada/sub04.htm

[Memo] Taguchi Genichi described on his biography received Ph.D. at Kyusyu University (1962). However, there is no his name on Ph.D. list of Kyusyu University. So, we have used the prof as an honorific title for him.
https://catalog.lib.kyushu-u.ac.jp/opac_search/?lang=0&appname=Netscape&version=5&sort_exp=6&disp_exp=20&amode=2&cmode=0&schemaid=823&brwflg=1&flflg=&smode=0&kywd=%E7%94%B0%E5%8F%A3