「Status of Scientific Methods for Product Development Outside of Japan」

Robust Optimization using Taguchi Methods

Epoch Making Case Studies・・

TRIZ Symposium

Friday 09-12-2014

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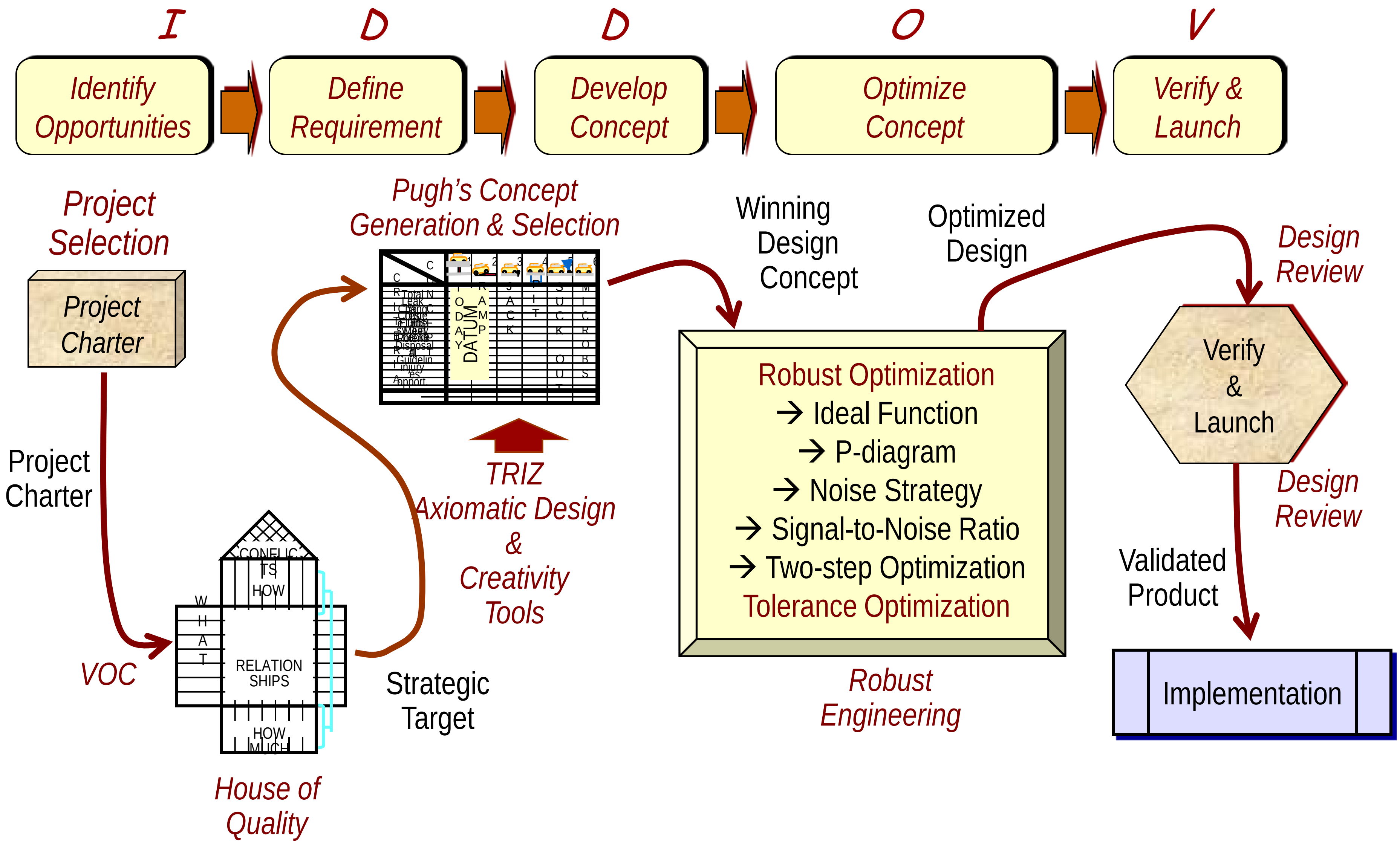
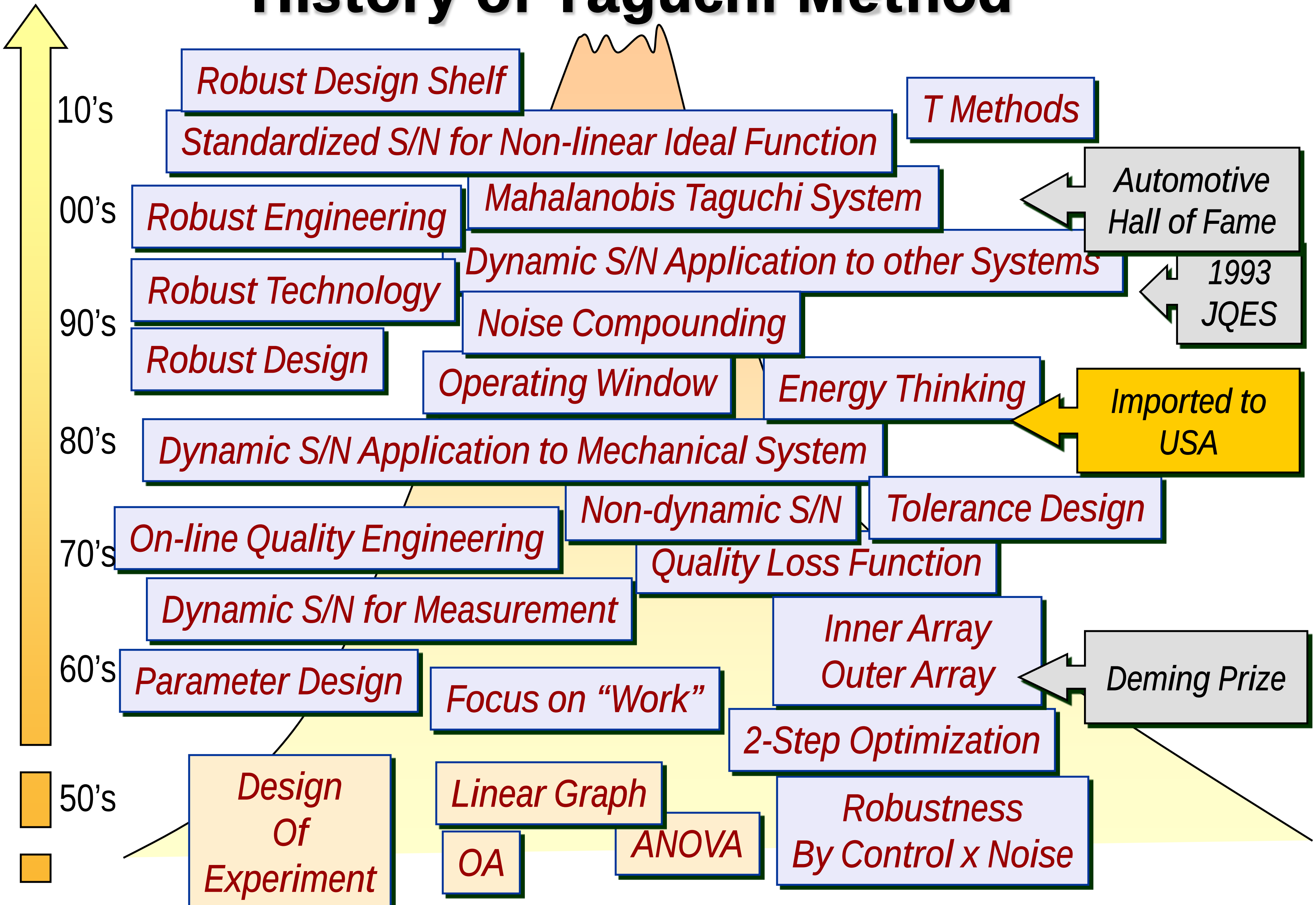
DFSS Process – IDDOV Project

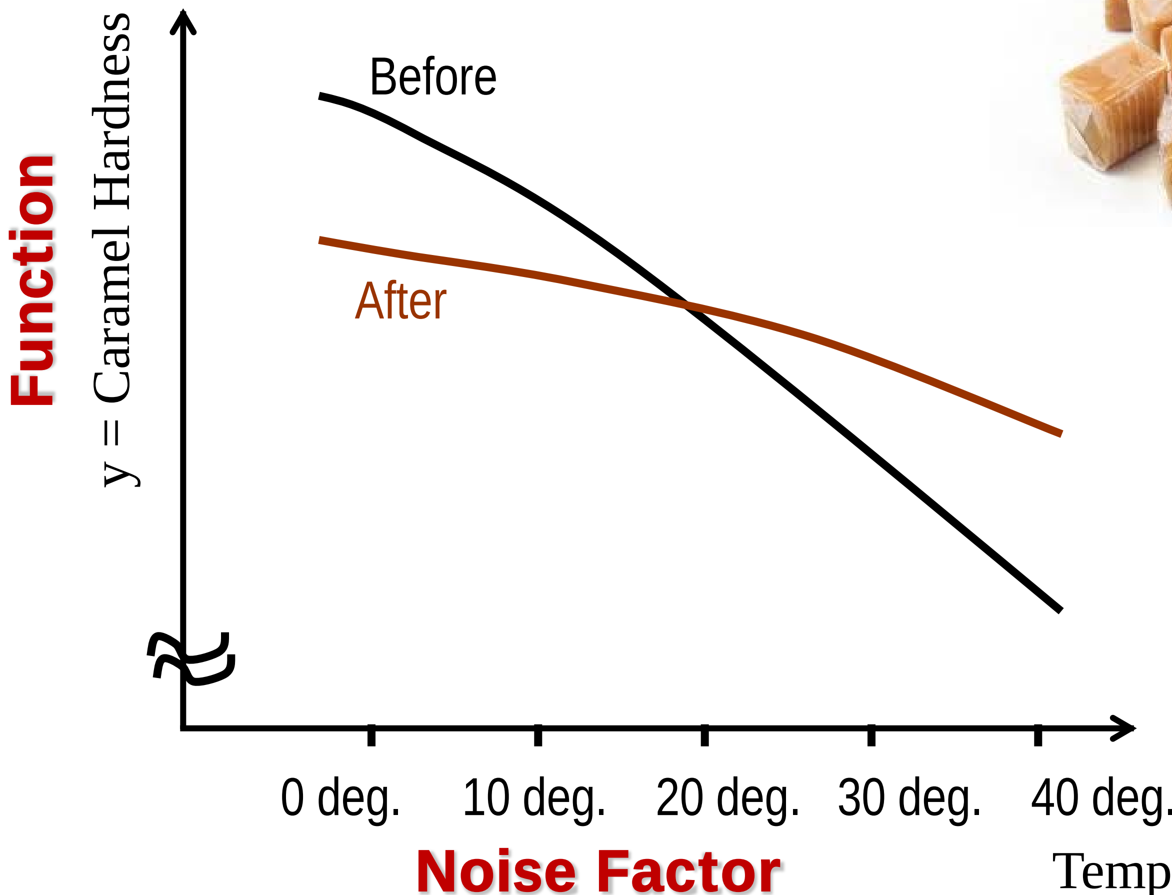


History of Taguchi Method



1948 Morinaga Company - Caramel Candy Hardness

Take advantage of
Interactions between Control & Noise , AxN, BxN, ..
to achieve "Robustness"



4 types of Countermeasures for Noises

I. Ignore

II. Control / Eliminate Noise

Example: Standardization, Control Charting, Poka-Yoke
Traditional Quality Assurance Activities, Tolerance Design

III. Compensate Effect of Noise(s)

Example: Feedback Control, Adaptive Control
(Feed forward Control), Engine Control,
Matching Assembly, Anti-lock Brake, Etc.

If you decide to add a compensation system, you like to optimize the compensation function for "Robustness"

IV. Minimize Effect of Noises

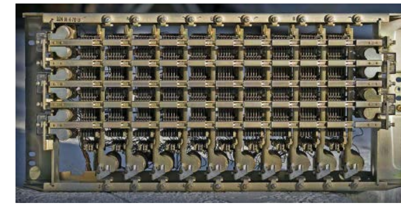
Example: Generation & Selection of Robust Design Concept
Optimization for Robustness (Parameter Design)

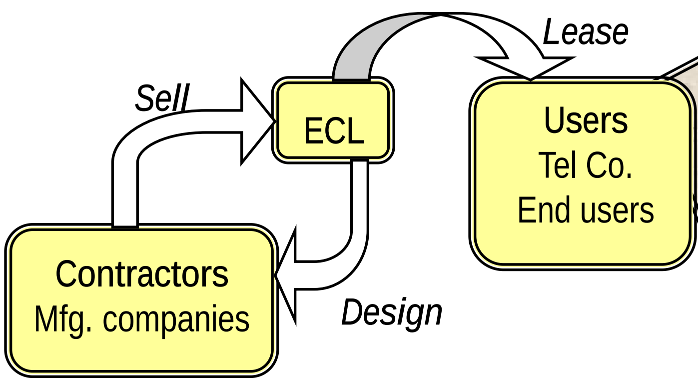
The better you can achieve IV, the less $ needed to do II & III

1950 ~ 56: NT&T Cross Bar Switching System

Winning competition by optimizing "Robustness"

	Budget	# People	# Years	Result
AT&T Bell Labs	*50*	*5*	*7*	*Not finished*
NT&T ECL	*1*	*1*	*6*	*Superior*





Leasing by ECL has 100% Warranty

- 40 Years for Exchanger
- 15 Years for Tel. sets

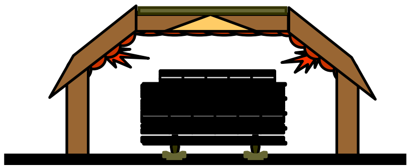
Need for Robust Design

During six years of development, ECL has optimized over 3000 Design Control Factors for "Robustness", i.e. looking for robustness by studying interactions between Control and Noise.

1953 Ina Seito (INAX) Tile Manufacturing Tunnel Kiln

Optimization using small scale pilot

Reducing Variability → Speed up the process



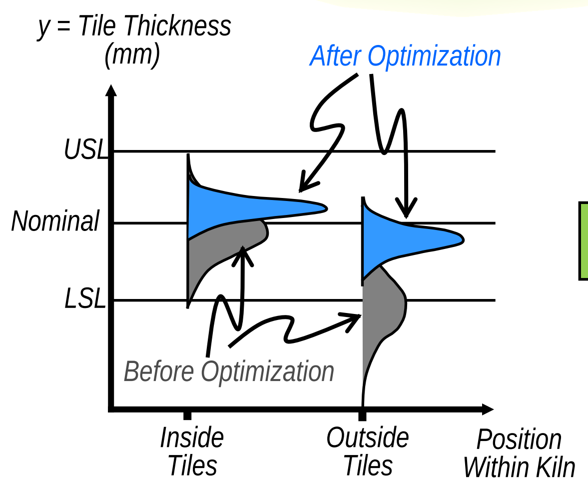
- Tunnel Kiln -

R&D

L27 was conducted using small pot mill.

Mass production

L8 was conducted using full mfg. scale to confirm



Speed up the process for higher productivity

1959 Japan National Railroad Train Body Welding

...ith Multiple Response

1963 Bullet Train

L16	A 1	G 2	A x G 3	H 4	A x H 5	6	7	8	9	10	11	12	13	14	15			Tensile Strength m^2	Elonga-tion %
1	1	1	1	1															33.6
2	1	1	1																
3	1	1	1																
4	1	1	1	2	2														
5	1	2	2	1	1	2													
6	1	2	2	1	1	2	2	2											
7	1	2	2	2	2	1	1	1	1	2									
8	1	2	2	2	2	1	1	2	2	1	1	1							
9	2	1	2	1	2	1	2	1	2	1	2	1	2	1					
10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1	o			
11	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1	o			
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2	o			
13	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1				
14	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2				
15	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2				
16	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1		0		

Of course, today we do not recommend this!

Why?

Workability
Response Table
ANOVA (Optional)

Appearance
Response Table
ANOVA (Optional)

X-Ray
Response Table
ANOVA (Optional)

Tensile Strength
Response Table
ANOVA (Optional)

Elongation
Response Table
ANOVA (Optional)

Trade-off Decisions

Overall Optimization

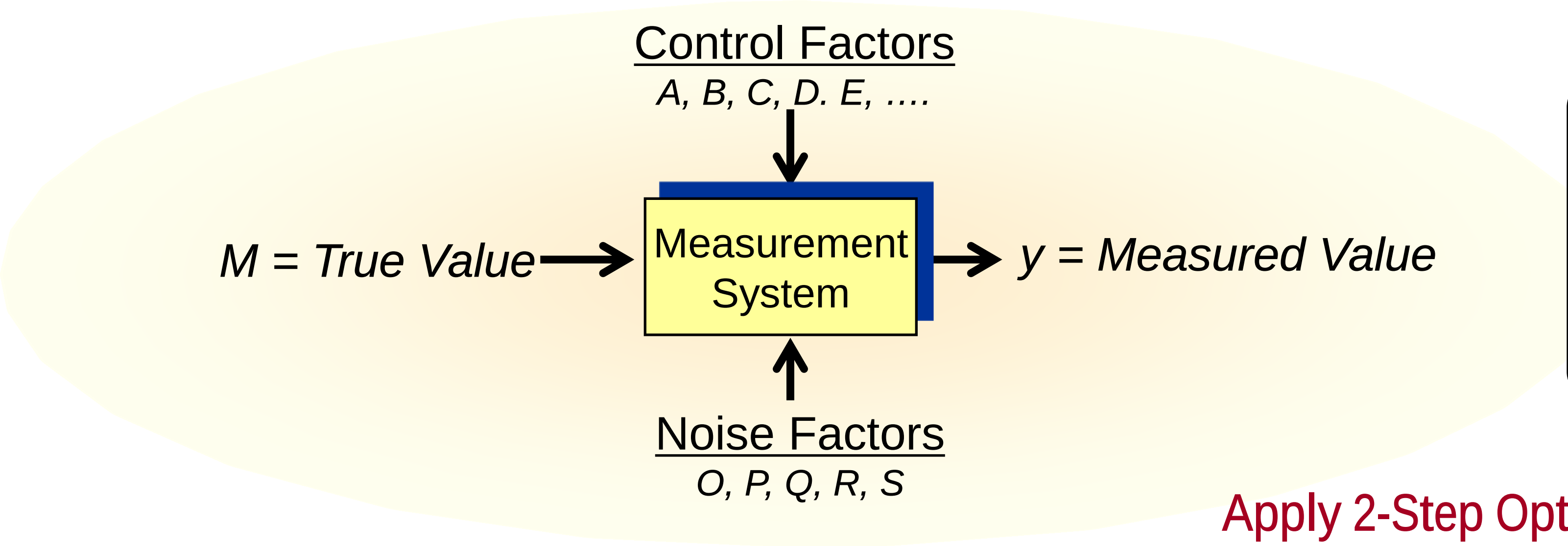
Prediction & Confirmation

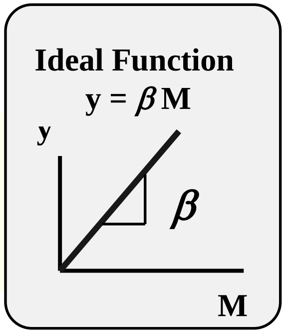
1960's to Present: Metrological Institute of Japan

Government Research Institute for Metrology

Ideal Function for Measurement System

Two-step Optimization for Measurement Function





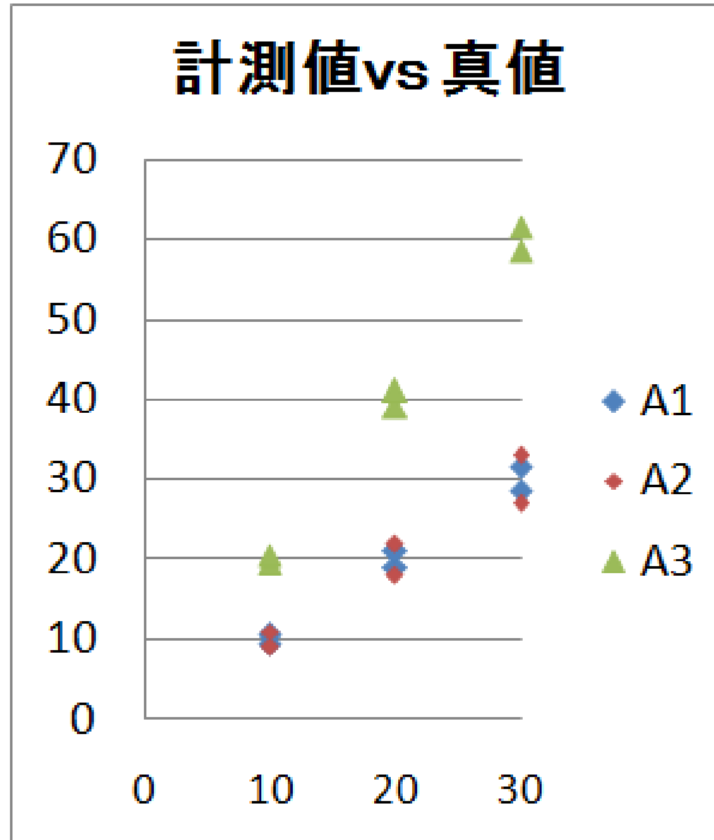
Apply 2-Step Optimization
Step-1: Maximize S/N
Step-2: Adjust β to 1.000

QUIZ !

Data Obtained During Development of Bathroom Scale

Input M is the True Value and Output Response is Measured Value.
N1 and N2 are Compounded Noise Conditions
Among three designs A1, A2 and A3, which design is the most robust, and why?

	M1=10 Kg		M2=20Kg		M3=30Kg	
	N1	N2	N1	N2	N1	N2
A1	*9.9*	*10.1*	*19.8*	*20.2*	*29.7*	*30.3*
A2	*9.8*	*10.2*	*19.6*	*20.4*	*29.4*	*30.6*
A3	*19.9*	*20.1*	*39.8*	*40.2*	*59.7*	*60.3*



Answer ______________

True/ False Questions

Answer by Brad

	True	False
Correct Answer True	100%	0%
Correct Answer False	0%	100%

$$S/N = +\infty\ dB$$

Answer by Shin

	True	False
Correct Answer True	50%	50%
Correct Answer False	50%	50%

$$S/N = -\infty\ dB$$

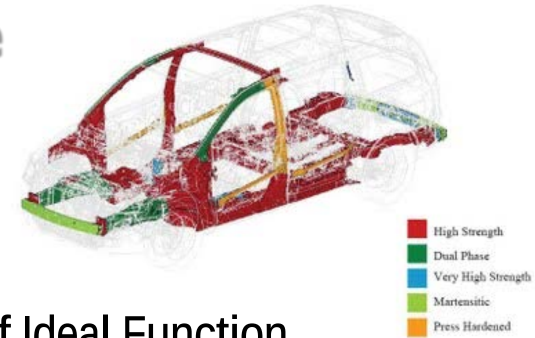
Answer by Mike

	True	False
Correct Answer True	0%	100%
Correct Answer False	100%	0%

$$S/N = +\infty\ dB$$

1979 Toyota Van Body Structure

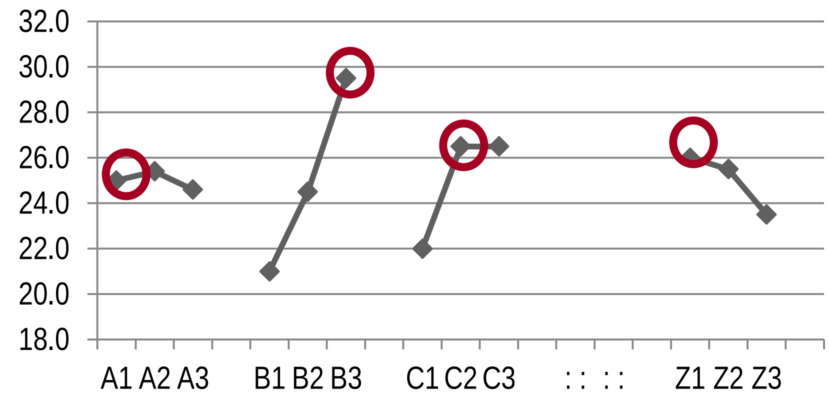
Optimize Function to Reduce Cost & Weight



Control Factors & Levels

	Level-1	Level-2	Level-3
Component- A	Lighter	Base	Heavier
Component- B	Lighter	Base	Heavier
Component- C	Lighter	Base	Heavier
: :	: :	: :	: :
Component- Z	Lighter	Base	Heavier

S/N of Ideal Function



Measure Ideal Function (Crash Performance)

Challenge to improve function and reduce weight simultaneously!

Design Space in Inner Array
Measure Ideal Function under Noise Strategy

Use S/N to Assess Robustness!

Design Space

	A 1	B 2	C 3	D 4	E 5	e 6	e 7	e 8	Outer Array
1	1	1	1	1	1	1	1	1	
2	1	1	2	2	2	2	2	2	
3	1	1	3	3	3	3	3	3	
4	1	2	1	1	2	2	3	3	
5	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	
6	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	
7	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	
8	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	
9	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	
10	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	
11	2	1	2	1	1	3	3	2	
12	2	1	3	2	2	1	1	3	
13	2	2	1	2	3	1	3	2	
14	2	2	2	3	1	2	1	3	
15	2	2	3	1	2	3	2	1	
16	2	3	1	3	2	3	1	2	
17	2	3	2	1	3	1	2	3	
18	2	3	3	2	1	2	3	1	

Inner Array

Explore Design Space

Function

Outer Array

Ideal Function with Noise Strategy

		V1	V2	V3	V4	V5
N1	P1	*y1*	*y2*	*y3*	*y4*	*y5*
	P2	*y6*	*y7*	*y8*	*y9*	*y10*
	P3	*y11*	*y12*	*y13*	*y14*	*y15*
	P4	*y16*	*y17*	*y18*	*y19*	*y20*
N2	P1	*y21*	*y22*	*y23*	*y24*	*y25*
	P2	*y26*	*y27*	*y28*	*y29*	*y30*
	P3	*y31*	*y32*	*y33*	*y34*	*y35*
	P4	*y36*	*y37*	*y38*	*y39*	*y40*

The Taguchi Study Group has been meeting every month to discuss practical applications, one group in Nagoya since 1953, and another group in Tokyo since 1964. Through these successes and failures, the method has taken huge evolutions.

Dr. T to USA

W. E. Deming Yuin Wu Genichi Taguchi

1979 Basement of Dr. Deming's House

1980 Bell Labs 256k Chip Photolithography Window Size

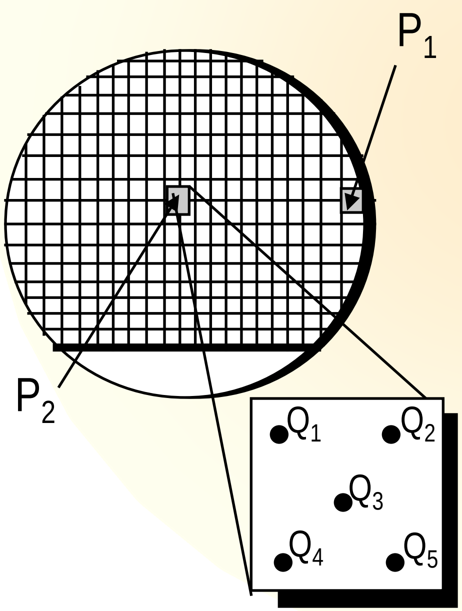
Science vs. Engineering | **Two-step Optimization**

Photolithography → y = Window Size (Nominal-the-Best) → Apply 2-step Optimization

<u>Noise Factors</u>

Chip to Chip

Within Chip



<u>Control Factors</u>

Plasma Etching Time

Exposure Time

Spin Speed

Bake Time

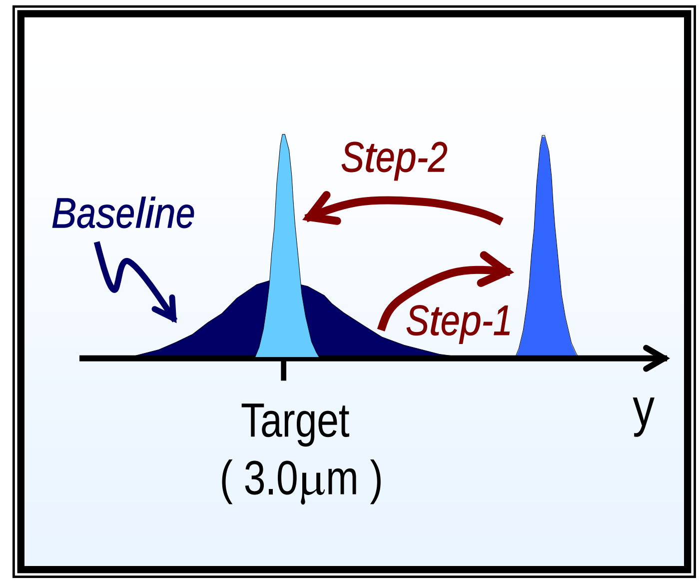
Aperture, Etc.

↓

Three 2-level factors
Six 3-level factors

↓

$L_{18}(2^3 \times 3^6)$



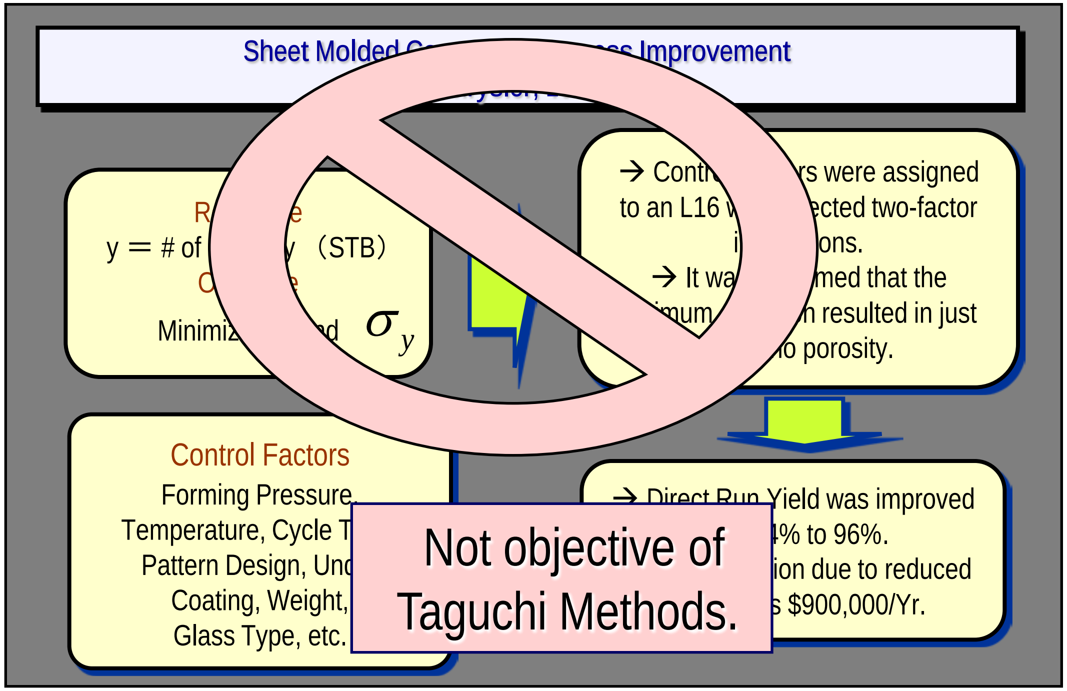
Yield: 33% → ***87%***

Bell Systems Technical Journal May 2003

1985 Chrysler Sheet Mold Compound

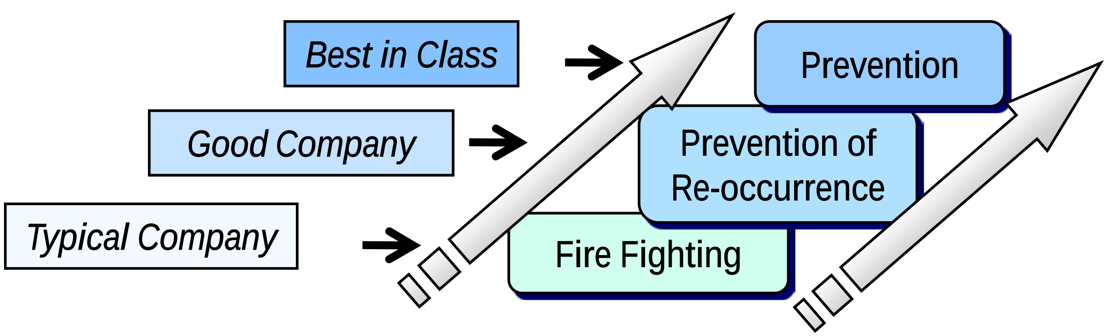
Reduced Rework Cost by $900k/Year

Fire Fighting to Fire Prevention



I have a big problem with my son, Shin.
He helps his clients to fire fight.
I am not interested in Fire-Fighting.
Please do not use Taguchi Methods for Fire Fighting

G. Taguchi, 1988



1988 ASI Symposium's Theme was:

TO GET "QUALITY",

DON'T MEASURE ~~"QUALITY"~~!

An 8 letter word

So, what do we measure?

Answer: Function !!

Robust Assessment vs. Validation

It is most important is to recognize the difference between:

"Robust Assessment" and "Validation".

Conduct "Robust Assessment" first, then "Validate"

Short Time,
~ One Day

To evaluate how robust the function is against various customers usage conditions

Ideal Function + Noise Strategy

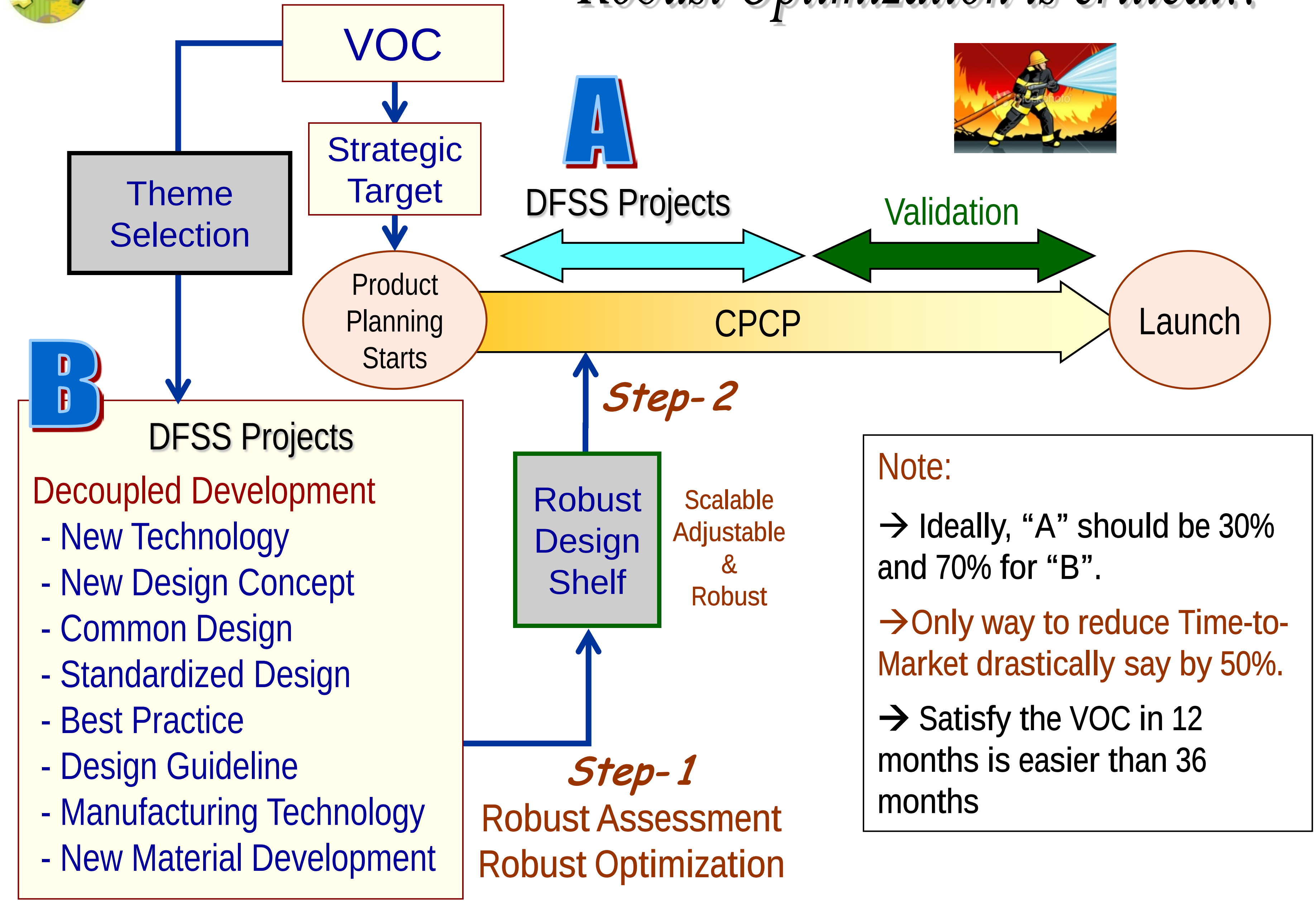
→ Signal-to-Noise Ratio

Longer Time,
~ 12 Months.

1. To check if the product meets all requirements.
2. Detect all "Buds" of problems.

Why is this so critical ???

Robust Optimization is critical!!



1990 Hardness Tester Standard Sample by Asahi Giken

Achieved the Best in Industry

- Asahi Giken is a very small company with XXX people.
- They were able to develop new hardness standard samples that is the best in industry in "price" and "accuracy".

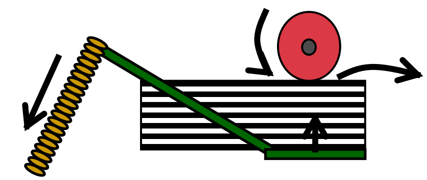
M
Heat Energy → **Sample Hardening** → y
Δ Hardness

1980's Paper Feeder by Xerox

Operating Window Concept

1 Hr Robust Assessment Test

Noise Compounding

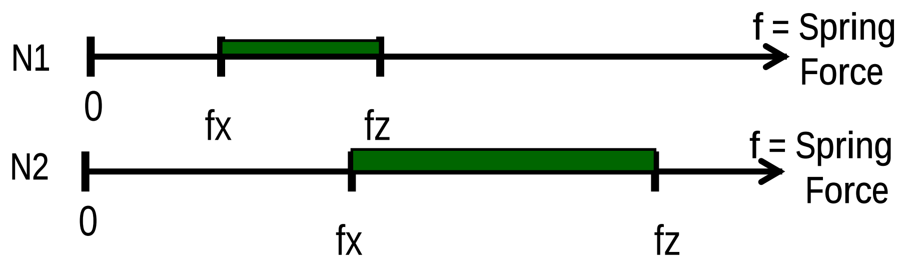


Control Factors

	A	B	C	D	E	F	G	H	
	1	2	3	4	5	6	7	8	
1	1	1	1	1	1	1	1	1	Result-1
2	1	1	2	2	2	2	2	2	Result-2
3	1	1	3	3	3	3	3	3	Result-3
4	1	2	1	1	2	2	3	3	Result-4
5	1	2	2	2	3	3	1	1	Result-5
6	1	2	3	3	1	1	2	2	Result-6
7	1	3	1	2	1	3	2	3	Result-7
8	1	3	2	3	2	1	3	1	Result-8
9	1	3	3	1	3	2	1	2	Result-9
10	2	1	1	3	3	2	2	1	Result-10
11	2	1	2	1	1	3	3	2	Result-11
12	2	1	3	2	2	1	1	3	Result-12
13	2	2	1	2	3	1	3	2	Result-13
14	2	2	2	3	1	2	1	3	Result-14
15	2	2	3	1	2	3	2	1	Result-15
16	2	3	1	3	2	3	1	2	Result-16
17	2	3	2	1	3	1	2	3	Result-17
18	2	3	3	2	1	2	3	1	Result-18

For each run of L18, measure the operating window

Operating Window Response



fx = Force to start feeding one by one, say 4 sheets

fz = Force to start multi-feed/ paper jam

2 Step Optimization

Step-1: Maximize O.W.

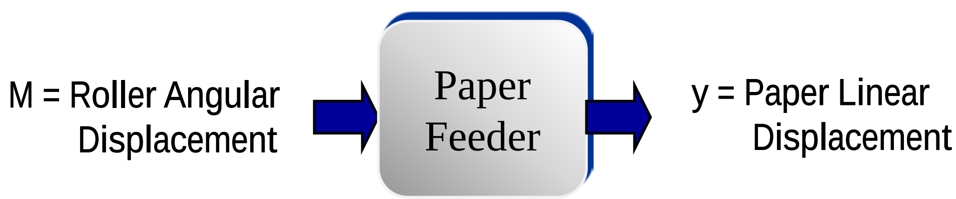
Step-2: Adjust Force

Noise Compounding

N1 = Noise Condition which tends to miss-feed = Slippery & Heavy Paper + Worn Roller + High Humidity

N2 = Noise Condition which tends to multi-feed = Coarse & Light Paper + New roller + Dry

Dynamic Response with Ideal Function



2 Step Optimization

Step-1: Maximize S/N

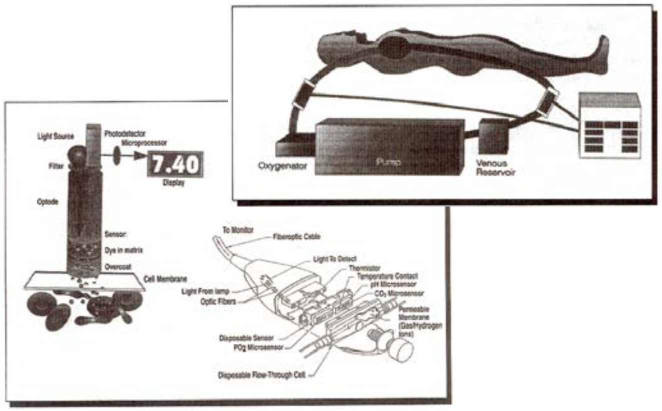
Step-2: Adjust β

1993 Oxygen Sensor by 3M

Main Function + Compensation

M = Actual Oxygen Concentration → **Oxygen Sensor** → y = Io/I (Measured Oxygen Concentration)

M* = Blood Temperature (Vary from 17C to 37C) → **Oxygen Sensor**



Three approaches

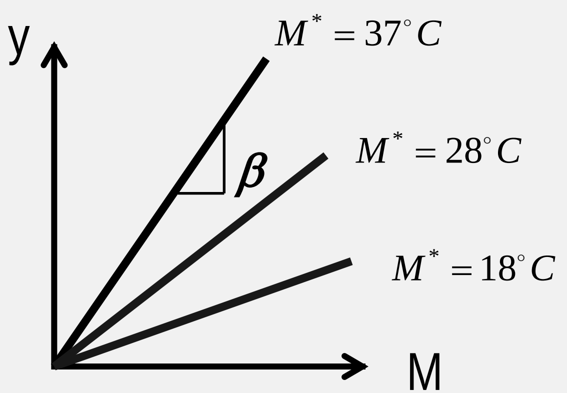
(a) M* is a noise factor.

(b) M* is a signal factor if its effect is to be compensated

(c) M* is an indicative factor if its effect is to be compensated by "Look-up Table" approach. We need to know the values of β1, β2 and β3.

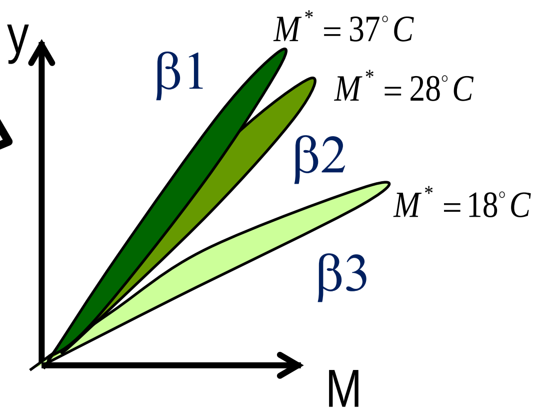
Ideal Function for (b)

$$y = \left[\beta + \beta^{*}(M^{*} - M_S^{*})\right]M$$



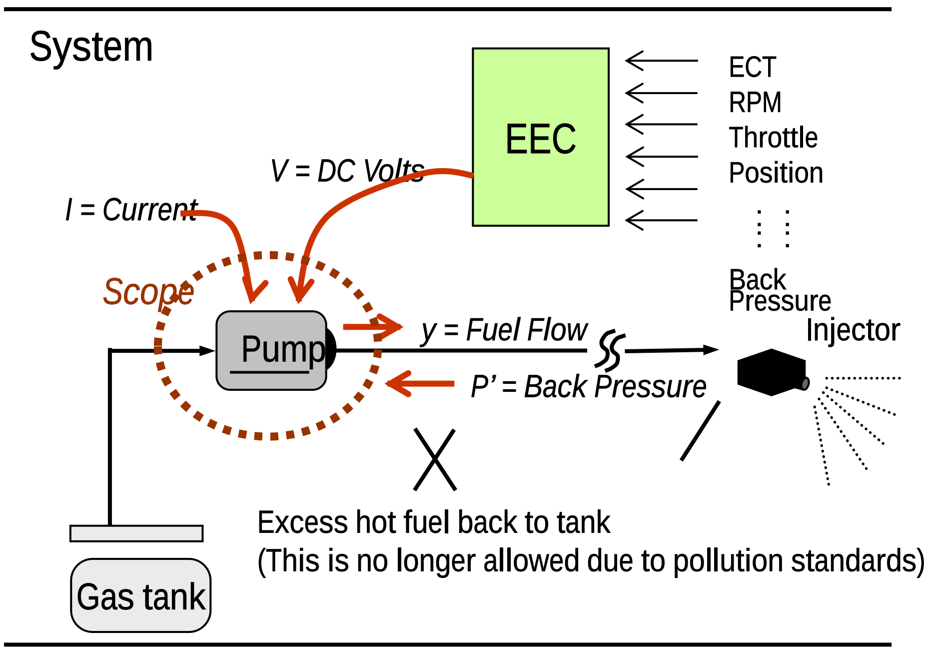
Ideal Function for (c)

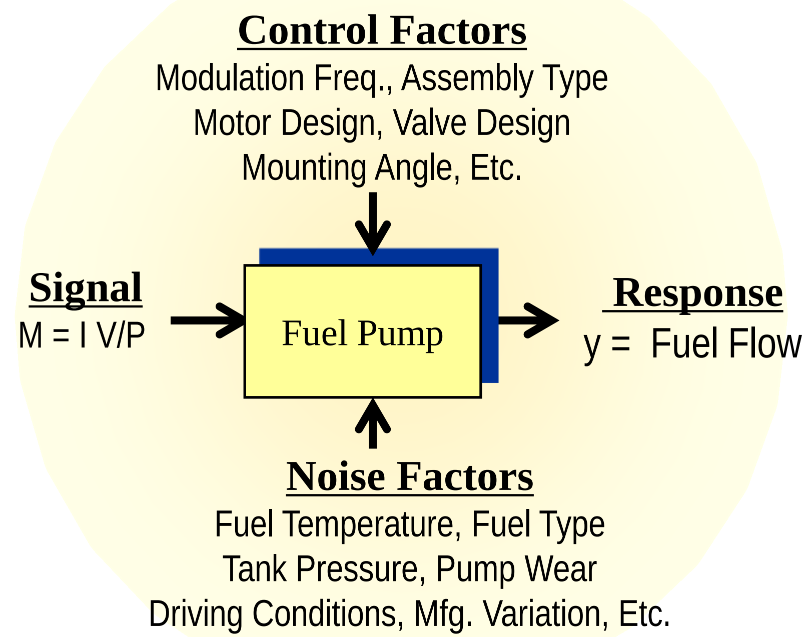
As long as values of β1, β2, β3 are known, the effect of temperature can be compensate.



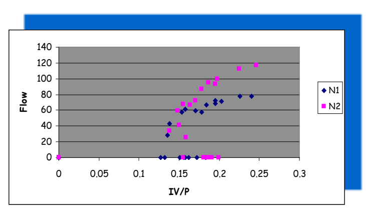
1993 Ford Fuel Pump

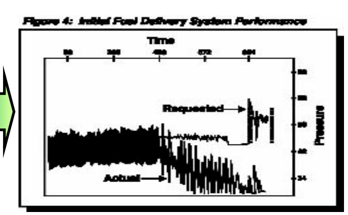
Main Function + Compensation



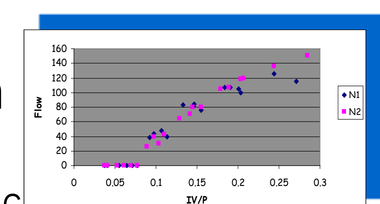


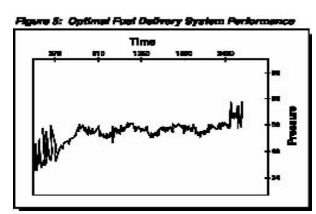
Baseline Design



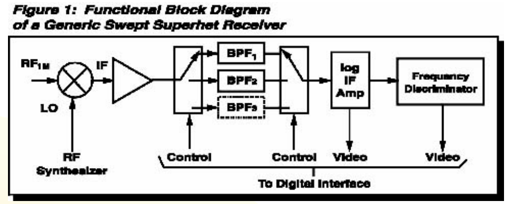


Optimum Design





1988 ITT EW Receiver



Signal Time → EW Receiver → **Response** Probability of Detection

Ideal Function: $P = e^{-\beta T}$

FORMULATION OF ROBUST OPTIMIZATION

M = Time → EW Receiver → P = Prob{Not Detecting}

Noise Factors — Control Factors

Noise Factors and Levels	1	2	3
G: # of LPI Threats	g	g+5	g+10
H: LPI Starting Time	Low	Med	High
I: LPI Amplitude	Low	Med	High
J: # of PR Threats	m	m+5	m+10
K: PR Starting Time -1	Low	Med	High
L: PR Starting Time -2	Low	Med	High

Control Factors and Levels	1	2	3
A: LPI Scanning	Std	+9	+19
B: # of Priority Scan	Std	+4	+9
C: PR Scanning	Std	+9	+39
D: Additional Dwell LPI	Std	+7	+15
E: Additional Dwell PR	Std	+7	+15
F: Receiver Threshold	Std	+0.1	+0.2

	1	A 2	B 3	C 4	D 5	E 6	F 7	8
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	3	3	3	3
4	1	2	1	1	2	2	3	3
5	1	2	2	2	3	3	1	1
6	1	2	3	3	1	1	2	2
7	1	3	1	2	1	3	2	3
8	1	3	2	3	2	1	3	1
9	1	3	3	1	3	2	1	2
10	2	1	1	3	3	2	2	1
11	2	1	2	1	1	3	3	2
12	2	1	3	2	2	1	1	3
13	2	2	1	2	3	1	3	2
14	2	2	2	3	1	2	1	3
15	2	2	3	1	2	3	2	1
16	2	3	1	3	2	3	1	2
17	2	3	2	1	3	1	2	3
18	2	3	3	2	1	2	3	1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
8	1	2	3	3	1	2	3	1	2	1	2	3	2	3	1	2	3	1
L 7	1	2	3	3	1	2	2	3	1	2	3	1	3	1	2	1	2	3
K 6	1	2	3	2	3	1	3	1	2	2	3	1	1	2	3	3	1	2
J 5	1	2	3	2	3	1	1	2	3	3	1	2	3	1	2	2	3	1
I 4	1	2	3	1	2	3	2	3	1	3	1	2	2	3	1	3	1	2
H 3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
G 2	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3
1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2

Result & Benefit:

Achieved a remarkable 57% reduction in detecting time under a dynamic EW environment.

1999 UTA Clutch Subsystem for Lift-gate Multiplexed Node

Dynamic response with:

$$M = Spring\ Force$$

$$y = Torque\ to\ Engage$$

FACTORS & LEVELS

Signal Factor	Level-1	Level-2	Level-3
M: Spring Force	-30%	Nominal	+30%

Noise Fcator	Level-1	Level-2	Level-3	Level-4	Level-5
W: Aging	Initial	Ambient	Cold	Hot	Final

Control Factors:

$6^1 \times 3^5 \rightarrow L18(6^1 x 3^6)$

Convinced engineers to conduct this L18. After hard work they came with this result.

→ No.1 to No.6 were infeasible!!

→ Many data are missing due to not being able to have samples.

	y = Torque to Engage														
L18	W1			W2			W3			W4			W5		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
1	No engagement														
2	No engagement														
3	No engagement														
4	No engagement														
5	No engagement														
6	No engagement														
7	80	-	-	0	-	-	0	-	-	0	-	-	0	-	-
8	41	40	34	42	0	42	47	0	40	41	0	31	44	0	0
9	52	44	50	0	53	0	0	0	0	0	0	0	0	0	0
10	-	56	-	-	102	-	-	60	-	-	51	-	-	56	-
11	57	61	46	0	0	55	0	0	0	0	0	0	0	0	0
12	52	33	57	60	26	38	85	73	48	35	33	28	52	35	33
13	54	-	51	0	-	0	0	-	0	0	-	0	0	-	0
14	57	-	40	0	-	0	0	-	0	0	-	0	0	-	0
15	42	-	-	0	-	-	0	-	-	0	-	-	0	-	-
16	38	42	42	44	0	36	29	0	36	21	0	0	24	0	0
17	45	42	41	0	0	0	0	0	0	0	0	0	0	0	0
18	56	56	-	0	0	-	0	0	-	0	0	-	0	0	-

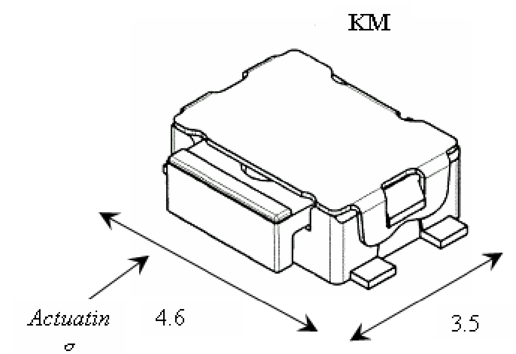
Conducted data analysis using S/N, and it has confirmed successfully!!

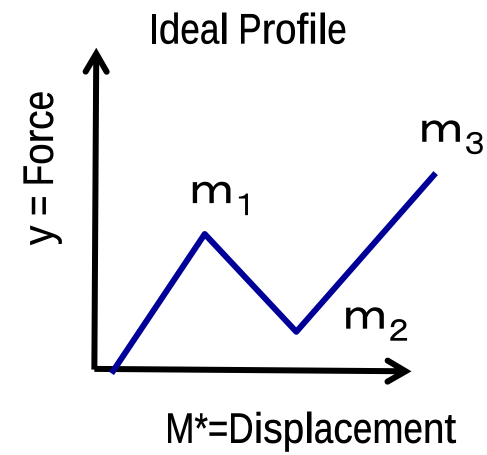
This is a good set of data!!

2000 ITT Switch Feel for Micro Switch

Double Nominal-the-Best

New Idea :
Standardixed S/N



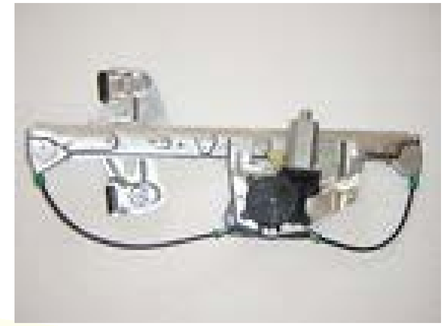


- L18 Optimization by Simulation
- Initially "Double Nominal-the-Best" was used with 20dB gain. Dr. Taguchi thought too much gain and something is wrong. He developed the idea of "Standardized S/N."

2002 Nissan Window Regulator Motor

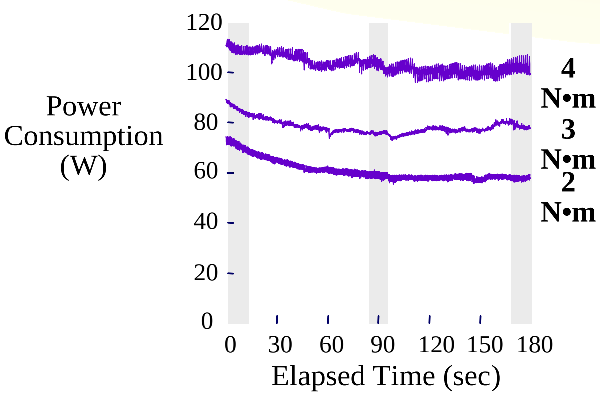
"To get Quality, Don't Measure Quality"

Creative Noise Strategy for Robust Assessment



Input Signal	→	System or Sub-System	→	Output Response
M: Electrical Power		Automotive Direct Current (DC) Motor		y: Mechanical Power

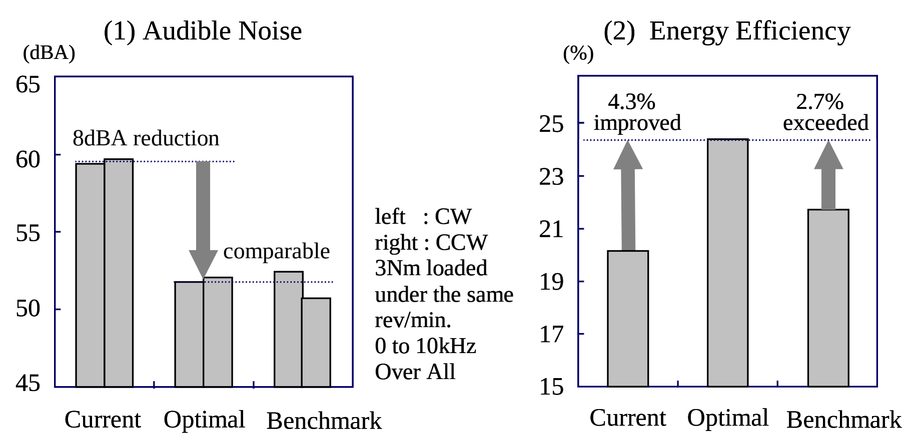
Measurement for Ideal Function



Noise Strategy

	N1	N2
Motor-On Time	0 sec	180 sec

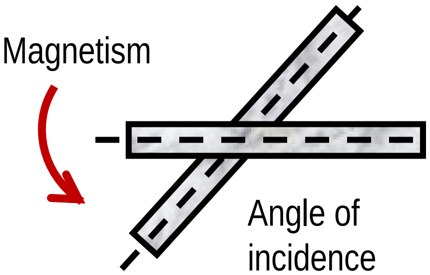
Figure6. Performance Comparison with Benchmark Product

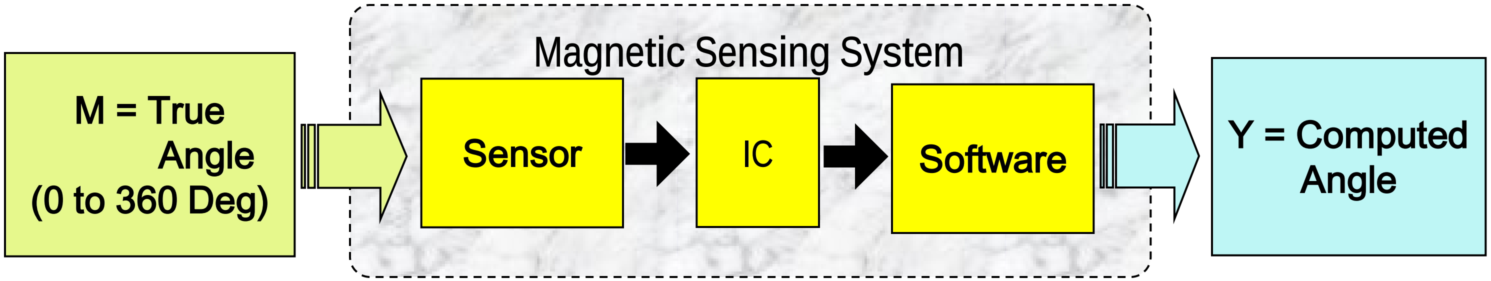


2006 Position Sensor by Alps Electric

Scope Big!!

Make it measurable!! → Simulation Engine



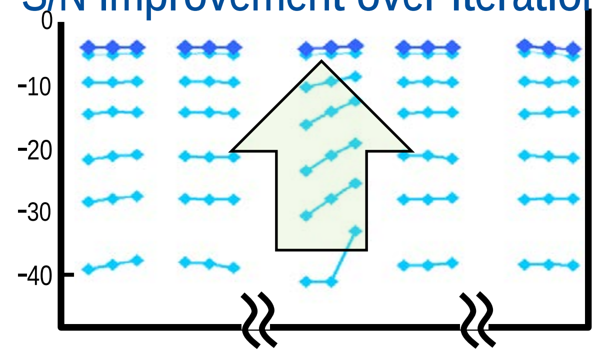


L108 49 Noise Factors

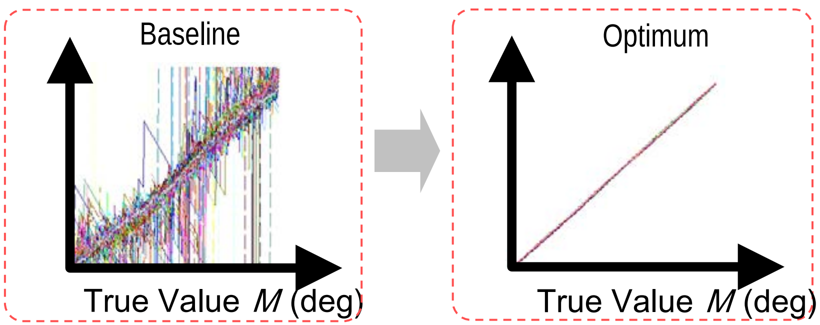
L108 48 Control Factors

108x108x360 = 4,199,090 computations

x 11 iterations



38.7 dB Improvement



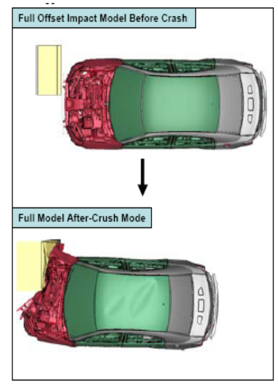
<u>Number of Designs Explored</u>

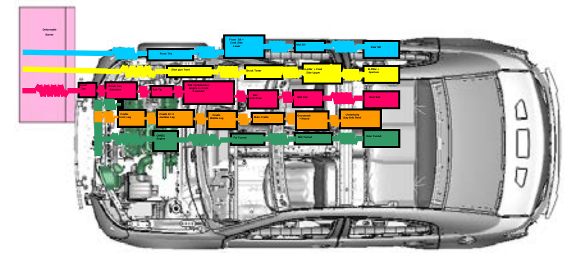
3^{48} x 11 = 877,430,873,845,598,000,000,000

= 0.88 Septillion

2008 Chrysler Frontal Crash

Use of 10-min. Spring Mass Model Simulation vs. 36 Hour Full CAE Simulation

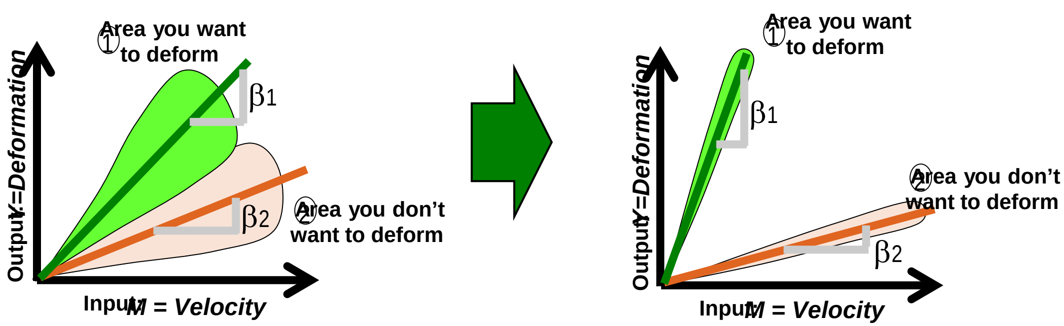


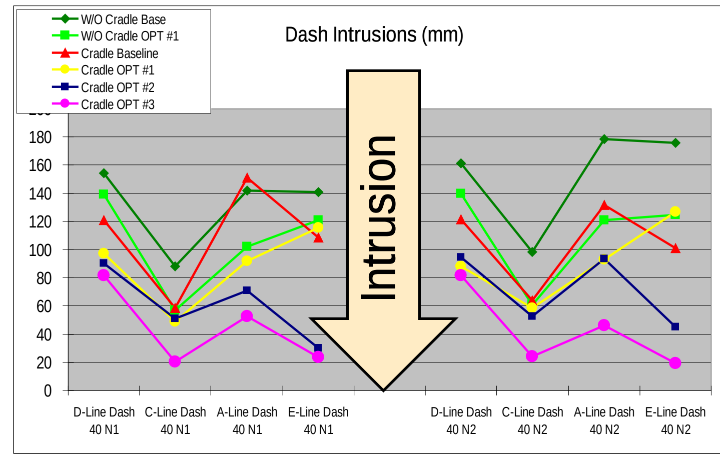


Loading Zone Mass Legends

Dynamic Operating Window

Dynamic Operating Window Ideal Function





Cradle Concept → L54 iterated 5 times

K-member Concept → L54 iterated 5 times

Short Front Concept → L54 iterated 5 times

# of Designs Explored = 3^{23} x 3 x 5 iterations > 1,400,000,000,000