Multivariate Methods for Process and Product Development and Monitoring

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What is Quality?

$$Quality = Fitness\ for\ Use$$ Definition 1

$$Quality \propto \frac{1}{Variability}$$ Definition 2

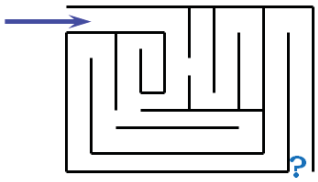
$$Quality = f(Process\ Inputs + Material\ Attributes + \cdots)$$

The key question is to find those variables that most influence quality and minimise their variability

Approaches to Quality

One Variable at a Time (OVAT)
Trial and Error Approach

Six Sigma and Related Approaches
Systematic OVAT



Design of Experiments (DoE) and Multivariate Analysis (MVA)
Smart Design and Manufacturing

What is Design of Experiments?

Design of Experiments (DoE) is the pre-planned, systematic variation of controllable experimental factors that induce a response in a system. The factors are measured in such a way that the minimum effort is required to gain a maximum amount of information.

$$\textbf{Minimum Effort} \Rightarrow \textbf{Maximum Information}$$

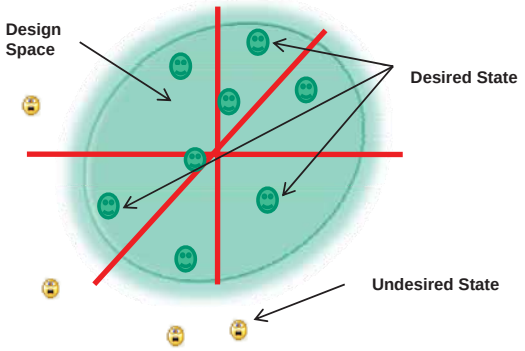
Goals in Product /Process Development

- Develop new products
- Improve existing product
  - Optimal production conditions
  - Stable product quality
  - Decrease cost
  - Bring product close to competitor
- Improve Driver Comfort
- Improve Fuel Efficiency

Link Between Multivariate Analysis and QbD

- The **information** and **knowledge** gained from pharmaceutical development studies and manufacturing experience provide *scientific understanding* to support the establishment of the **Design Space**, Specifications, and **Manufacturing Controls**.

Design Space*: The multidimensional *(i.e. Multivariate)* combination and interaction of input variables and process parameters that have been demonstrated to provide *assurance of quality



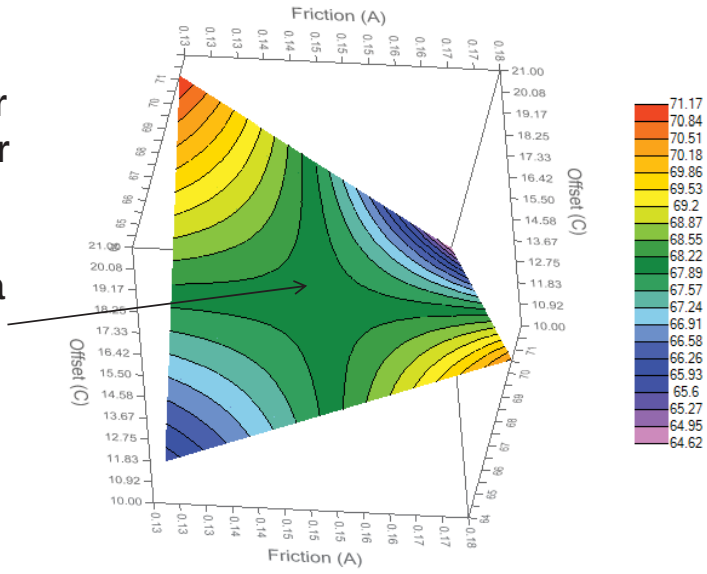
Knowledge* = *Understanding

Output of a Designed Experiment

Example from cross member component manufacture

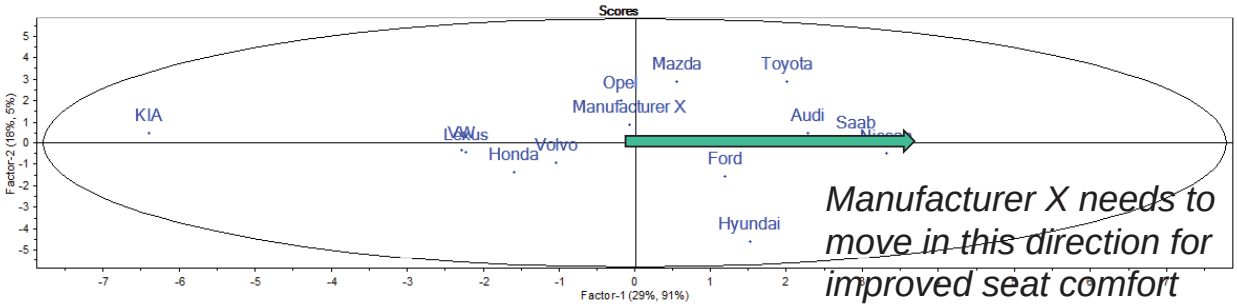
Aim: Find a stable region for springback in cross member production

DoE is able to isolate such a region for consistent manufacture

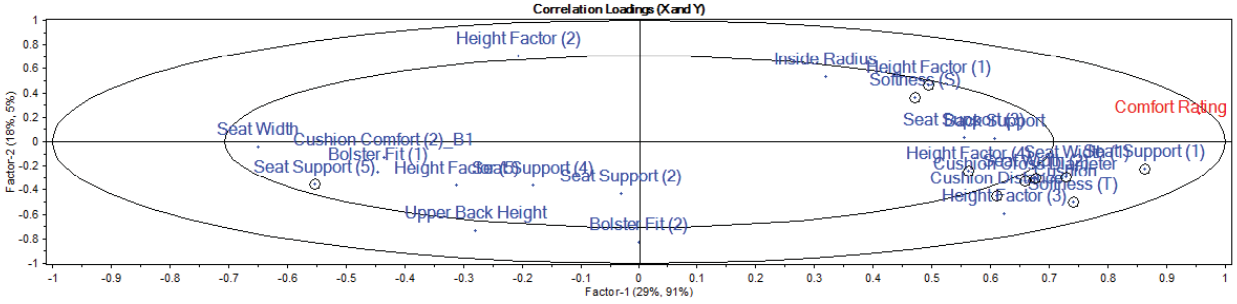


Multivariate Analysis and Sensory Data

A complete map of seat comfort parameters

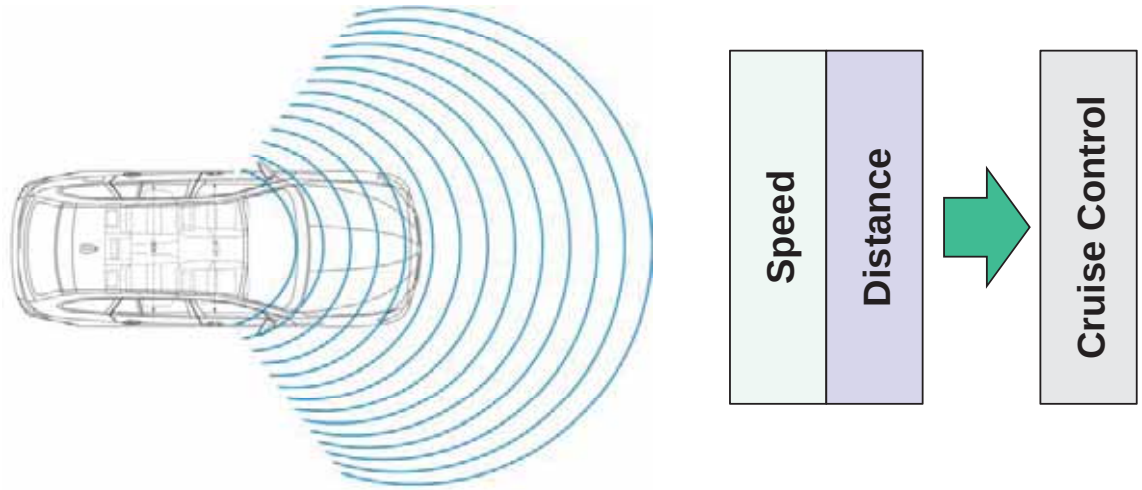


Manufacturer X needs to move in this direction for improved seat comfort



Sensor Fusion Applications

Sensor fusion combines information from multiple sensors such that the information obtained is more complete or dependable than that which would be acquired from the individual sensors



Application of Multiblock Multivariate Analysis

Real Time Monitoring of Process with MVA

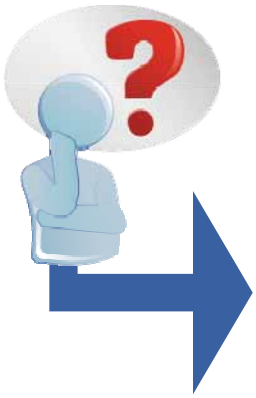
Other Automotive Applications

- **Injection moulding operations**
- **Sensory evaluation of comfort and design aspects**
- **Welding optimisation for enhanced strength and durability**
- **Visual inspection systems for classifying good and bad products**

It's all about Benefits

Objective
- Process Understanding
- Identification and understanding of raw materials
- Product and Process Development
- Root Cause Analysis
- Prediction of Quality

Software Tools
- Design of Experiments (DoE)
- Statistical Hypothesis Tests
- Exploratory Data Analysis
- Regression modelling
- Classification
- Prediction



Benefits
- Time and cost reduction
- Timely development
- Increased market share
- Open new business opportunities and innovations

Automotive example: optimalisation of welding with DOE

Welding machine (40kW)

Automotive example

The main activity of the company is the production of welded and stamped automotive bodywork components for the automotive industry.

The components - after cutting into the right size and shape, then cold forming, pressing, punching, calibration and further cutting - are then assembled and fitted with the necessary binding elements by highly skilled welders on resistance welding machines and on welding robots.

Automotive example

Plate: The screw should be placed here.

Goal: to find the optimal settings (quality & productivity & cost)

M6x16 screw, material: 19MnB4

Automotive example

Destructive test: Each legs have to break out from plate surface.

camo.com Bring data to life

Automotive example

With old settings

evaluation

Pressure	Welding current	Power up timing	Welding time	Torn legs	Visual evaluation
2 – 3 bar	47 – 49 [%]	3 – 8 (periods)	7 – 15 (periods)	2 - 3	2 - 5

The legs were torned, but the plate was not torned completely.

Bring data to life

Automotive example

Torn legs

To be optimised further

Not significant in this range (after screening)

Pressure	Welding current	Power up timing	Welding time	Torn legs	Visual evaluation
3 - 4,5 bar	30 – 47 [%]	3 – 6 (periods)	7 – 9 (periods)	?	?

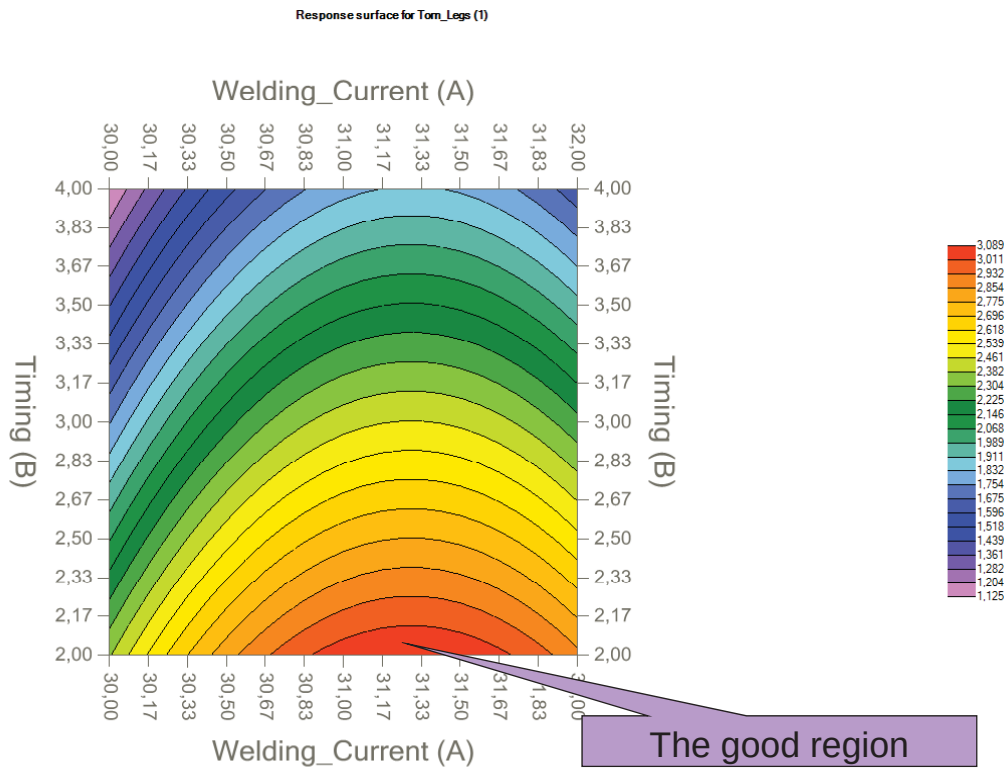
Not significant in the range

ANOVA Table - Torn_Legs					
ANOVA	SS	DF	MS	F-ratio	p-value
Summary					
Model	4,3107	3,0000	1,4369	7,5652	0,0051
Error	2,0893	11,0000	0,1899		
Corr. total	6,4000	14,0000			
Variables					
Welding_Current (A)	0,5000	1,0000	0,5000	2,6325	0,1330
Timing (B)	3,1250	1,0000	3,1250	16,4530	0,0019
Welding_Current*Welding_Current (AA)	0,6857	1,0000	0,6857	3,6103	0,0839
Model check					
Mean	72,6000	1,0000	72,6000	382,2359	0,0000
Linear	3,6250	2,0000	1,8125	9,5427	0,0040
Interaction 2					
Interaction 3					
Quadratic	0,6857	1,0000	0,6857	3,6103	0,0839
Cubic					
Total					
Lack of Fit					
Lack of fit	1,4226	9,0000	0,1581	0,4742	0,8226

Bring data to life

Automotive example

Torn legs



Automotive example

Visual evaluation

To be optimised further

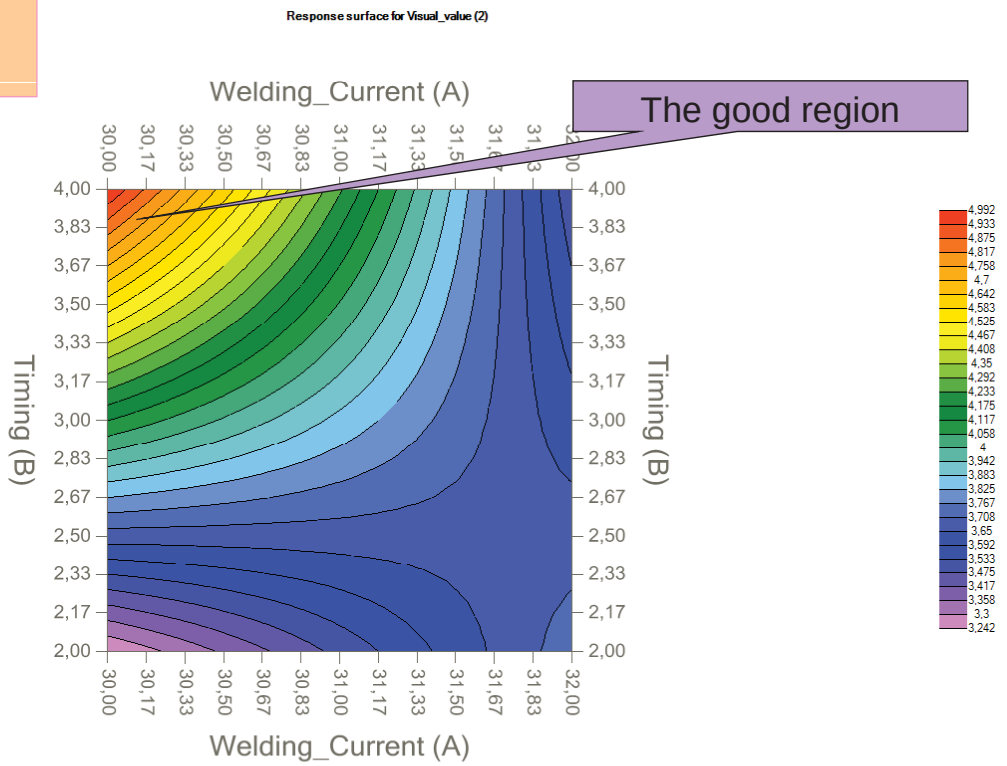
Pressure	Welding current	Power up timing	Welding time	Torn legs	Visual evaluation
3 - 4,5 bar	30 – 47 [%]	3 – 6 (periods)	7 – 9 (periods)	?	?

Not significant in the range

ANOVA Table - Visual_value					
ANOVA	SS	DF	MS	F-ratio	p-value
Summary					
Model	3,7500	4,0000	0,9375	4,7269	0,0212
Error	1,9833	10,0000	0,1983		
Corr. total	5,7333	14,0000			
Variables					
Welding_Current (A)	0,5000	1,0000	0,5000	2,5210	0,1434
Timing (B)	1,1250	1,0000	1,1250	5,6723	0,0385
Welding_Time (C)	1,1250	1,0000	1,1250	5,6723	0,0385
Welding_Current*Timing (AB)	1,0000	1,0000	1,0000	5,0420	0,0486
Model check					
Mean	224,2667	1,0000	224,2667	1130,7563	0,0000
Linear	2,7500	3,0000	0,9167	4,6218	0,0282
Interaction 2	1,0000	1,0000	1,0000	5,0420	0,0486
Interaction 3					
Quadratic					
Cubic					
Total					
Lack of Fit					
Lack of fit	1,3167	8,0000	0,1646	0,4938	0,8058

Automotive example

Visual evaluation



Automotive example

With new settings

Pressure	Welding current	Power up timing	Welding time	Torn legs	Visual evaluation
4,5 bar	31 [%]	3 (periods)	8 (periods)	3	4 - 5

The legs were torned.

Welding current were minimised: savings!

31/48=0,65 → 35% savings

The torning lines are more defined.

Automotive example

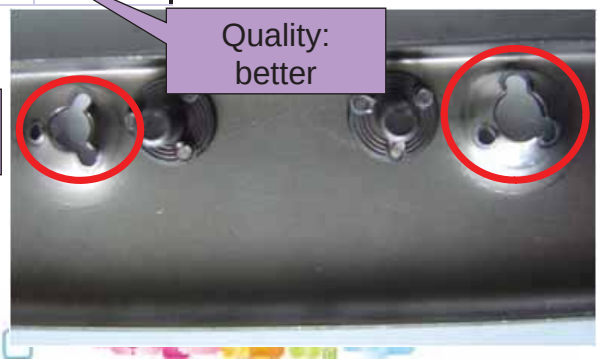
Summary

Pressure	Welding current	Power up timing	Welding time	Torn legs	Visual evaluation
2 – 3 bar	47 – 49 [%]	3 – 8 (periods)	7 – 15 (periods)	2 - 3	2 - 5
Averages:	48%	5,5	11		

Pressure	Welding current	Power up timing	Welding time	Torn legs	Visual evaluation
4,5 bar	31 [%]	3 (periods)	8 (periods)	3	4 - 5

Cost: 35% savings

Productivity: 33% better



Quality: better

Thank you for your attention

Questions and Answers