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Robust Design Principles to Evaluate Additive Manufacturing Capabilities

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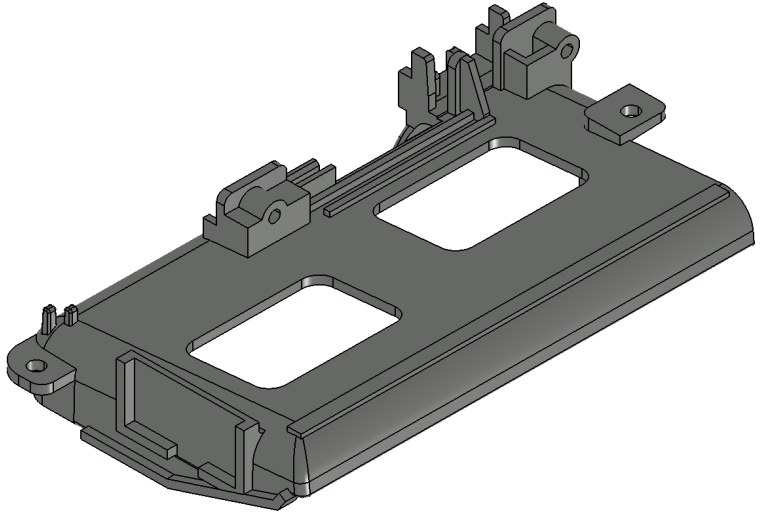
Geometry of the study case

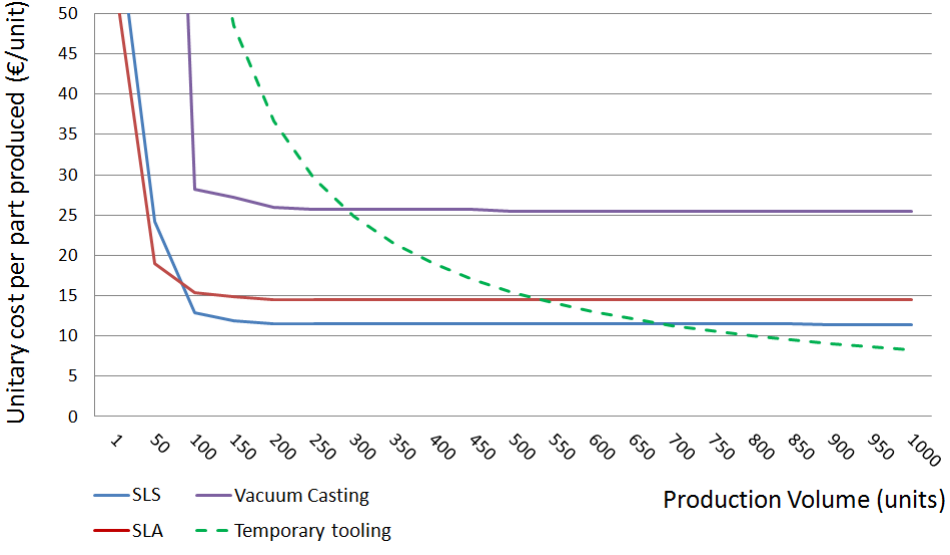
- Inner structural plastic part of a consumer-electronic product
- No aesthetic requirements - only dimensional
- Manufactured by injection molding

Injection moulding soft tooling investment	
Tool Investment cost	7,100 € / tool
Cost per part produced	1,15 € / unit



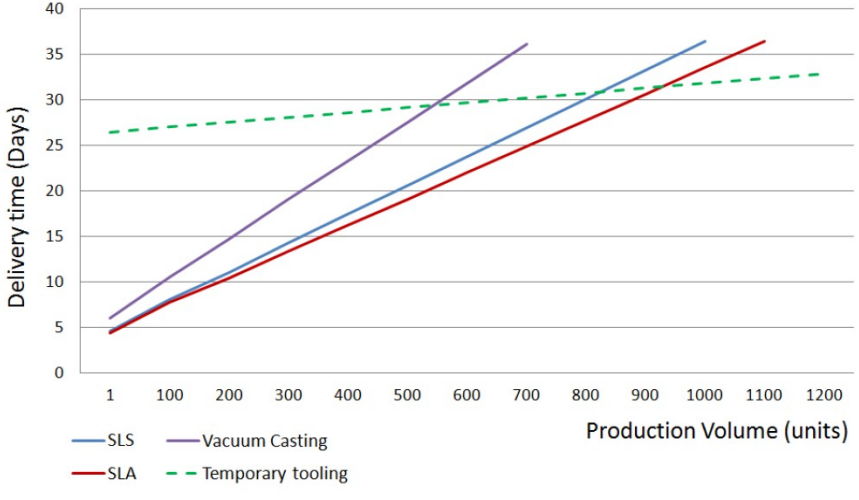
68.125mm X 37.241mm X 14.854mm

The engineering problem



- High initial investment in Injection Molding tooling
- Huge product portfolio, Multiple product variants

- High uncertainty during the Product Development
- Time to market and competition



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Additive Manufacturing

Technical prototyping and short-run production

Q1 – Is it possible to replace injection molded parts by AM parts?

Q2 – How can I select optimal machine and process variables?

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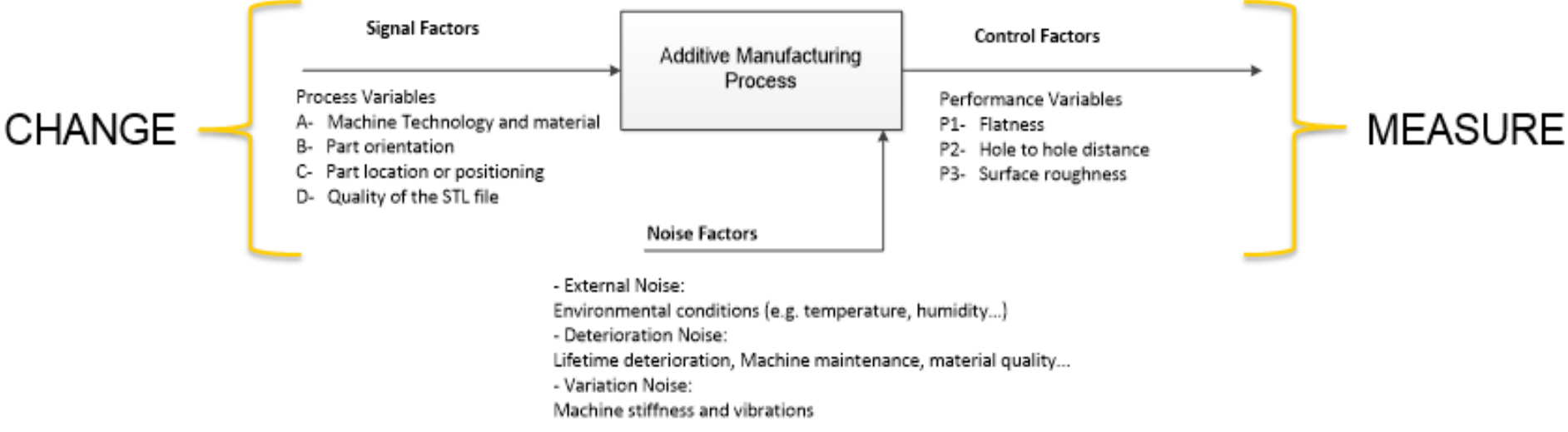
Why to use Robust Design methods in this research?

Parameter Diagram

When using robust methods, several Signal Factors can be varied simultaneously in a controlled manner to predict causal relationships towards the Control Factor, and therefore obtain reliable, repeatable and structured data.

Adapted from: R. A. Fisher, 1935, "The Design of Experiments".



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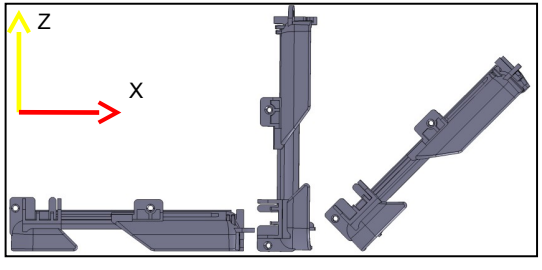
Signal Factors

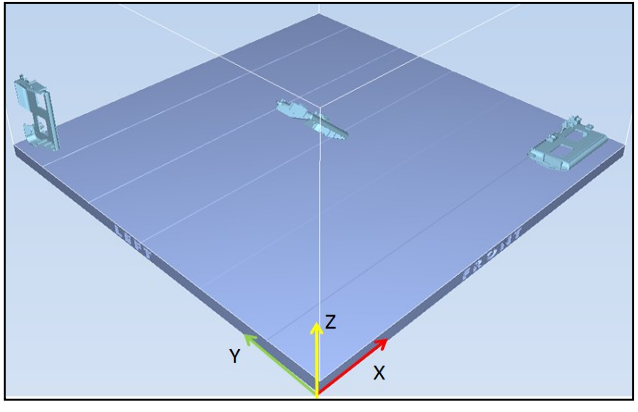
Process variables		Level 1	Level 2	Level 3
A	Machine and Material	M1 - SLA	M2 - Polyjet	M3 – Laser Sintering
B	Part Orientation	Horizontal	Vertical	Diagonal
C	Part Location	Top Left	Centre	Bottom Right
D	Digital Quality	High (0.001mm)	Medium (0.01mm)	Low (0.1mm)

A

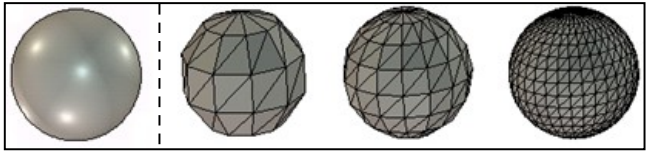
B



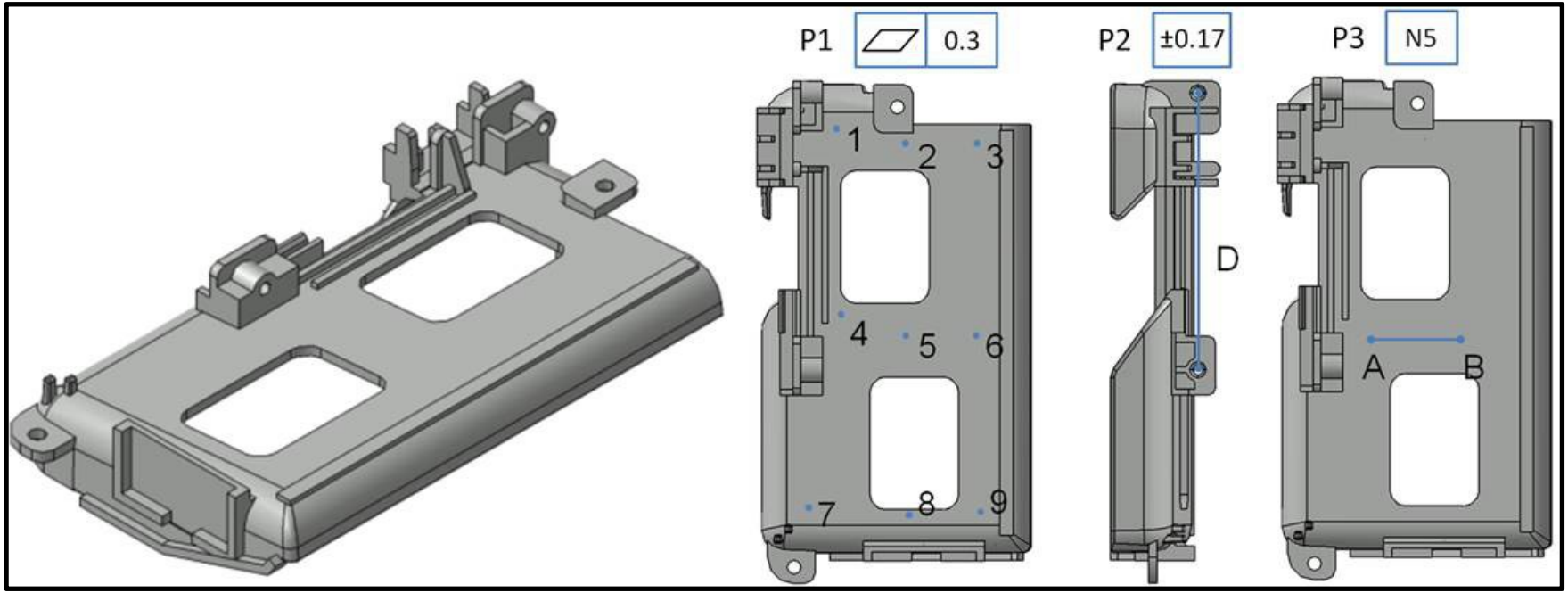
C



D



Control factors



Performance Variables		Optimization Objective	Requirement
P1	GD&T - Flatness (mm)	Minimize	0.3 mm (max.)
P2	Hole to hole distance D (mm)	On target	37.55 +/- 0.17 mm
P3	Surface roughness Ra (µm)	Minimize	0.8 µm (max.)

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DOE - Taguchi L9 Array

- By changing the factors “One At The Time” => *Levels Signal Factors*
- To simplify experimental approach, a Taguchi DOE was implemented.
- L9 orthogonal array was selected to drive the experiment

Exp.	A (Machine & Material)	B (Part Orientation)	C (Part Location)	D (Digital Quality)
1	M1	Horizontal	Top Left	High
2	M1	Vertical	Centre	Medium
3	M1	Diagonal (45deg)	Bottom Right	Low
4	M2	Horizontal	Centre	Low
5	M2	Vertical	Bottom Right	High
6	M2	Diagonal (45deg)	Top Left	Medium
7	M3	Horizontal	Bottom Right	Medium
8	M3	Vertical	Top Left	Low
9	M3	Diagonal (45deg)	Centre	High

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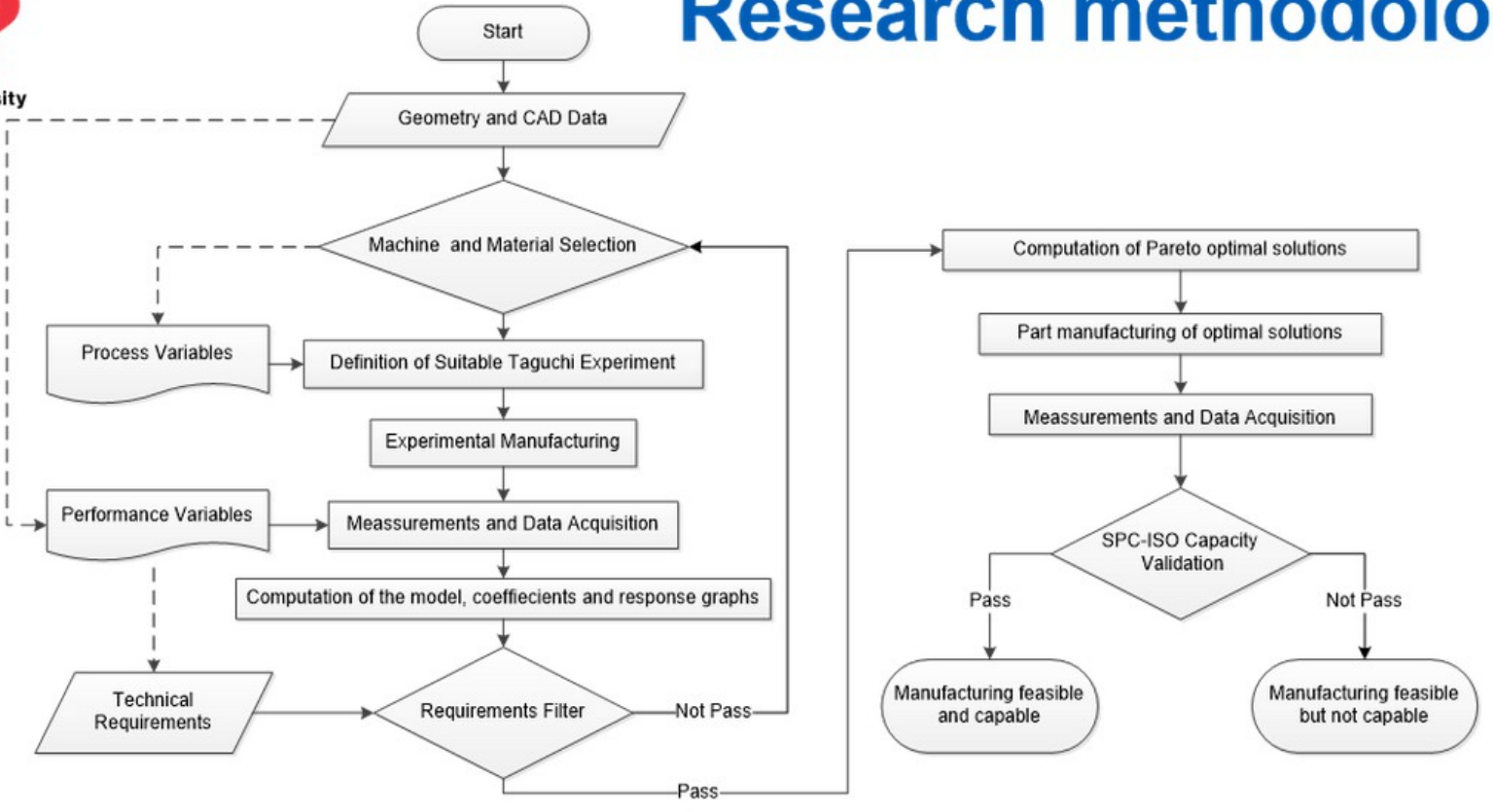
Research methodology



The research methodology uses Taguchi design of experiments, multi-objective optimization and statistical process control, to optimize the manufacturing process and fulfil multiple requirements imposed to an arbitrary geometry

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Experimental results, an overview:

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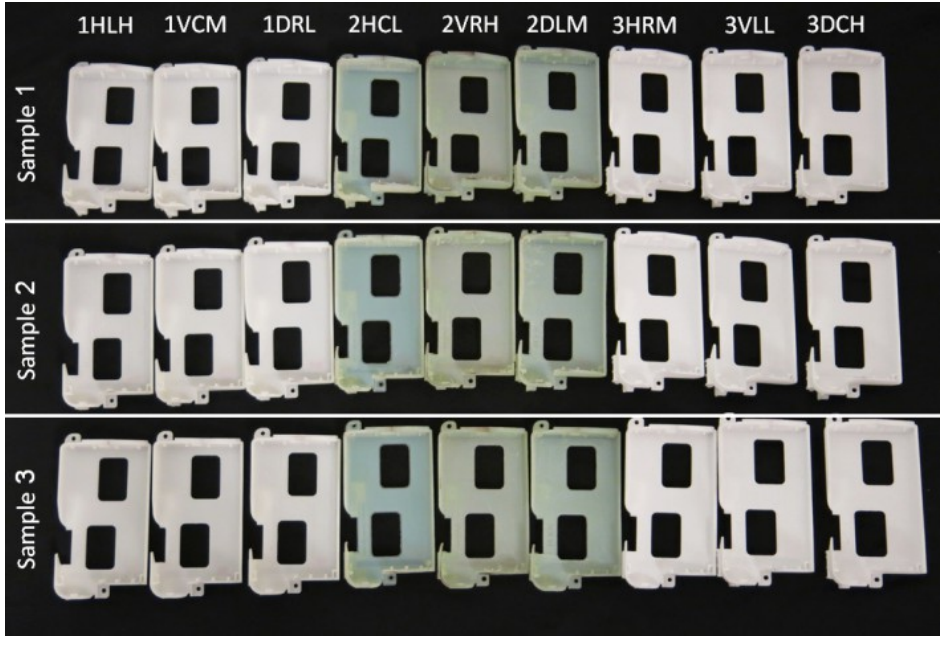
Manufactured sample during the DOE

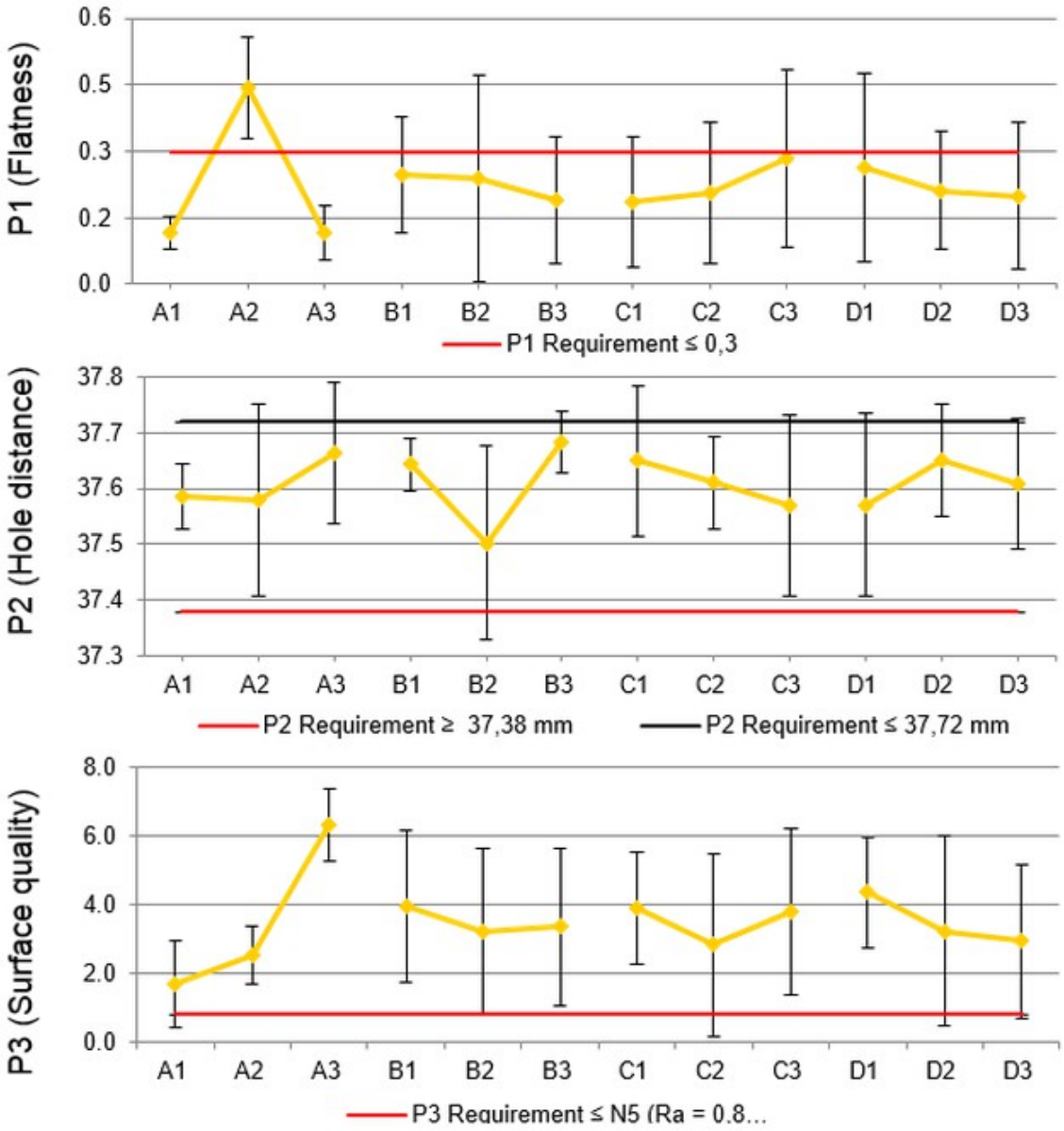


- Three samples of the L9 were produced
- Each sample was measured twice
- The variance of the experiment and measurement process was taken into account.

Response Graphics

Based on the results:

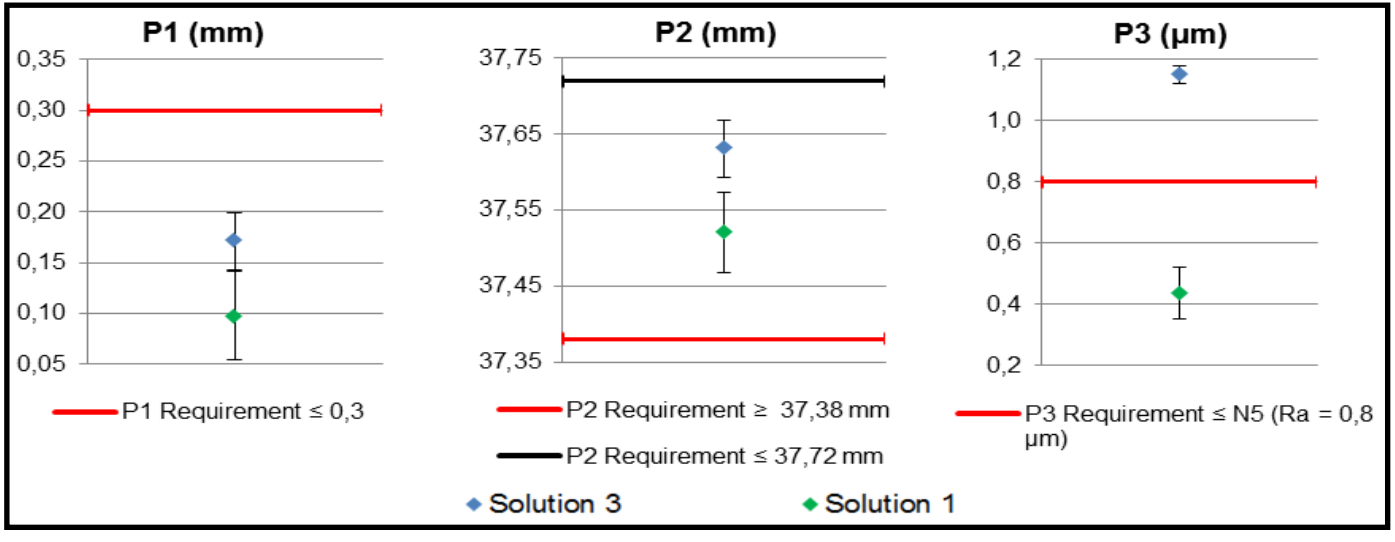
- Only M1 was potentially feasible
- M2 and M3 were not within requirements
- After the filter result, only three non-dominated solutions were able to satisfy the imposed requirements



Capability analysis (Cp and Cpk)

Results of the ISO-SPC capability analysis show that:

- Solution 1 is capable but not centred



Process variable	Solution 1
A (Machine and material)	A1 (M1)
B (Part Orientation)	B2 (Vertical)
C (Part Location)	C2 (Centre)
D (Digital Quality)	D2 (Medium)

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Conclusions

Q1 – Is it possible to replace injection molded parts by AM parts?

- Based on the results, typical requirements imposed to injection moulding plastic parts for consumer devices are challenging to fulfil by AM technology
- Full production feasibility and robustness cannot be yet met with AM technology when geometrical, dimensional and especially surface quality requirements are high
- Nevertheless, technical prototyping and short-run production is feasible using AM systems. Therefore, injection molding can be replaced in certain cases

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Learning outcomes

Q2 – How can I select optimal machine and process variables?

- Robust Design methodology can be used to create guidelines for machine users and increase the automation level of machine and process parameters selection
- In the future, standardized SPC methods will need to be applied to evaluate the robustness of AM systems for direct component manufacturing and short-run production
- Future research is planned to evaluate robustness of AM systems by including interactions between variables, mechanical performance variables and the effect of noise factors associated with AM technology (e.g. environmental noise, deterioration noise and variation noise).

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Questions?

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