Professor Rikard Söderberg

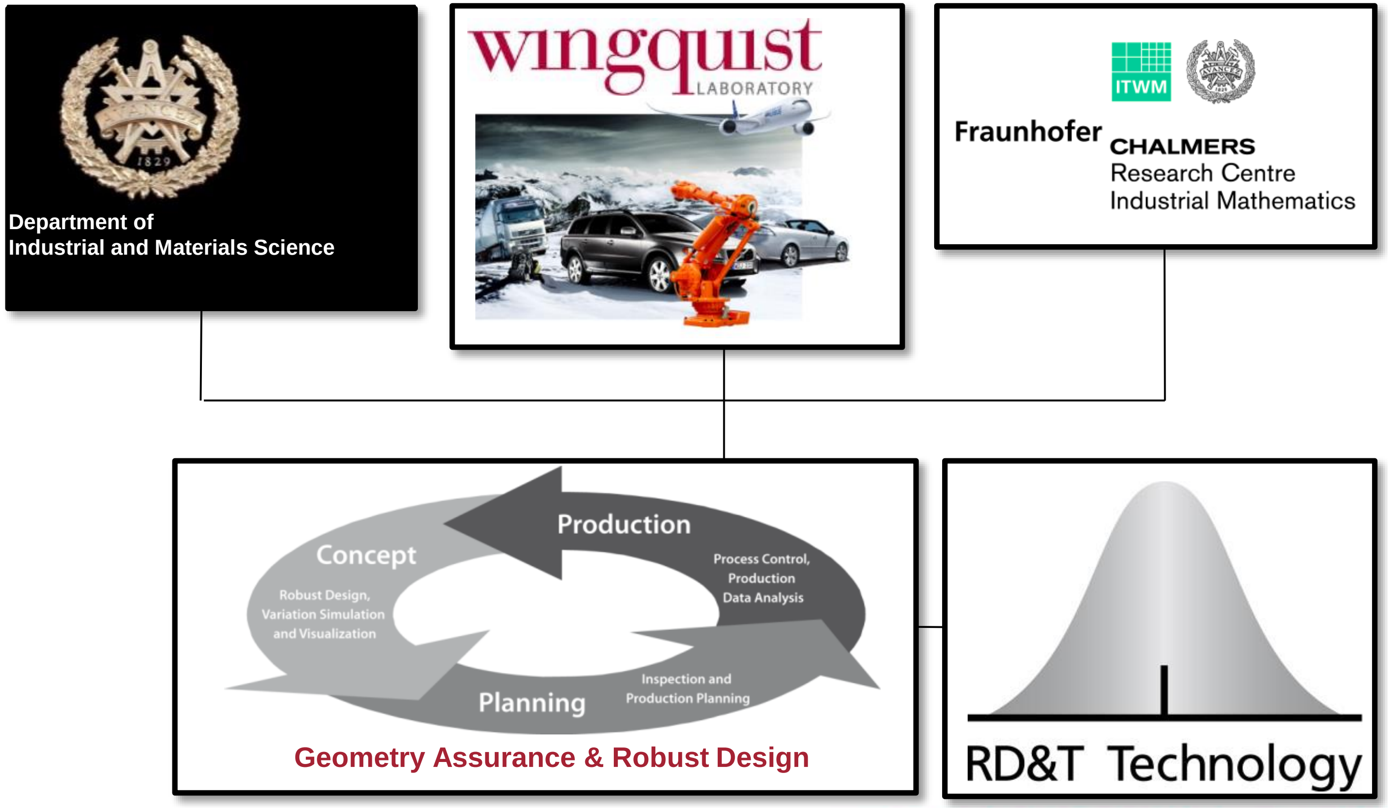
Head of Department of Industrial and Materials Science

Director for Wingquist Laboratory

Chairman of the board for Fraunhofer Chalmers Centre (FCC)

Research Leader Geometry Assurance & Robust Design

Founder of RD&T Technology

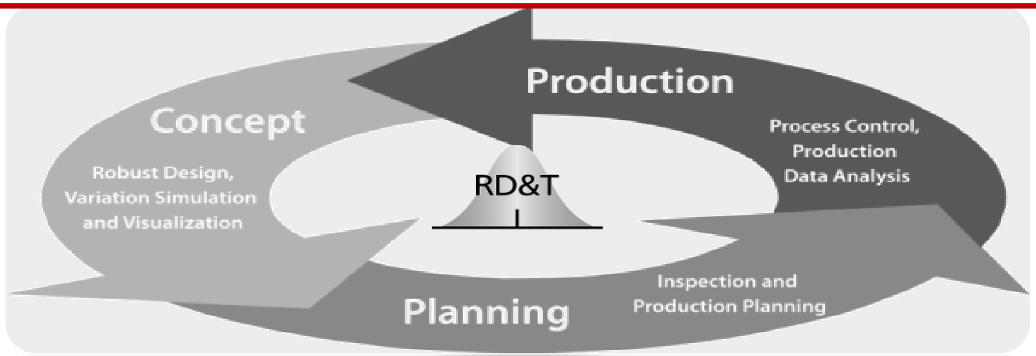


CHALMERS
UNIVERSITY OF TECHNOLOGY

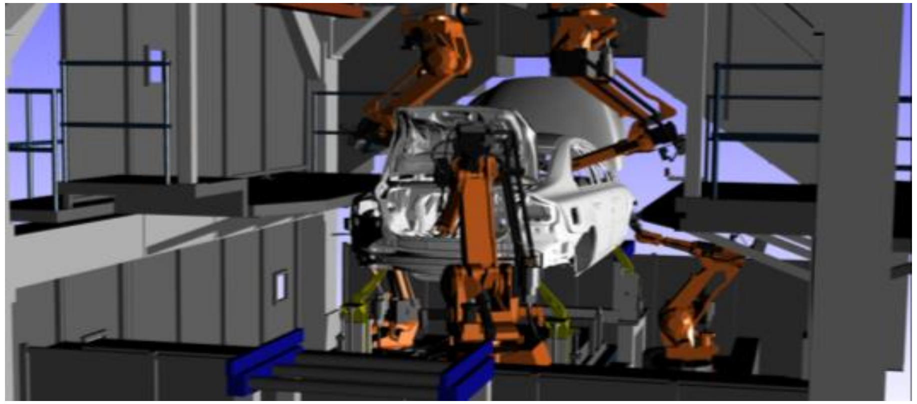
wingquist LABORATORY

Research Groups

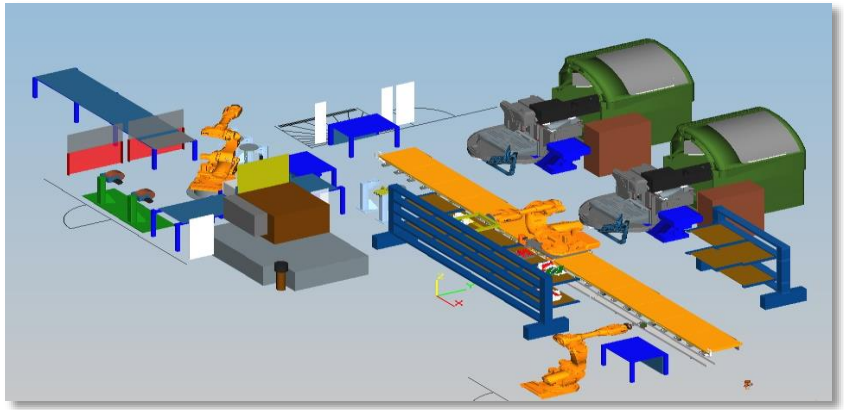
Systems Engineering and PLM
Lean development processes supported by IT-based methods & tools



Geometry Assurance & Robust Design
Minimizing the effect of geometrical variation in assembled products



Geometry and Motion Planning
Math based algorithms and software for efficient product and production development



Automation
Virtual development and integration of product, production and automation systems

CHALMERS UNIVERSITY OF TECHNOLOGY

wingquist LABORATORY

Geometry Assurance & Robust Design Group

- Rikard Söderberg, Professor, Research Group Leader
- Lars Lindkvist, Associate Professor
- Kristina Wärmefjord, Associate Professor
- Alf Andersson, Adjunct Professor (VCG)
- Andreas Dagman, PhD, lecturer

- Casper Wickman, PhD, industrial post-doc (VCG)
- Johan Lööf, PhD, industrial post-doc (GKN)
- Johan Vallhagen, PhD, industrial post-doc (GKN)
- Anders Forslund, PhD, post-doc (Chalmers)

- Johan Carlson, PhD, FCC
- Fredrik Edelvik, PhD, FCC
- Samuel Lorin, PhD, FCC
- Cristoffer Cromvik, PhD, FCC

- Björn Lindau, industrial PhD student (VCC)
- Peter Edholm, PhD student
- Mikael Rosenqvist, PhD student
- Julia Madrid, PhD student
- Konstantinos Stylidis, PhD student
- Soner Camuz, PhD student
- Tomas Hermansson, PhD student, FCC
- Domenico Spensieri, PhD student, FCC
- Vaishak Sagar, PhD student
- Roham Tabar, PhD student
- Abolfazl Rezaei Aderiani, PhD student
- Mohsen Bayani, industrial PhD student (VCC)
- Julia Orlowska, PhD student

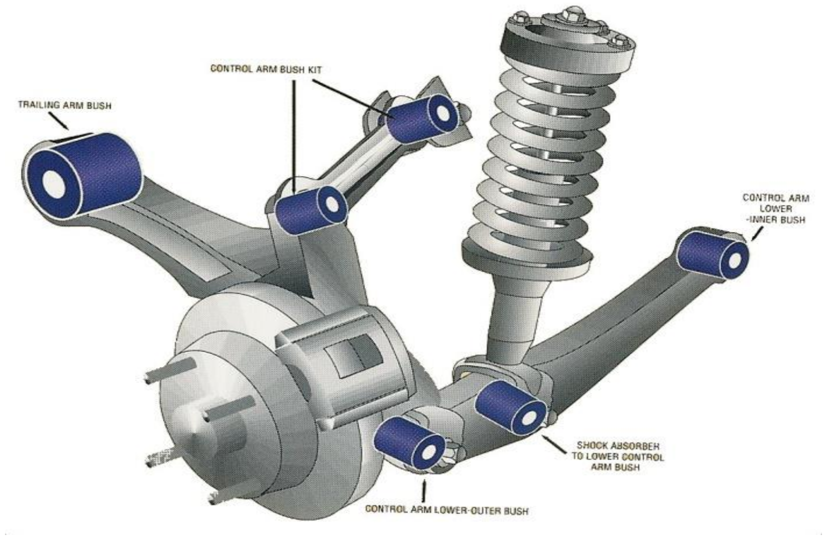
CHALMERS UNIVERSITY OF TECHNOLOGY

wingquist LABORATORY

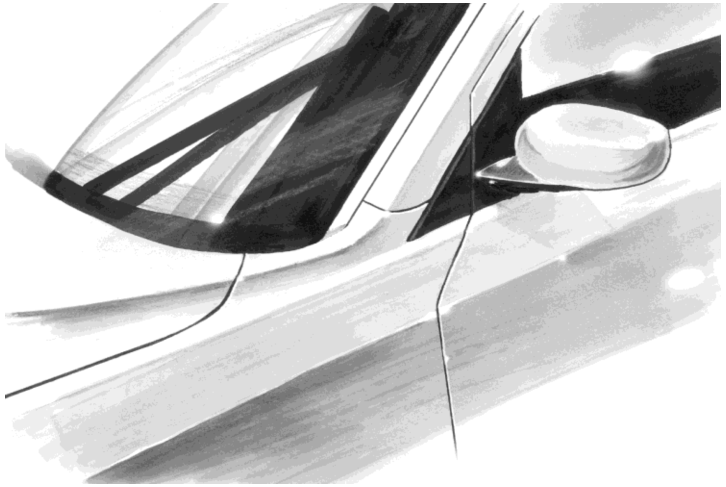
Geometrical Variation

Geometrical **variation** on **individual parts** (form and size), as well as **assembly** variation, affects requirements on:

Assembly



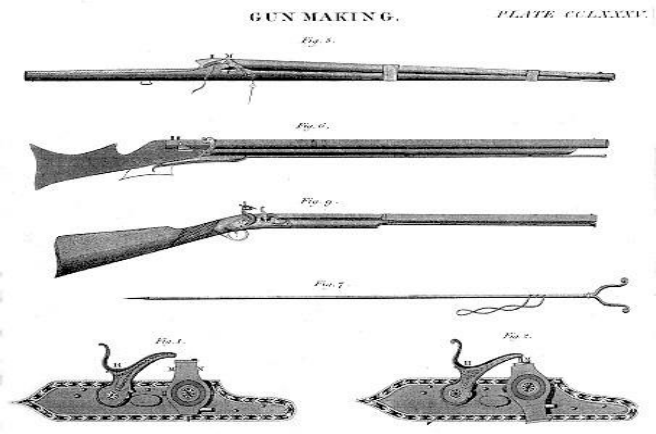
Function



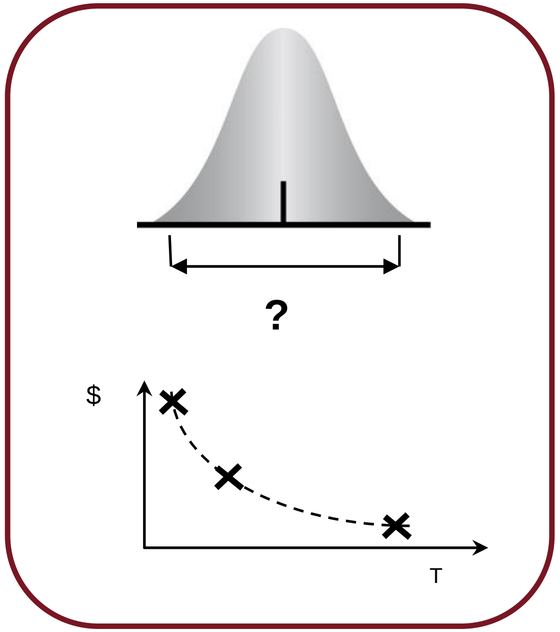
Perceived Quality

Tolerances - the key to mass production


Honoré Blanc, French gunsmith



Firearms with **interchangeable** flint locks, 1778.



The concept of **interchangeability** was **crucial** to the introduction of the **assembly line** at the beginning of the 20th century.


Ford assembly line, 1913.

CHALMERS UNIVERSITY OF TECHNOLOGY

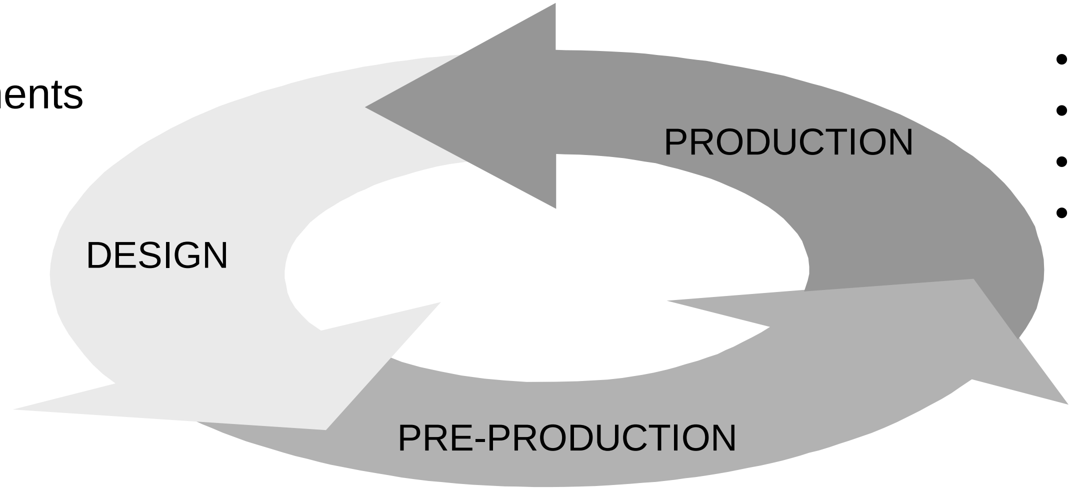
wingquist LABORATORY

Geometry Assurance

Geometry Assurance is the set of activities that aims to *minimizing the effect of geometrical variation in the final product*.

Specification of:

- product requirements
- part tolerances
- locators/datums



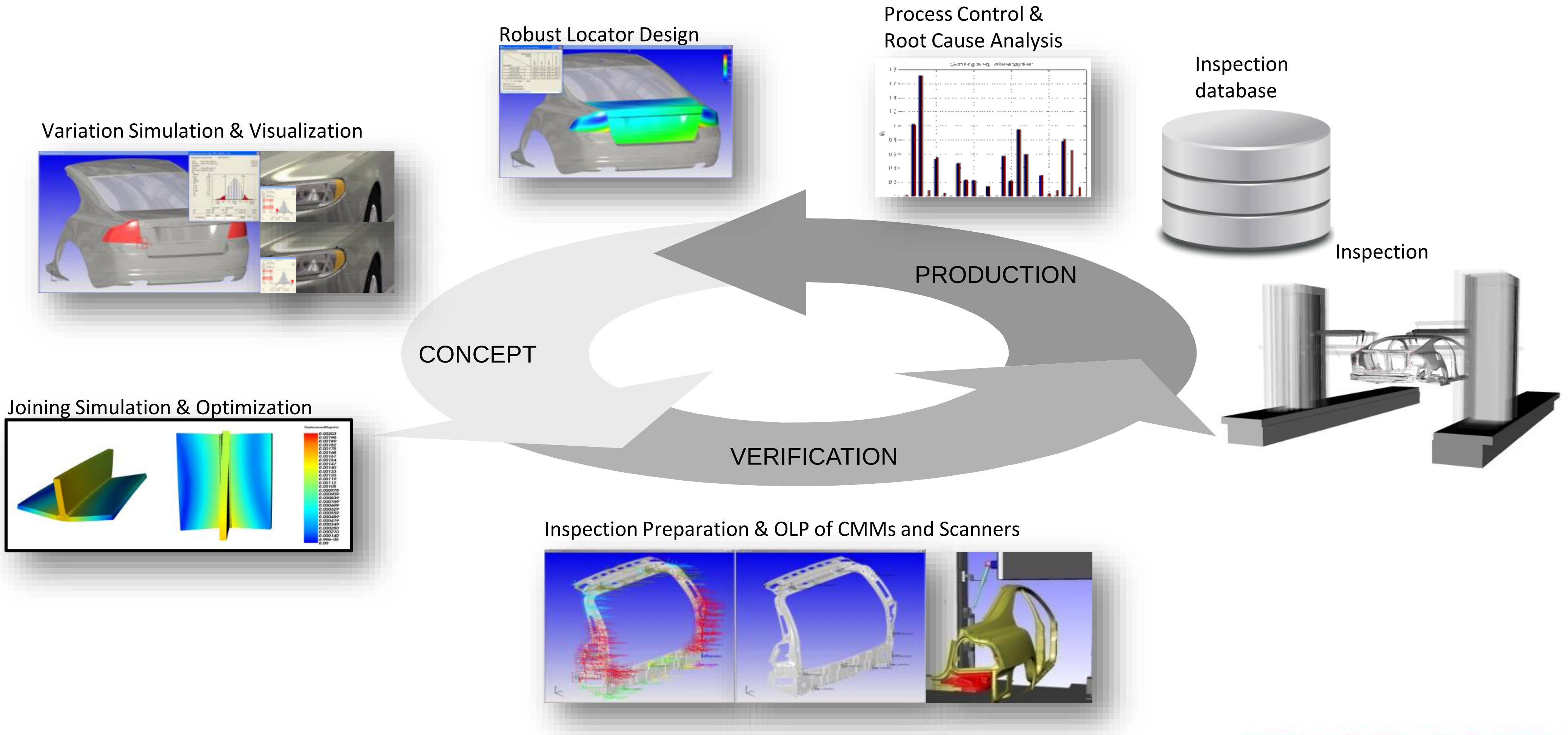
- Inspection
- Data analysis
- Process control
- Design feedback

- Inspection preparation
- OLP of inspection devices

Geometry assurance is to a great extent supported by simulation and digital tools

RD&T Geometry Assurance Toolbox

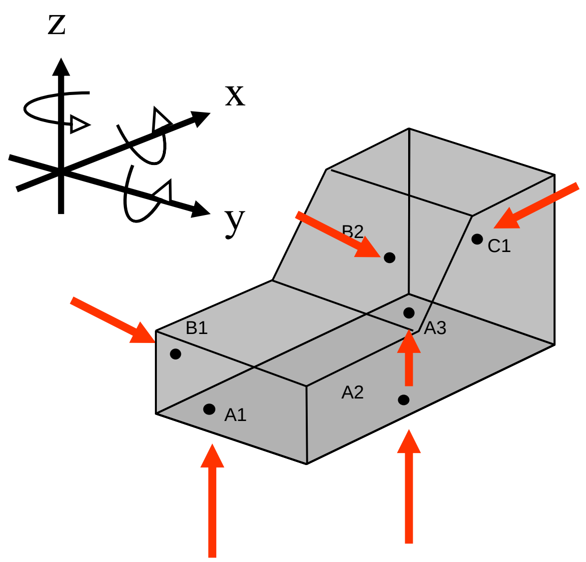
- minimizing the effect of geometrical variation



CHALMERS
UNIVERSITY OF TECHNOLOGY

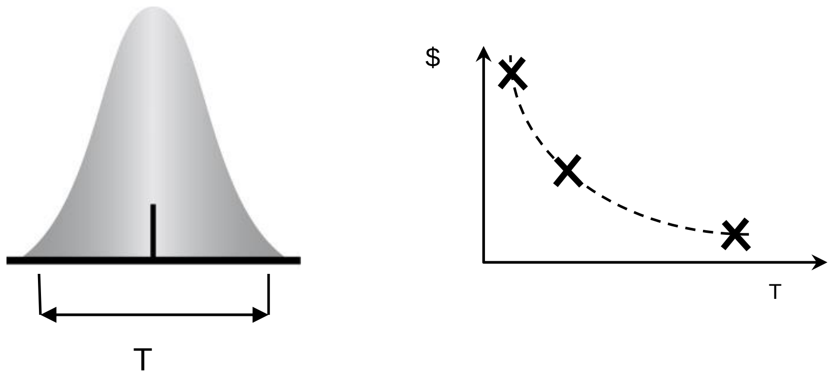
wingquist
LABORATORY

Two main “parameters”



Locating schemes

- Lock 6 DOFs in space
- Control robustness

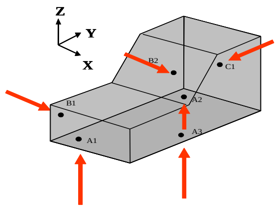


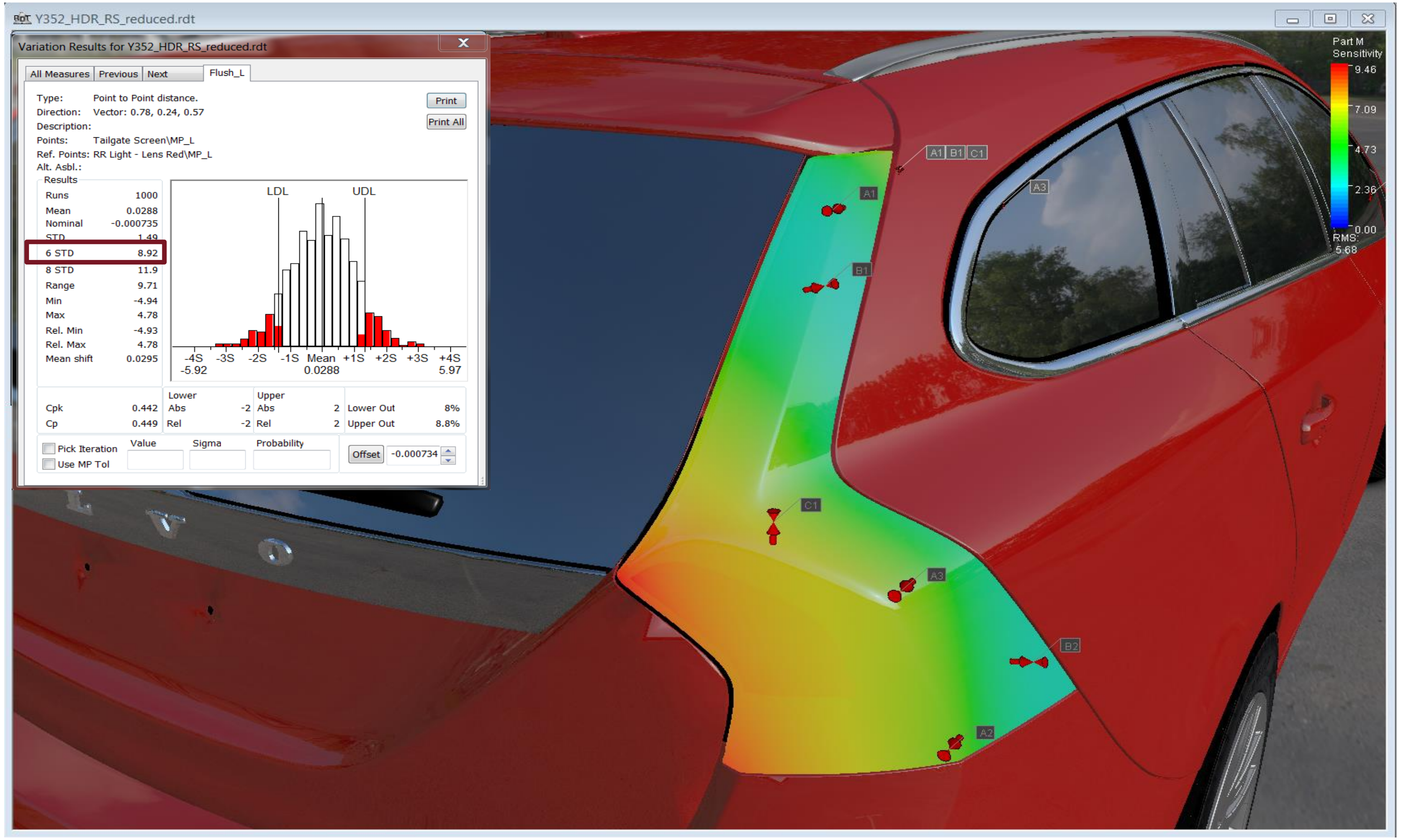
Tolerances

- Define allowed variation
- Control cost

RD&T Software

Stability Analysis



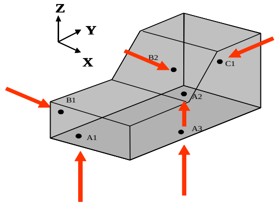


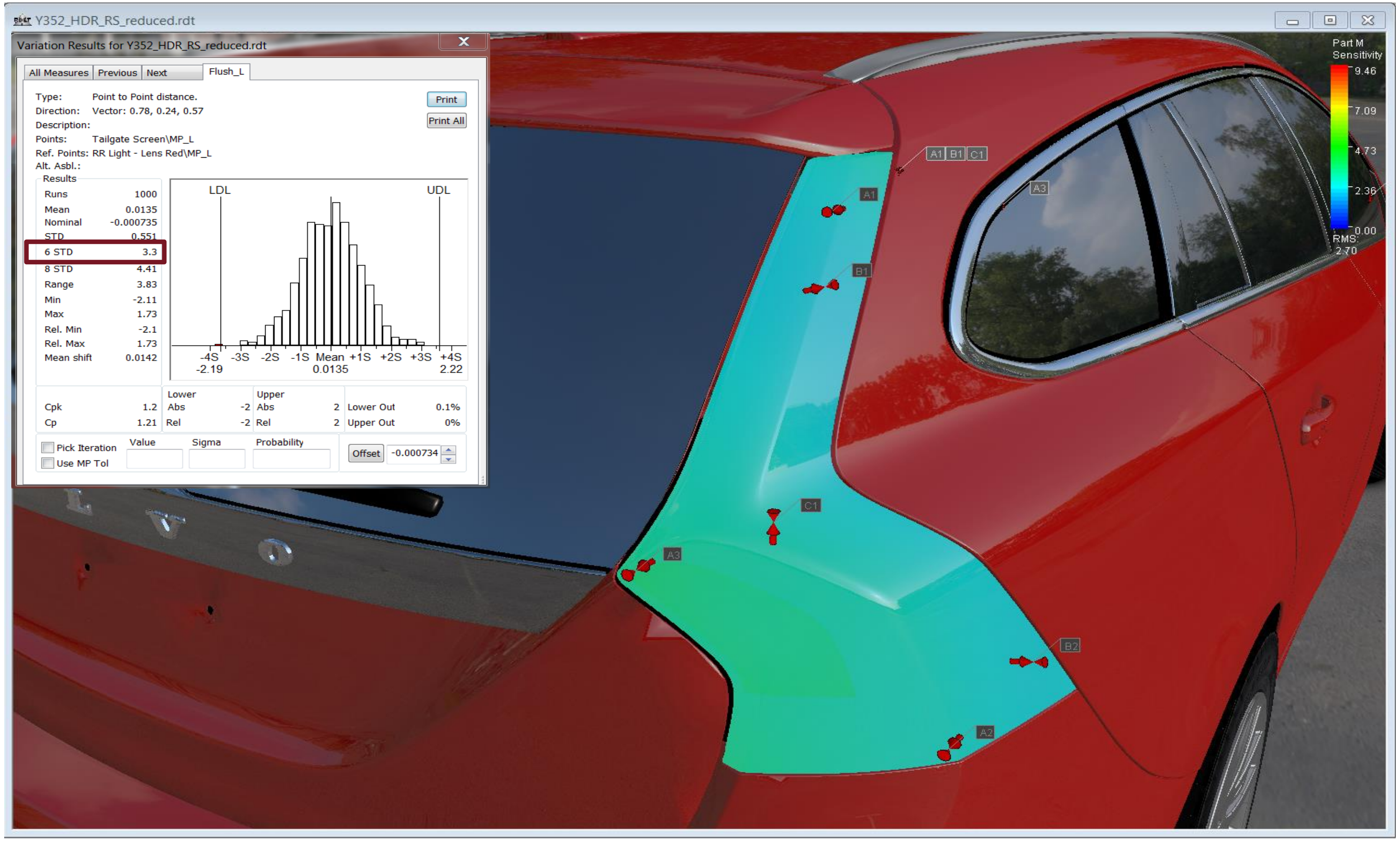
Identifies sensitive areas

CHALMERS
UNIVERSITY OF TECHNOLOGY

wingquist LABORATORY

Stability Analysis



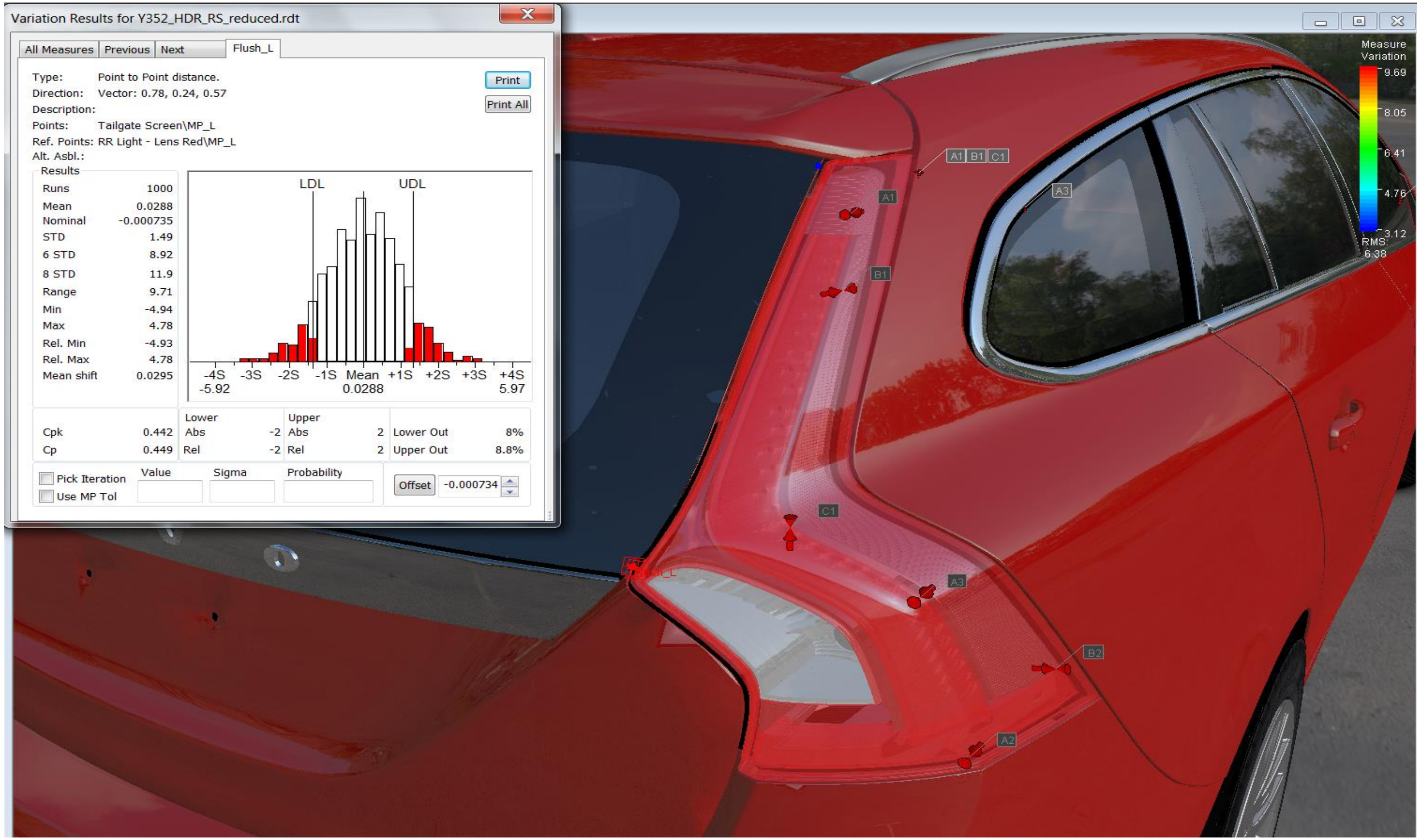


Reduced sensitivity – reduces variation

CHALMERS
UNIVERSITY OF TECHNOLOGY

wingquist
LABORATORY

Statistical Variation Simulation

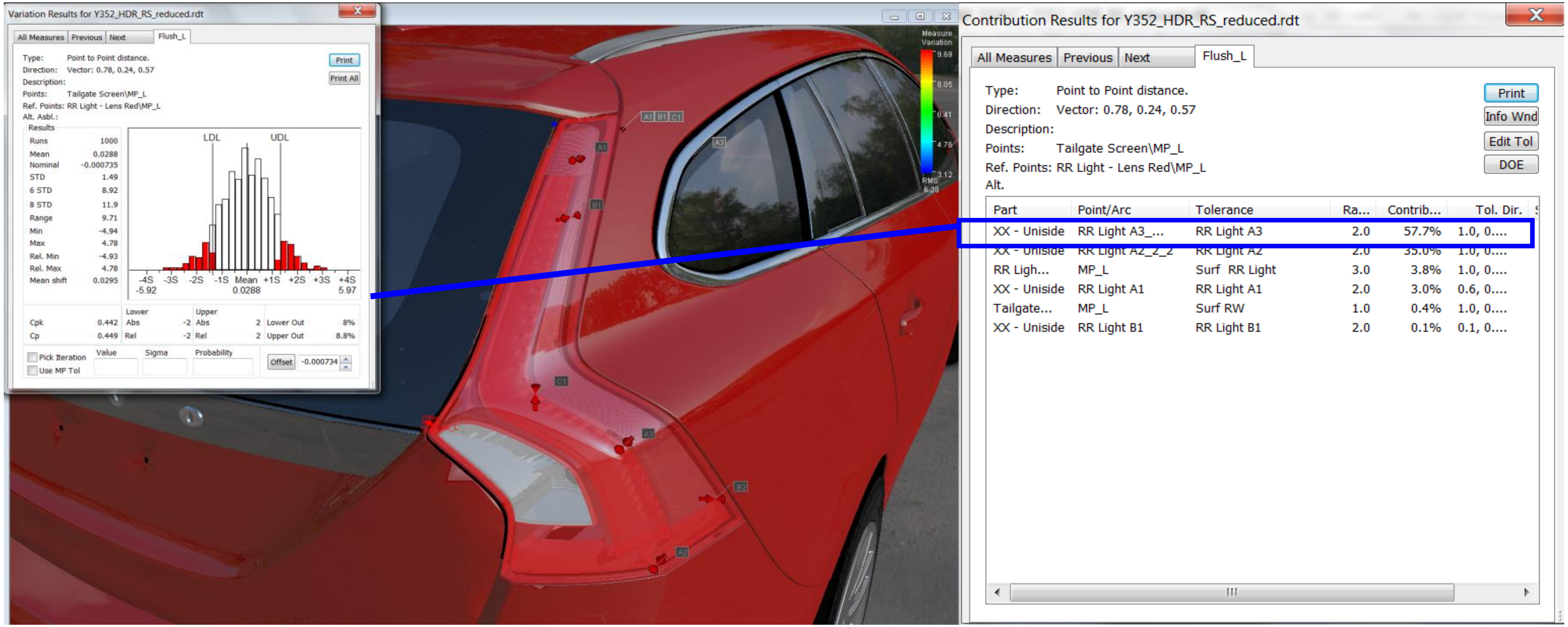


How much variation in critical dimensions?

CHALMERS UNIVERSITY OF TECHNOLOGY

wingquist LABORATORY

Contribution Analysis



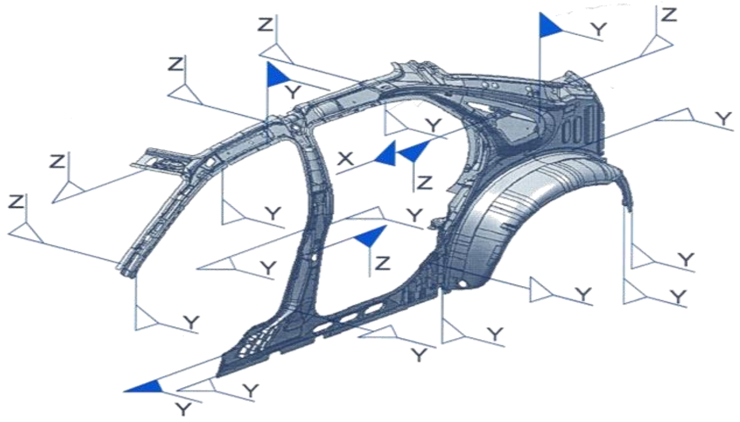
What are the main contributors to variation?

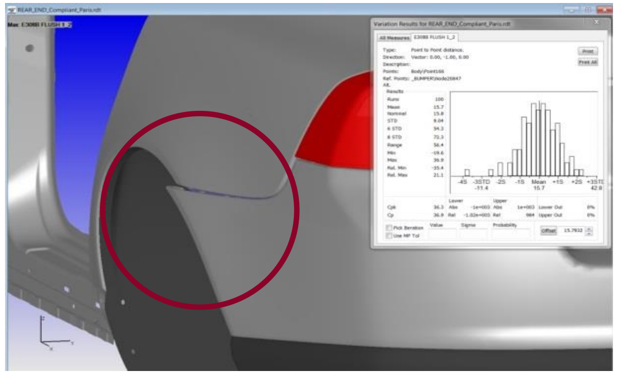
CHALMERS UNIVERSITY OF TECHNOLOGY

wingquist LABORATORY

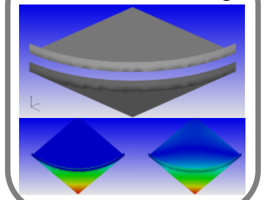
RD&T Non-rigid Variation Simulation

- Parts are allowed to bend during assembly due to errors in part geometries and fixtures
- FEA-based, including:
  - Over-constrained locating schemes
  - Forces, deformations and spring back
  - Contact modeling
  - Joining sequence
  - Stress
  - Heat
  - Gravity
  - Composites
  - Welding
- Monte Carlo Simulation (statistical)

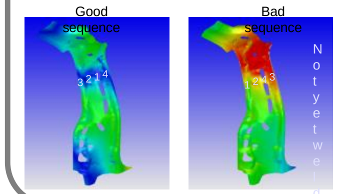




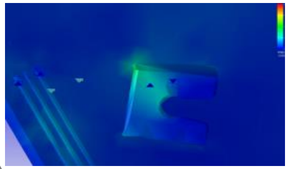
Contact modelling



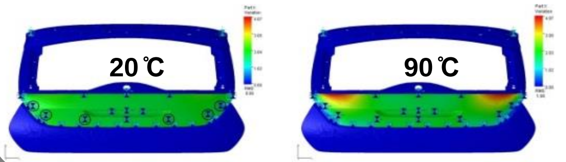
Joining sequence optimization



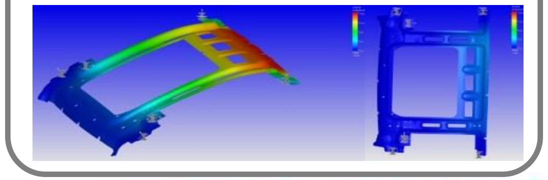
Stress analysis



Effect of heat



Effect of gravity

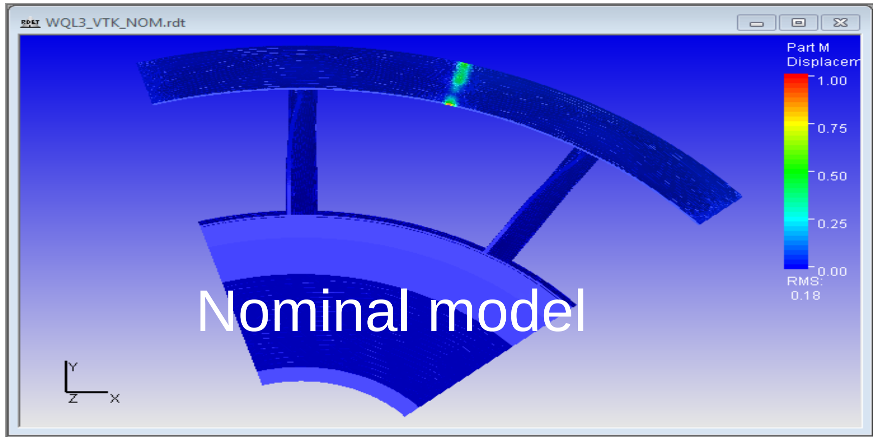


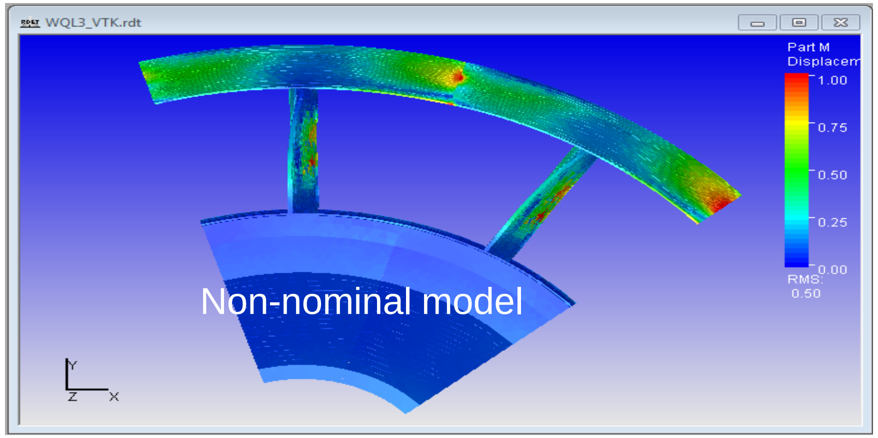
CHALMERS
UNIVERSITY OF TECHNOLOGY

wingquist LABORATORY

Combining Welding and Variation Simulation

- Traditionally, welding simulation is performed on nominal models
- However, variation stemming from welding is depended on geometrical variation in parts and assembly fixtures
- The effect of welding can not be added to the effect of geometrical variation (non-linear problem)





Pahkamaa, A., Wärmefjord, K., Karlsson, L., Söderberg, R. & Goldak, J., 2012, Combining Variation Simulation With Welding Simulation for Prediction of Deformation and Variation of a Final Assembly, *Journal of Computing and Information Science in Engineering*, 12:2.

CHALMERS UNIVERSITY OF TECHNOLOGY

wingquist LABORATORY

RD&T Showroom

Visualization of variation simulation

- Colors
- Textures
- Materials
- Illumination
- Reflections
- Shadows
- Viewing angles
- Environments

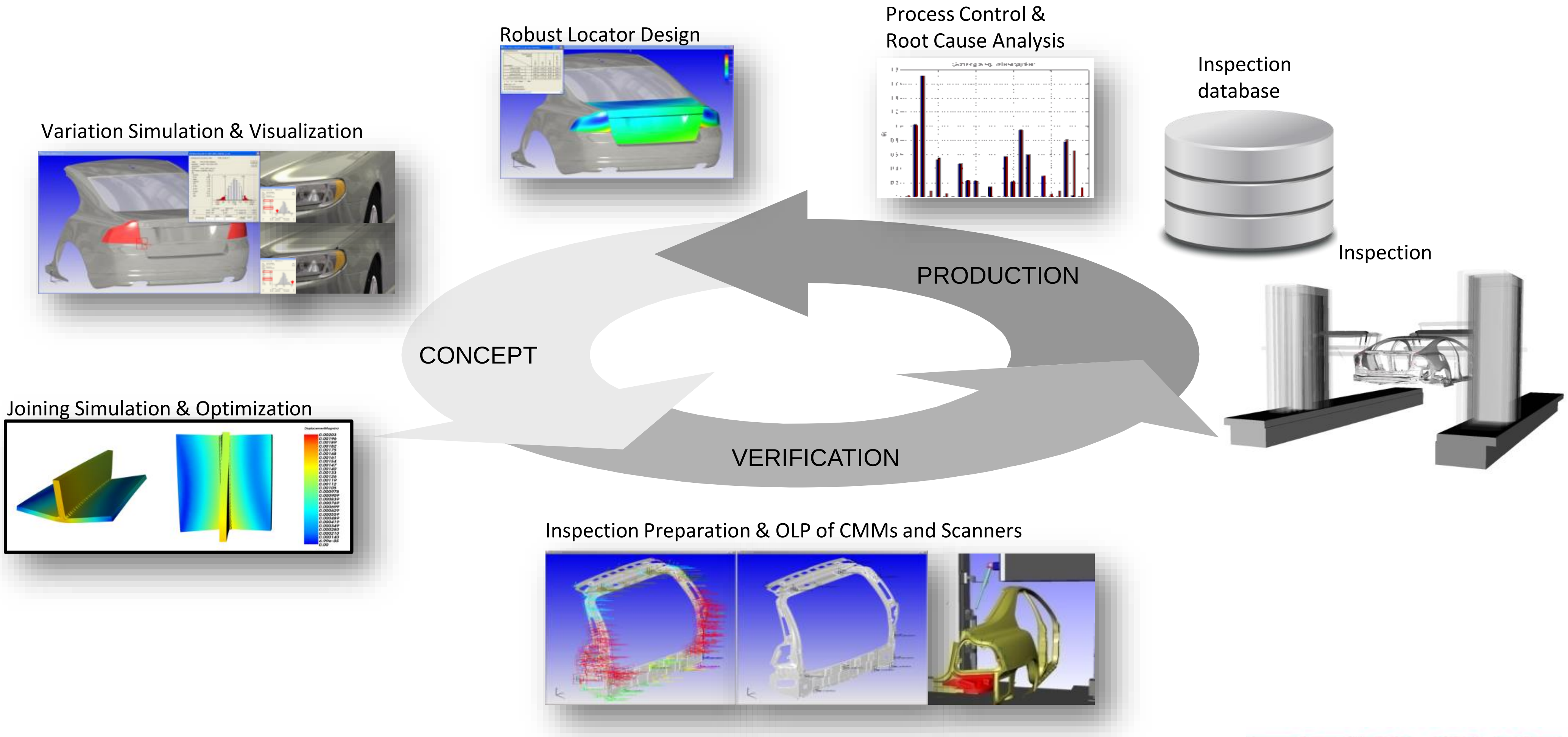
- Requirement definition
- Visual evaluation
- Decision-making in early phases

CHALMERS
UNIVERSITY OF TECHNOLOGY

wingquist
LABORATORY

Geometry Assurance Toolbox

- minimizing the effect of geometrical variation

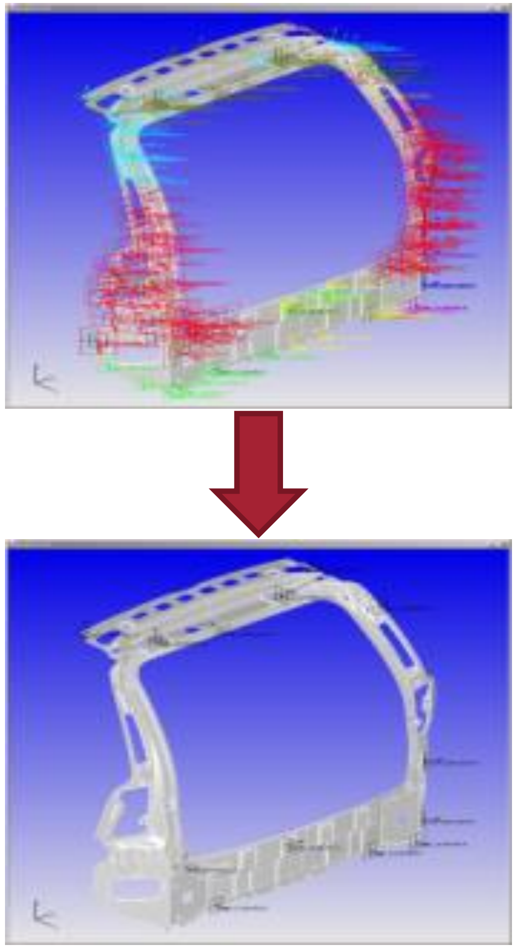


CHALMERS
UNIVERSITY OF TECHNOLOGY

wingquist
LABORATORY

Inspection Point Reduction

- Cluster analysis used for reducing the number of inspection points.
- Based on correlations between inspection points and a measure of information.
- Working procedure:
    1. Load measurement data.
    2. Specify what points that must not be removed.
    3. Conduct cluster analysis.
    4. One representative for each cluster is then inspected.



Case study: Ringframe

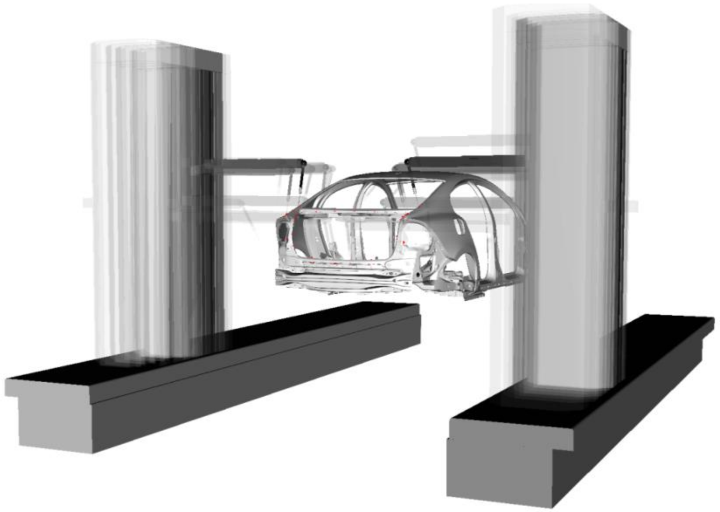
189 inspection points → 14 inspection points (7 %)

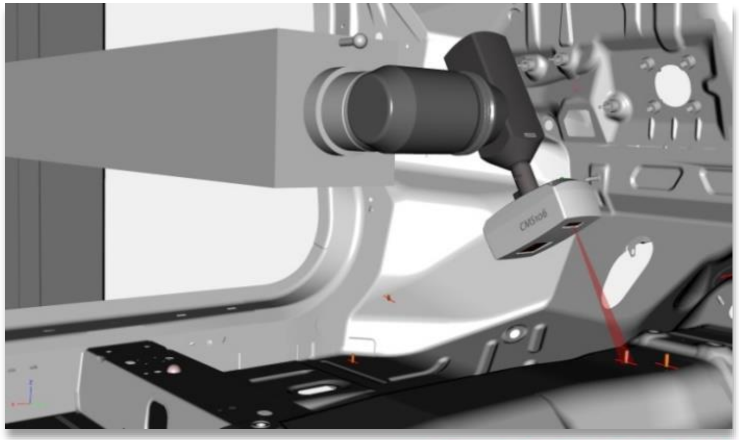
RD&T/IPS
Efficient Geometry Inspection and off-line Programming

Basic functionality

- parameterized inspection rules
- automatic generation of collision free motions
- sequence optimization of cycle time
- DMIS viewer
- easy alignments and advanced constructions
- supports twin inspection
- easy feature accessibility analysis
- minimizing probe configurations
- **support for CMM, scanners and robots**

- 25% faster programs
- 90% reduced programming time

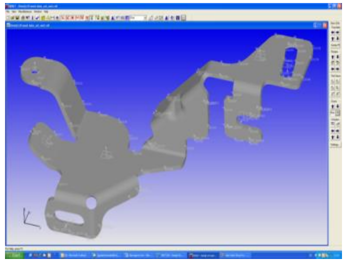


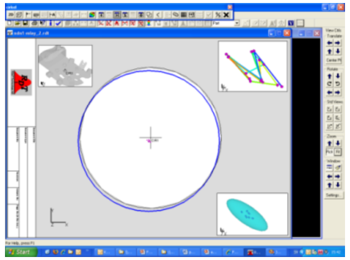


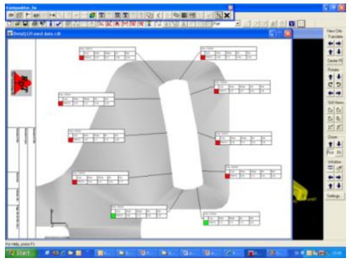
Inspection Database

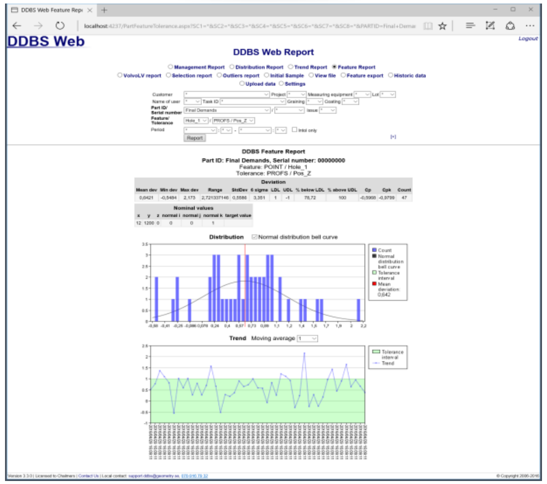
- Statistical analysis
- Visualization of data
- Reuse of inspection data (morphing)
- Web-interface

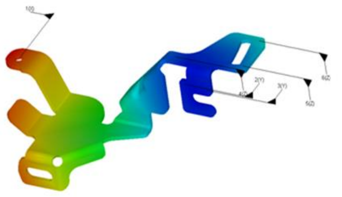
- Closed-loop link to variation simulation

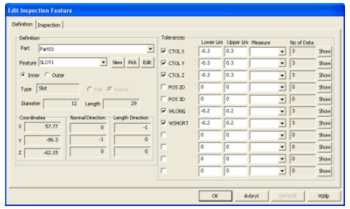


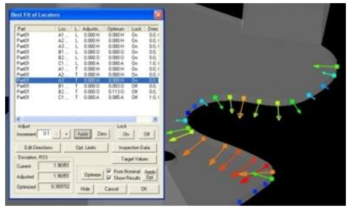






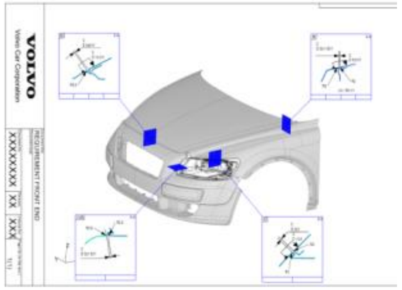




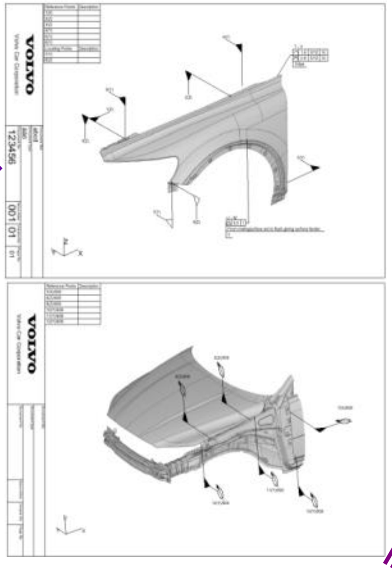


RD&T Engineering Documents

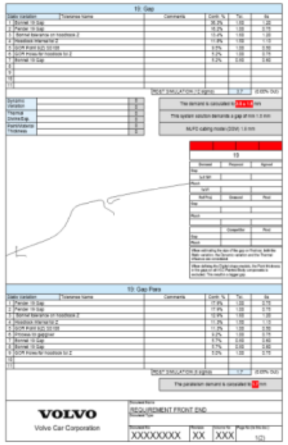
Design Quality Requirements Fit



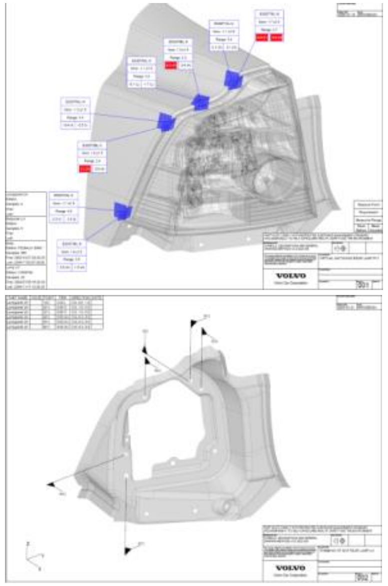
Master- and subsystem description



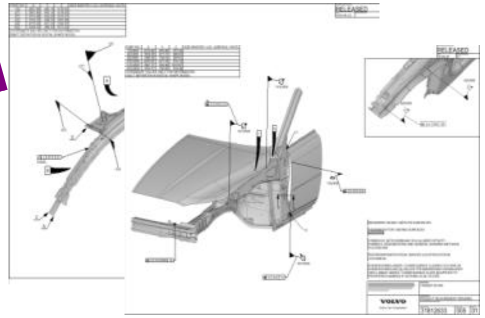
Final demands



Matching & Trimming



PKRV drawings



Other input documents ie REQ Handling

Towards Digital Twins

- **Competition** and sustainability drive
  - quality
  - flexibility
  - factory throughput
  - equipment utilization
  - reduced energy consumption

- **Simulation** can leverage on
  - faster optimization algorithms
  - increased computer power
  - amount of available data

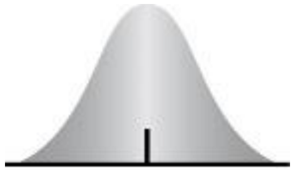
- **Digital Twins**
  - support development
  - enable real-time control & optimization
  - allow moving from mass production to more individualized production

CHALMERS
UNIVERSITY OF TECHNOLOGY

wingquist
LABORATORY

Digital Twin for Geometry Assurance

- A digital product description is nominal
- A real product is never nominal (includes variation)



- The manufacturing process adds variation to the final product
- A Digital Twin of the final product should include impact from manufacturing.

Part variation from stamping

Variation from assembly

Variation from joining

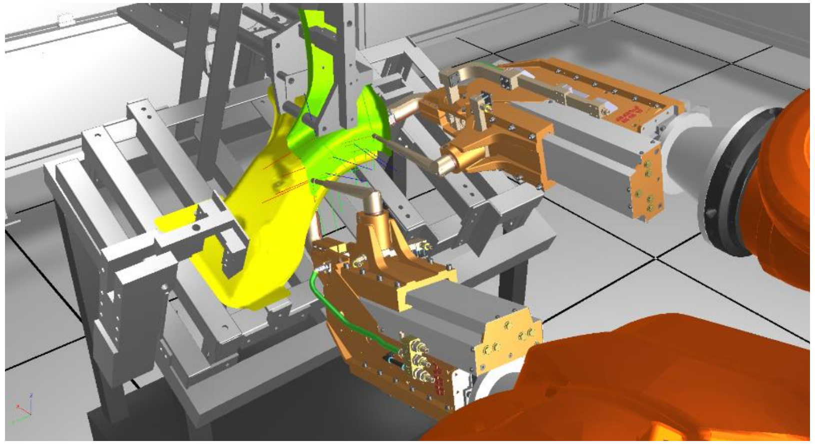
Variation in final product

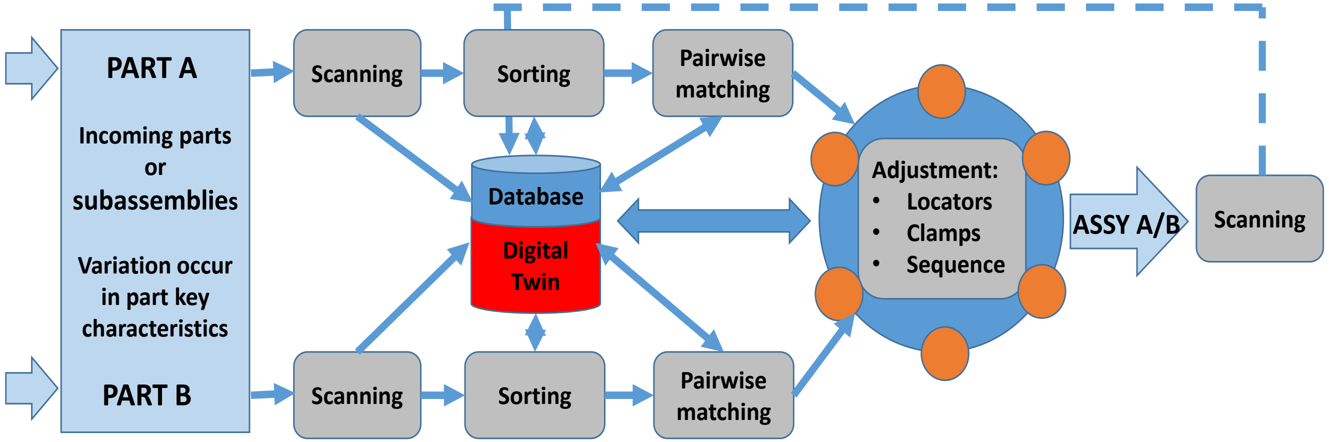
CHALMERS UNIVERSITY OF TECHNOLOGY

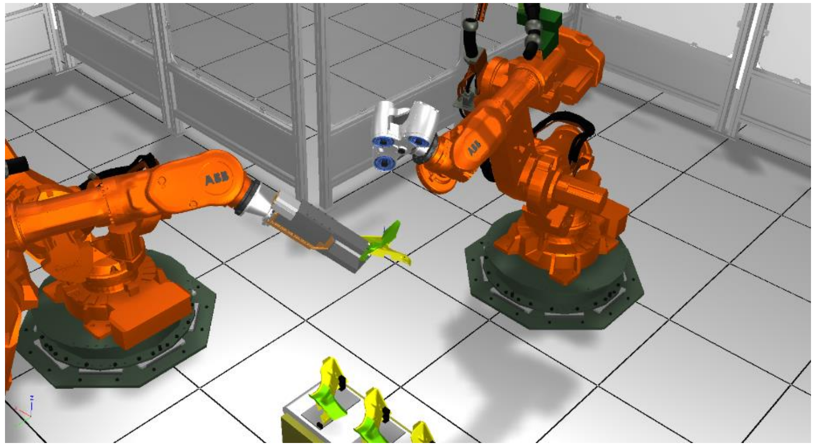
wingquist LABORATORY

What if scan data on individual parts were available in-line

- Sorting and matching of parts (selective assembly)
- Adjusting the fixtures to compensate for part errors
- Optimizing welding sequence to compensate for part errors
- Feed-back (learning) loop to improve the model



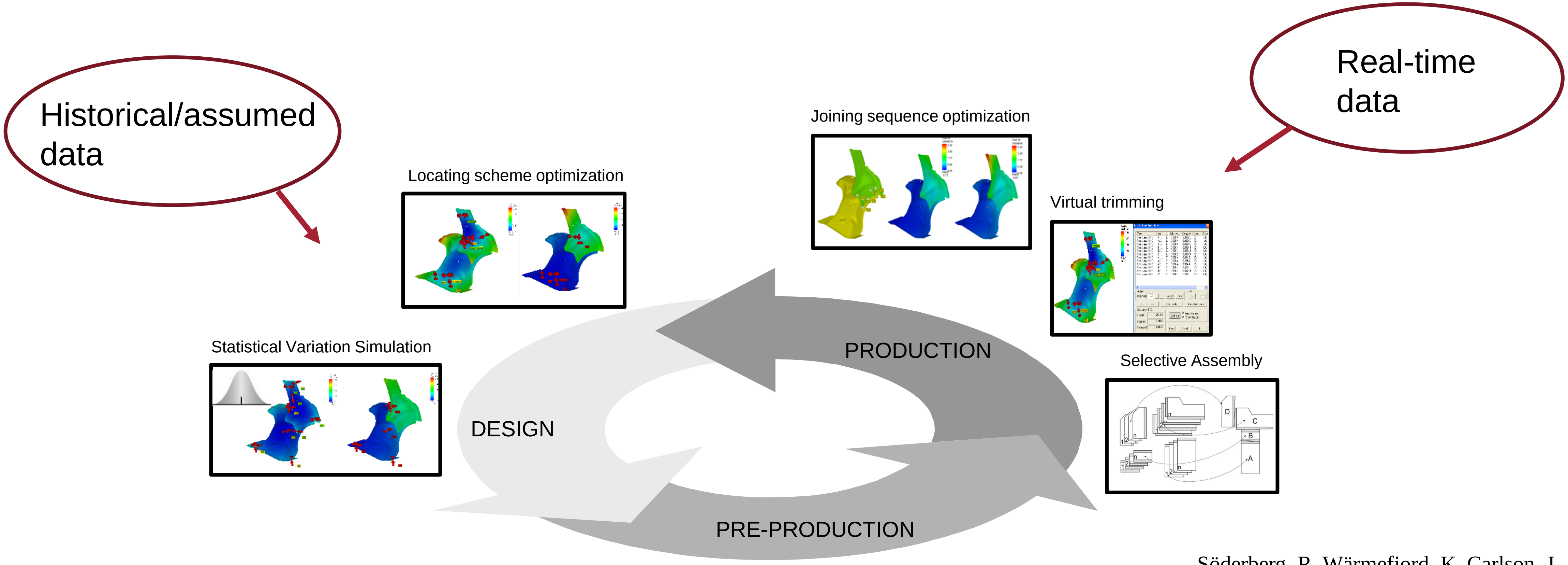




CHALMERS
UNIVERSITY OF TECHNOLOGY

wingquist
LABORATORY

Digital Twin for Geometry Assurance

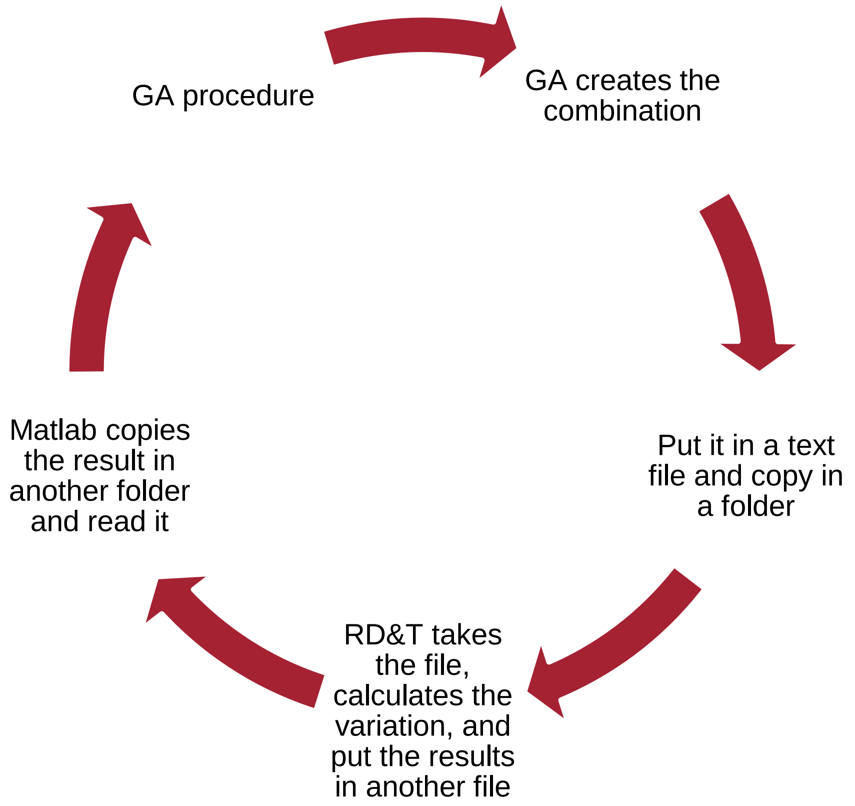


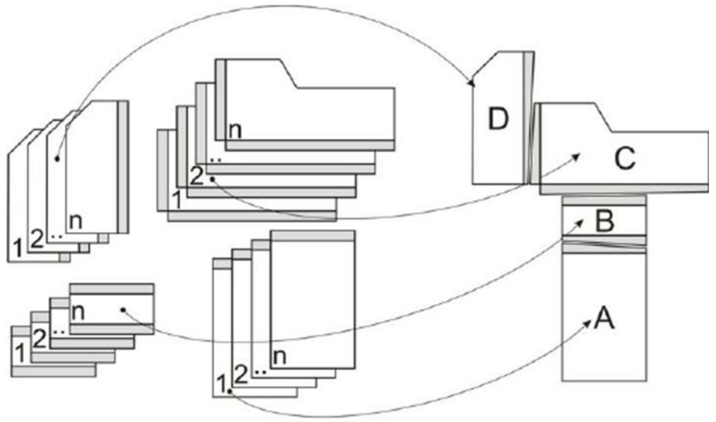
Söderberg, R, Wärmefjord, K, Carlson, J, Lindkvist, L., 2017, Toward a Digital Twin for real-time geometry assurance in individualized production, *CIRP Annals - Manufacturing Technology*, 66/1:137-140.

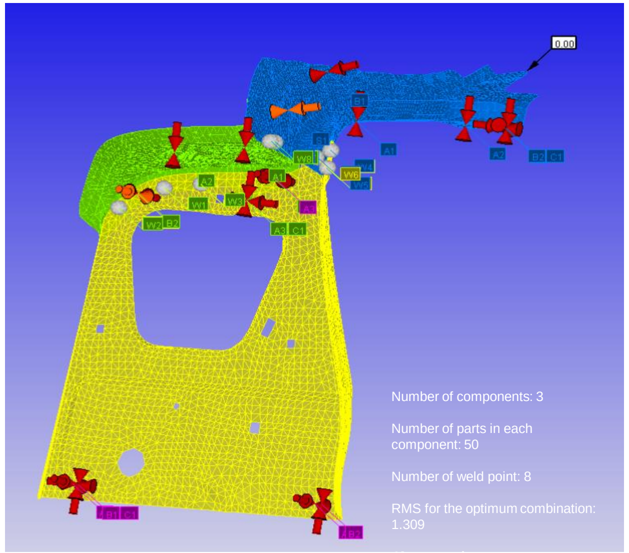
CHALMERS
UNIVERSITY OF TECHNOLOGY

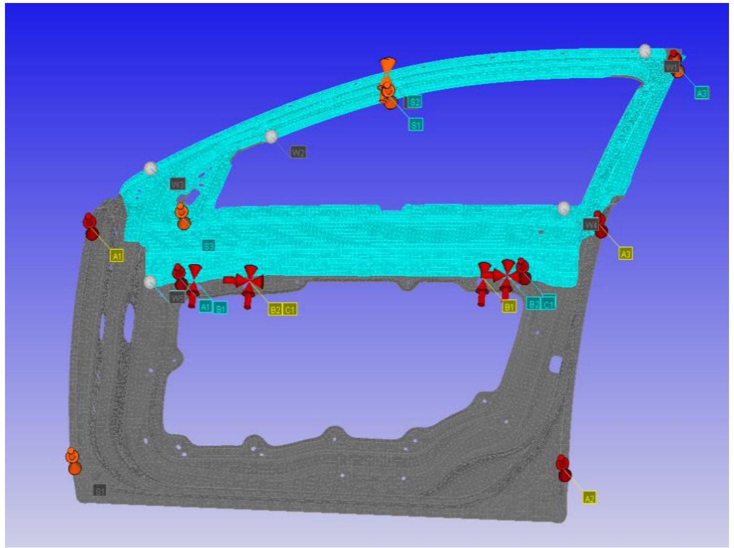
wingquist
LABORATORY

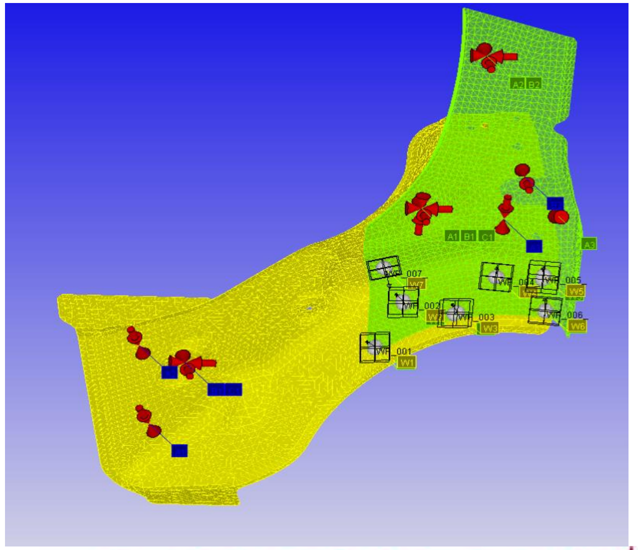
Selective Assembly in Non-rigid Assemblies









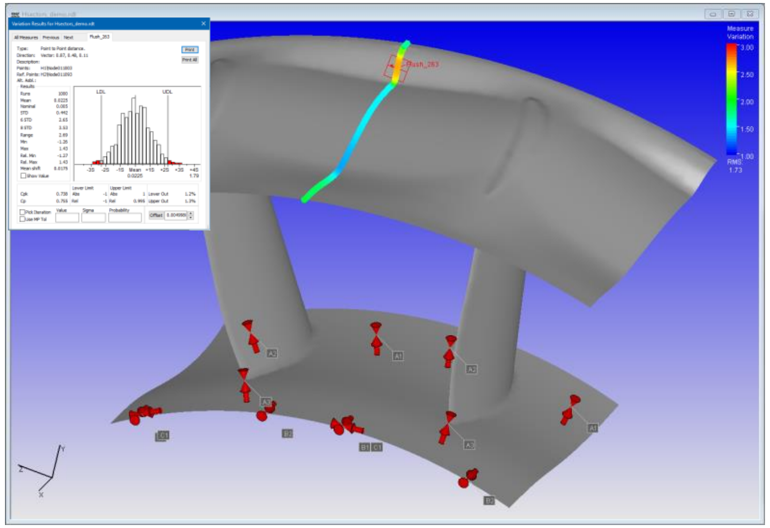


Abolfazl R. A., Wärmefjord K., Söderberg R., 2018, A Multistage Approach to the Selective Assembly of Components Without Dimensional Distribution Assumptions, Journal of Manufacturing Science and Engineering, Transactions of the ASME. Vol. 140 (7), p. 071015-071023

CHALMERS
UNIVERSITY OF TECHNOLOGY

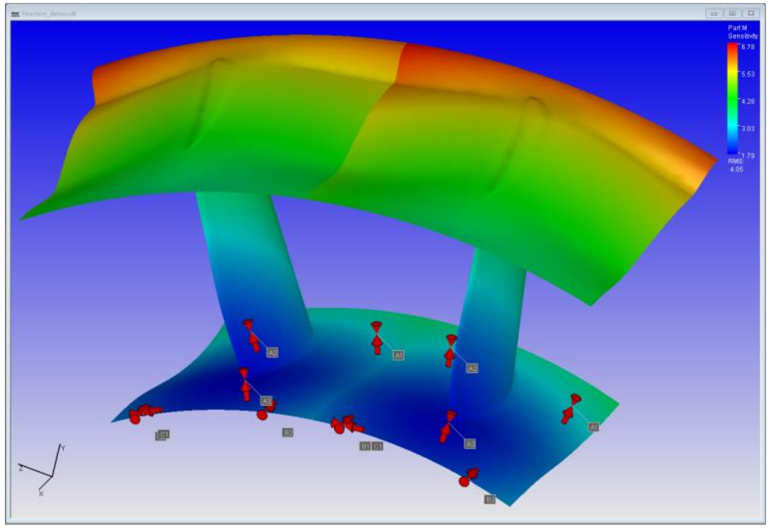
wingquist
LABORATORY

Virtual (locator) Trimming



1. Statistical variation analysis
Variation in critical dimensions due to form errors on individual parts can be statistically analysed (for batches or for individual assemblies).

Input: scan data for individual parts



2. Virtual (locator) trimming
Form errors on individual parts are compensated by changing the position of the locators (for batches or for individual assemblies).

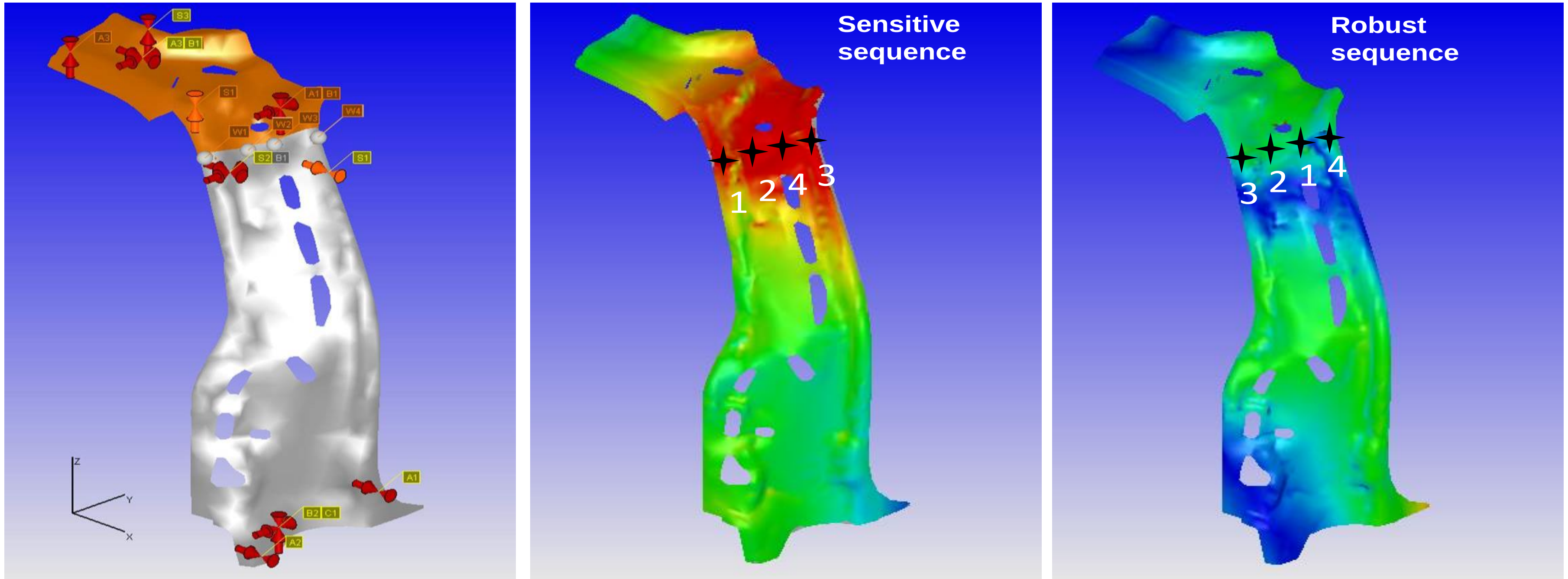
Input: scan data for individual parts

Söderberg, R., Lindkvist, L., Wärmefjord, K., Carlson, J. S., 2016, "Virtual Geometry Assurance Process and Toolbox," Procedia CIRP, 43, pp. 3-12

CHALMERS
UNIVERSITY OF TECHNOLOGY

wingquist LABORATORY

Joining sequence optimization



Different joining sequences - different geometrical quality

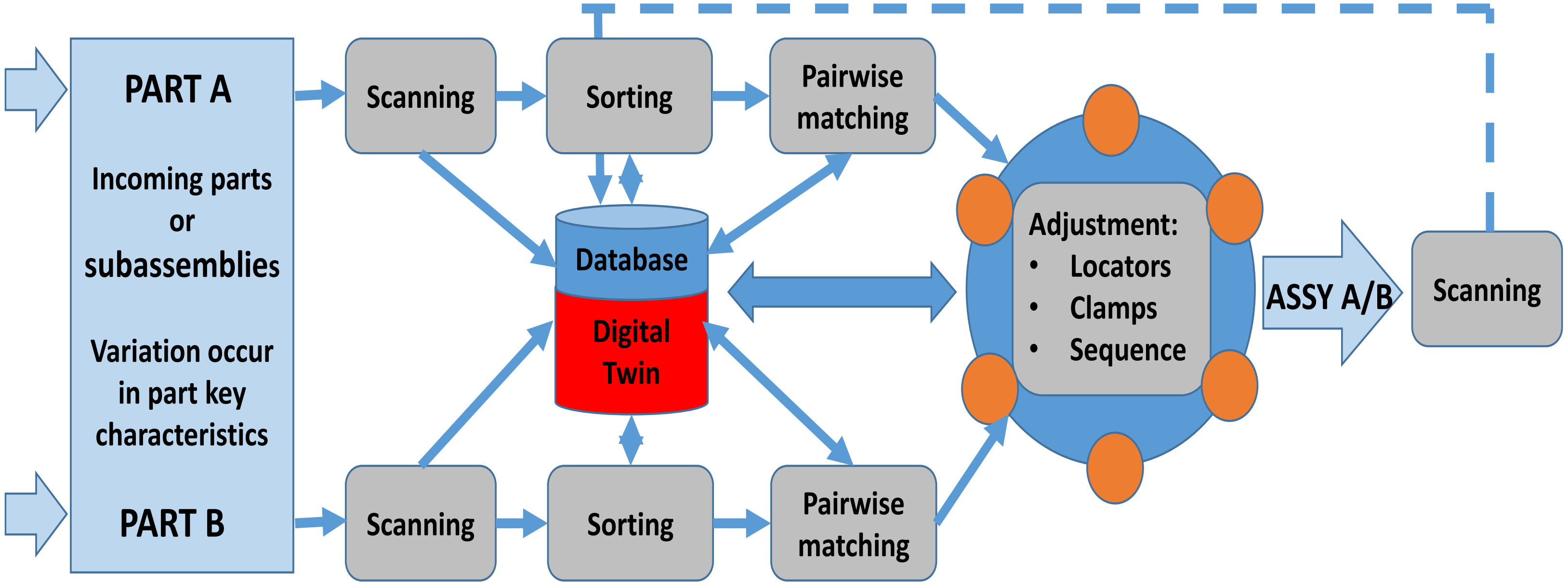
Wärmefjord, K., Söderberg, R., Lindau, B., Lindkvist, L., Lorin, S., 2016, "Joining in Nonrigid Variation Simulation," Computer-aided Technologies - Applications in Engineering and Medicine

CHALMERS
UNIVERSITY OF TECHNOLOGY

wingquist LABORATORY

Towards a Digital twin for geometry assured welded structures

- Scanning of all individual parts
- Sorting and matching of parts (selective assembly)
- Adjusting the fixtures to compensate for part errors
- Optimizing welding sequence to compensate for part errors
- Scanning of welded assembly - refinement of model

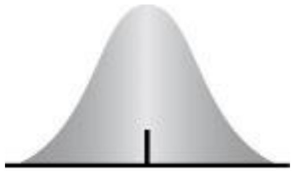


CHALMERS
UNIVERSITY OF TECHNOLOGY

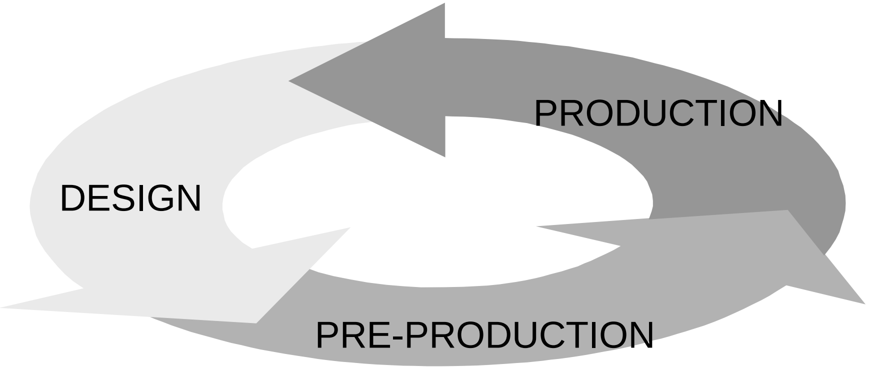
wingquist
LABORATORY

Summary

- The manufacturing process adds **variation** to the final product
  - Part variation (forming, machining…)
  - Assembly variation (fixtures, robots, operators..)
  - Joining variation (welding, riveting…)



- The **Geometry Assurance** process aims at minimizing the effect of geometrical variation in the final product



- A **Digital Twin** for geometry assurance can use inspection data from the parts to compensate in the assembly
  - Selective assembly (matching of parts)
  - Virtual trimming/shimming (adjusting the fixture)
  - Joining sequenze optimization (spot weld sequenze)

CHALMERS
UNIVERSITY OF TECHNOLOGY

wingquist
LABORATORY