Variation Analysis

Steve Scigliano
Director Quality Product Development
UGS

PLM World 2006

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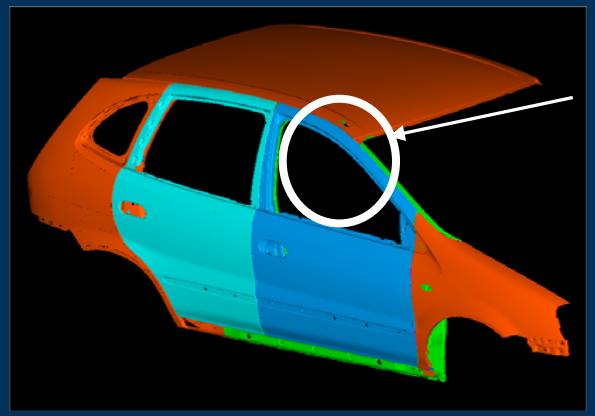
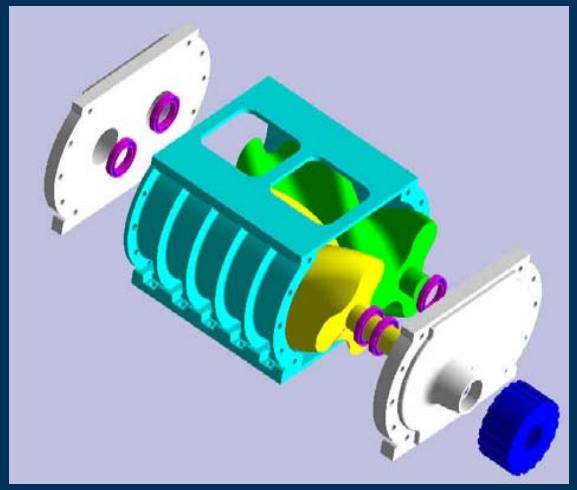
Challenges for product and process design



What's the variation of the gap between the door and the frame?



Which is the best way to assemble the components in order to minimize the variation of the gaps?

What's the process capability of the central console assembly?

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Challenges for product designer

- What's the right tolerance value?
- What's the impact of the tolerances on the Critical-To-Quality (CTQ) characteristics?
- Is that variation too much?
- Can I use larger, and therefore cheaper, tolerances?
- Will the Final Assembly be able to guarantee the minimum variation for that specific CTQ?

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Challenges for process engineer

- What will be the process capability of the assembly process? How many parts will be out-of-tolerance?
- How to determine the position of the holding fixtures so to minimize the variability?
- What are the features that effect the most the variability of the process?
- How can I compare two different alternatives for assembling the front lamp, and choose the solution that outputs better process capabilities and lower my rejection rate.

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Problems in Prototyping

- Product cannot be assembled requiring reworking
- Process is not under control showing too much variability
- Product is not compliant with the specifications
- Process requires expensive machining or tooling

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Problems in Full Production

- Assembly does not meet the required specification
- Sub-assembly cannot be assembled properly in the car, requiring manual rework
- High volume of TGW (Things Goes Wrong) reports

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Reasons

- Design is based on “perfect” geometry
- No effect of tolerance is considered
- If tolerance effect is considered is mainly in 1D
- No assembly sequence is considered
- Manufacturing tolerances and assembly methods have impact on the process variability
- Manufacturing process capabilities are not estimated

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Impact

- Time
  - Development phase delayed
  - Production stopped
  - High volume of design changes
- Cost
  - Cost of reworking to fix the process
  - Missed production
  - Replacement of customer parts
  - Customer claim handling
- Quality
  - Loss of customer confidence

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Typical business case

- Cost of each Design Change = 3-4K$; 36K$ per designed product
- 2 weeks of reworking involving 3 people: 24K$ per product issue
- Cost of handling customer recall: up to 300K$
- Missed profits due to production stop from 10K$ up to hundreds of thousand dollars per day

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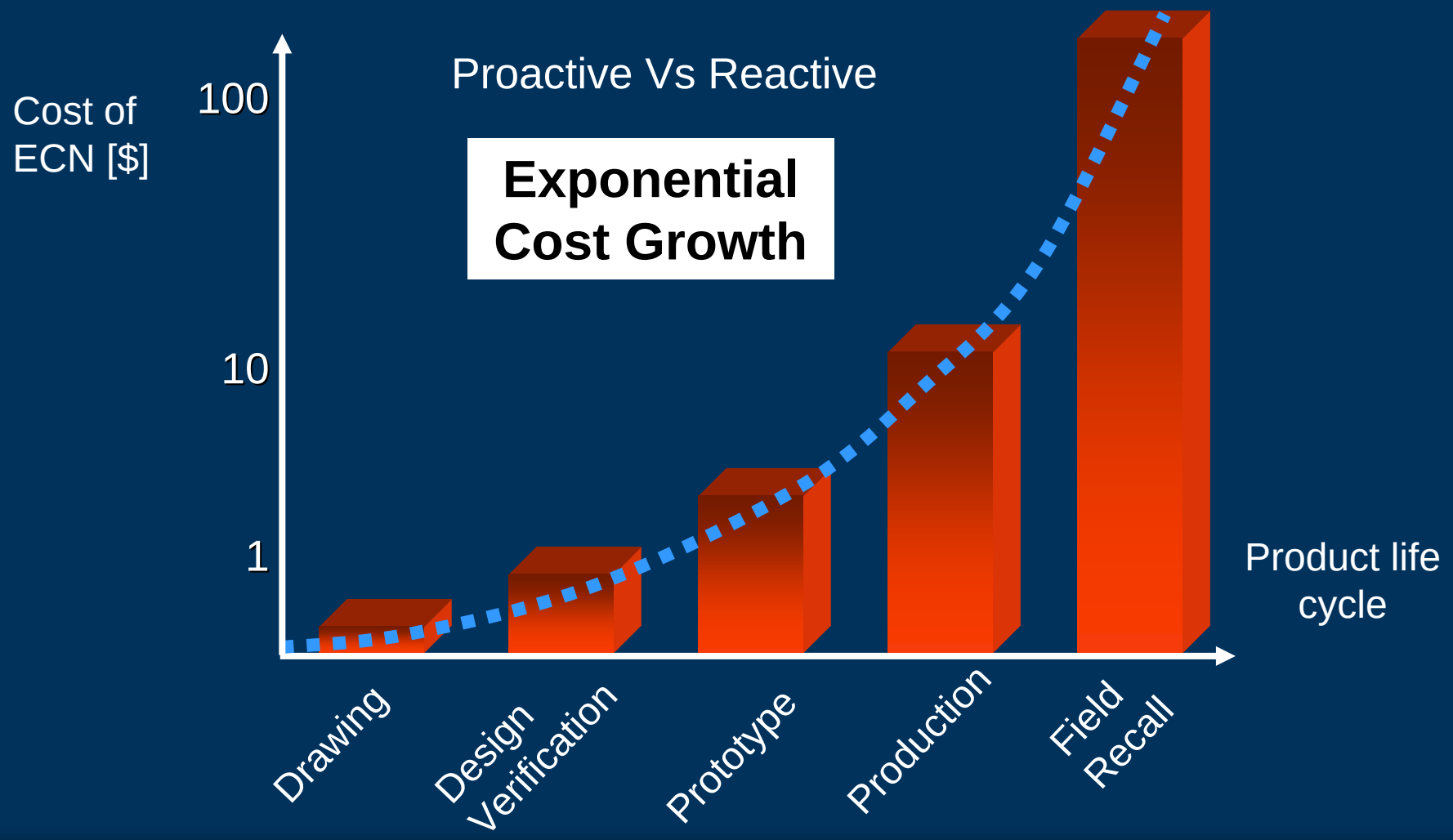
Why is it important to manage variation?



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Need

- Design for variability.
- Define and verify manufacturability and assemblability of the product
- Identify cheapest process that satisfies customer requirements
- Predict variability effects of tolerances and assembly methods
- Predict process capability
- Identify key parameters of the process

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The Answer is Variation Analysis

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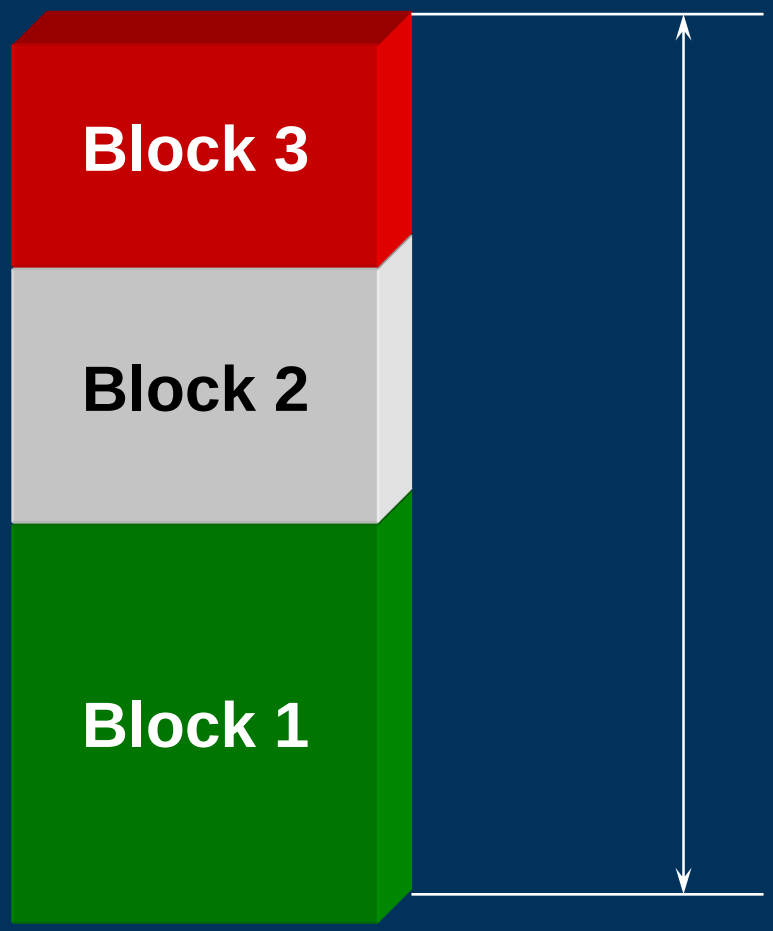
What is variation analysis?



What will be the height of the assembly?
Critical To Quality (CTQ) characteristic

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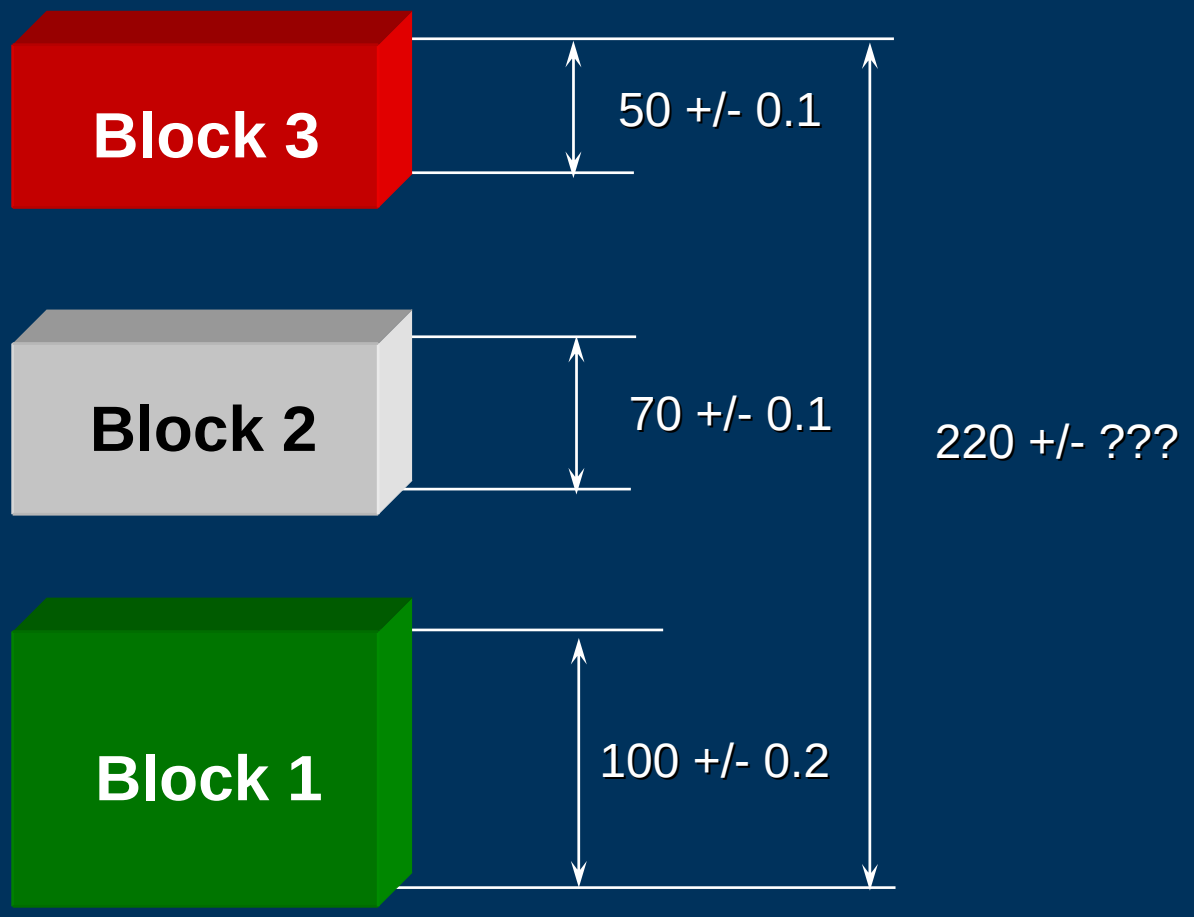
Parts tolerances



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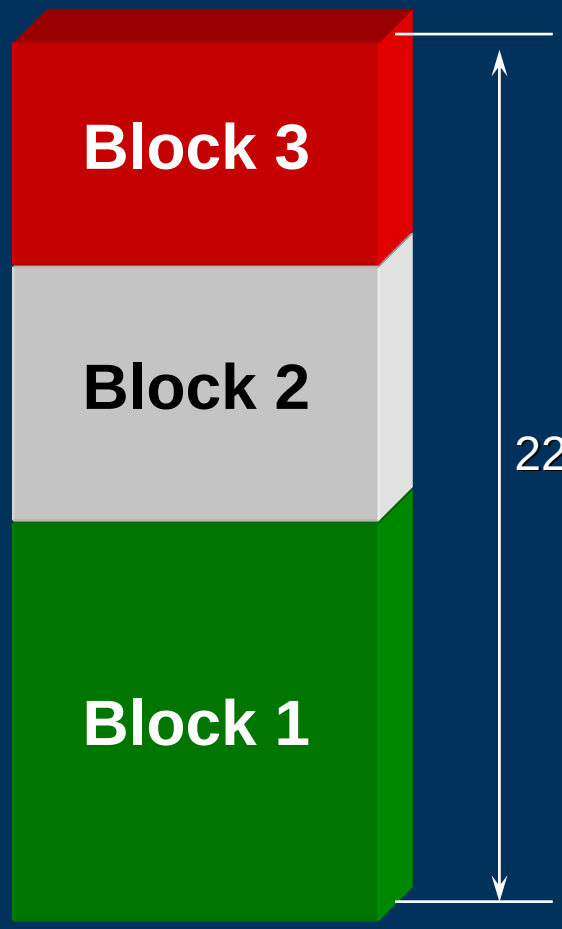
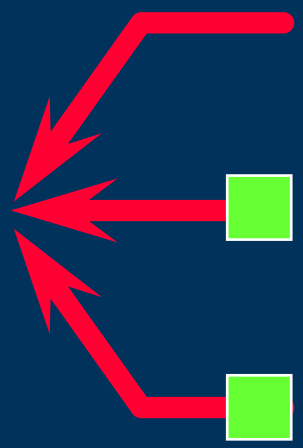
Sequence of Assembly & Assembly Methods



220 +/- ???

Block Assembly



Block 1

Block 2

Block 3

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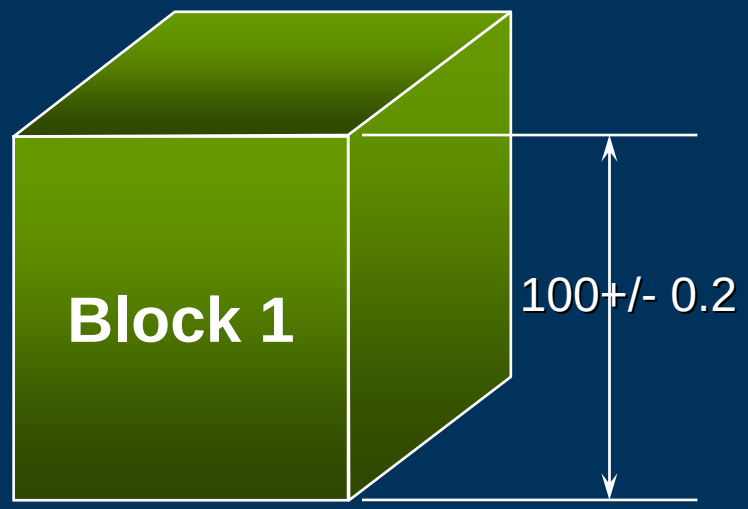
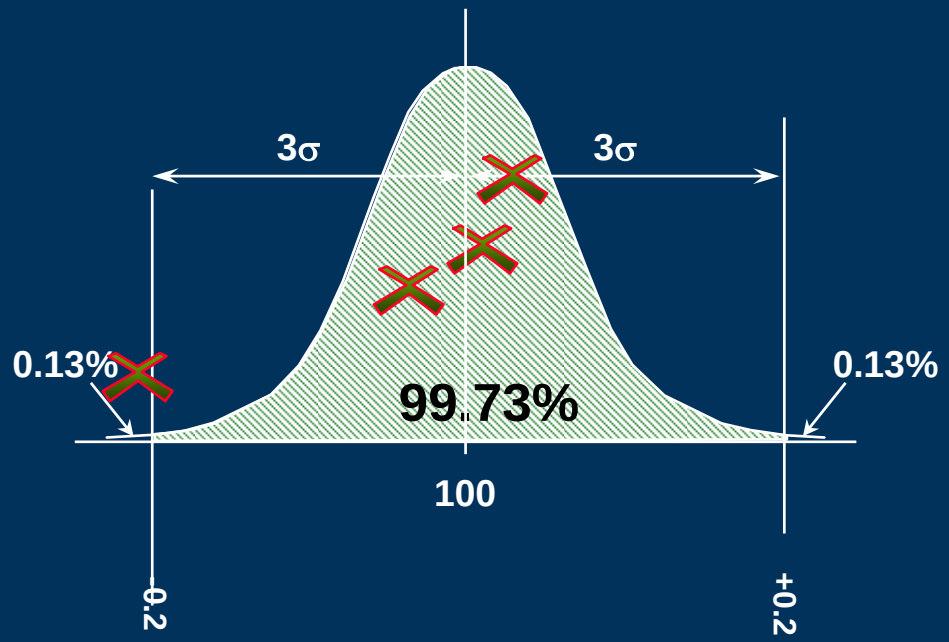
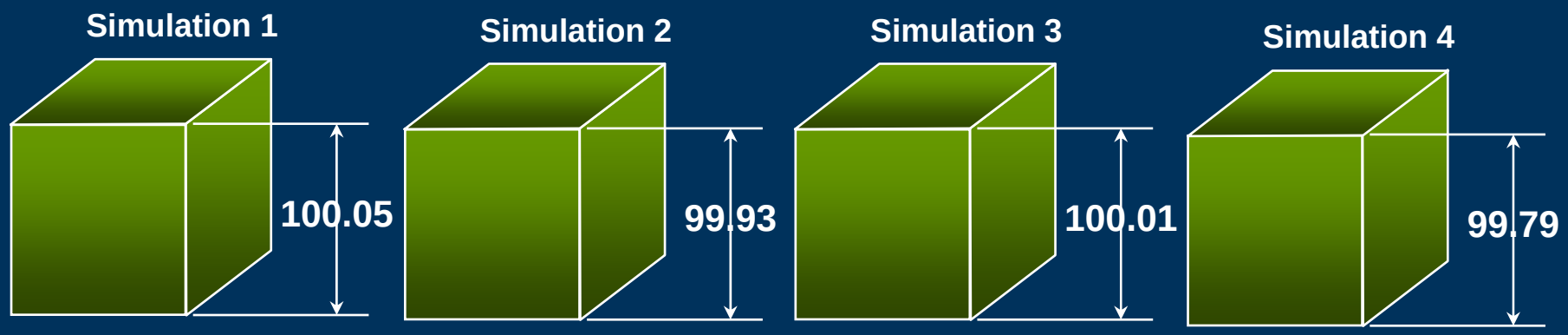
Tolerance Simulation







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Repetitive Simulations

Simulation = 10000

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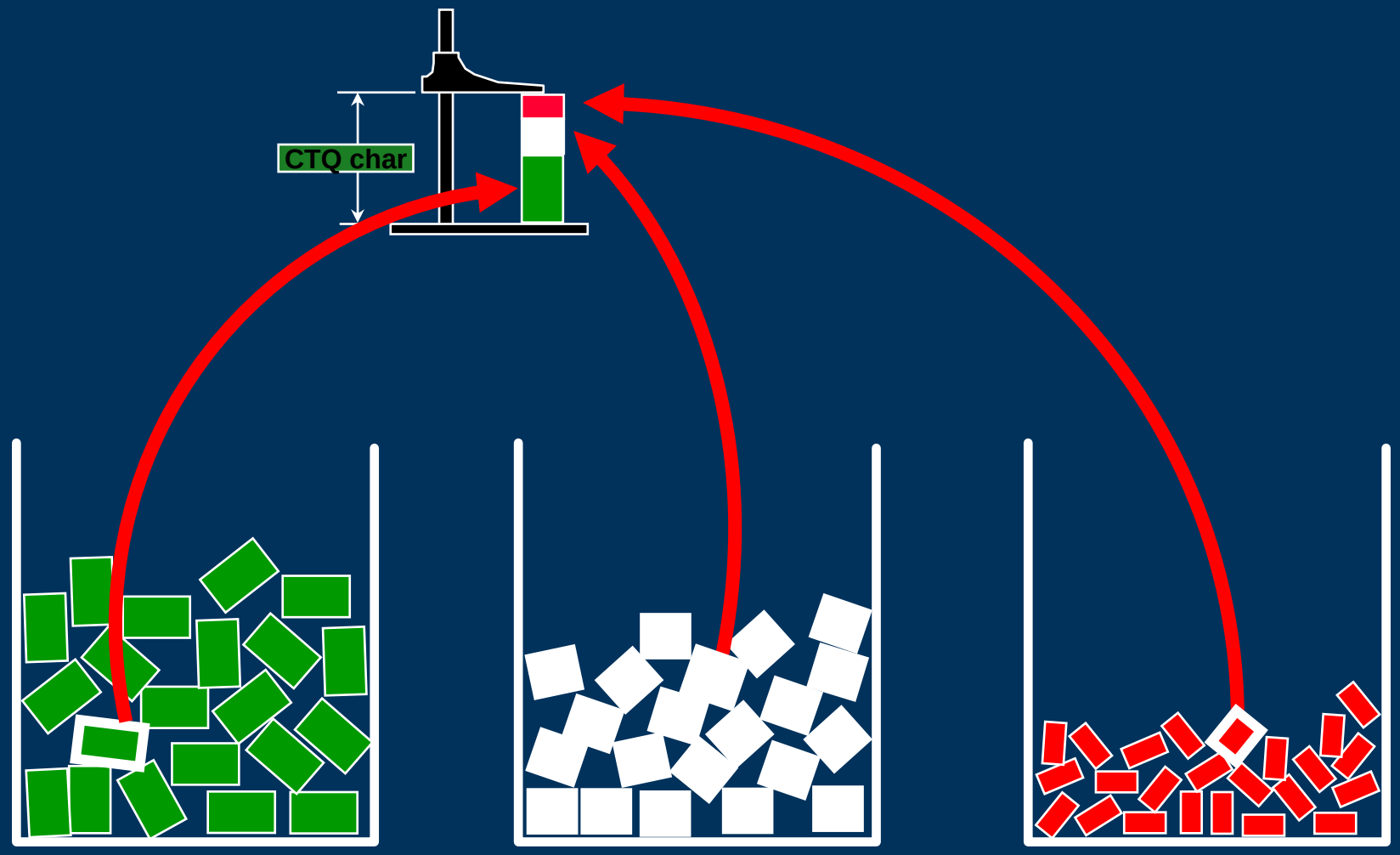
Calculation of the CTQ characteristic



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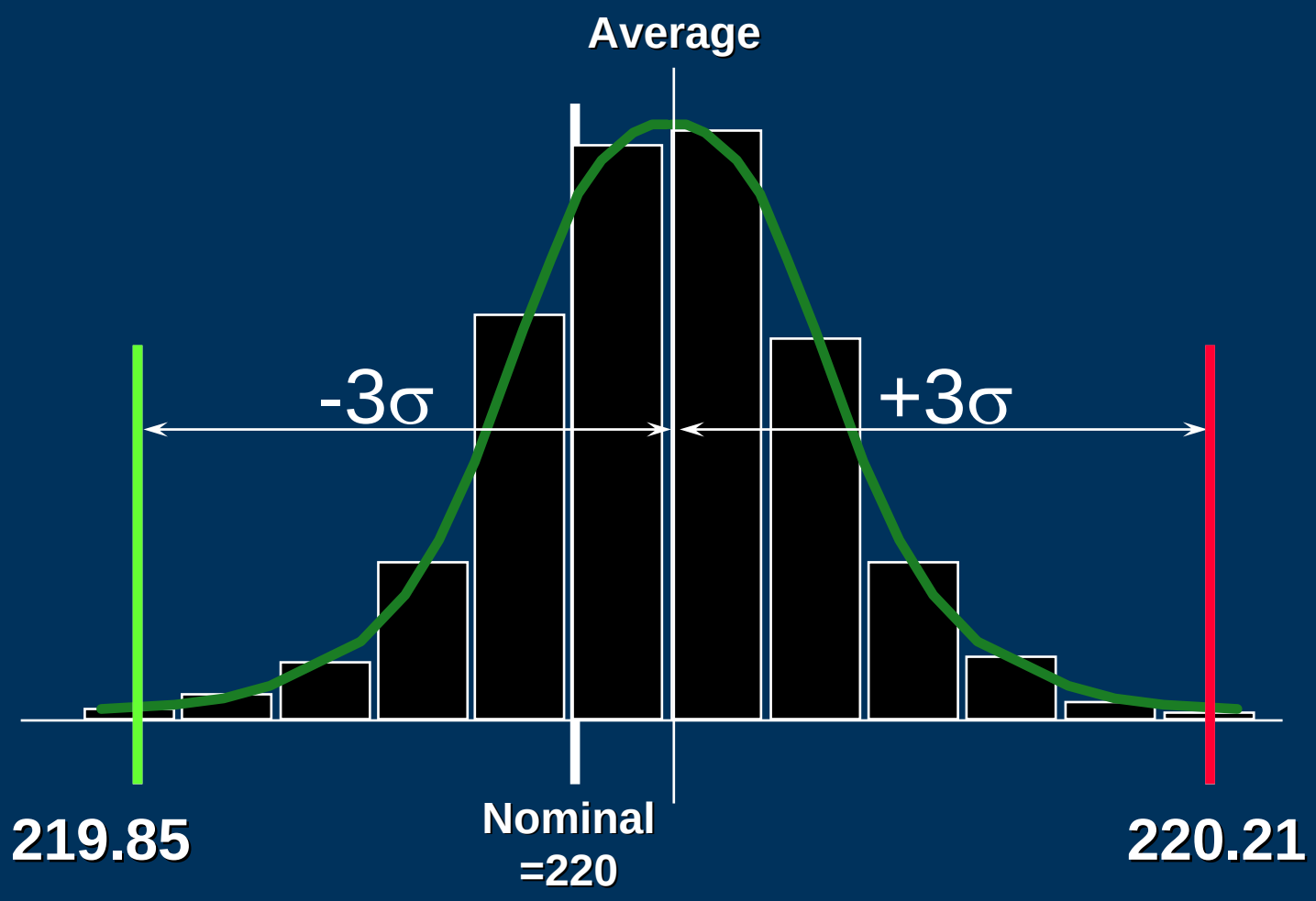
Variation results



Total range = 0.36

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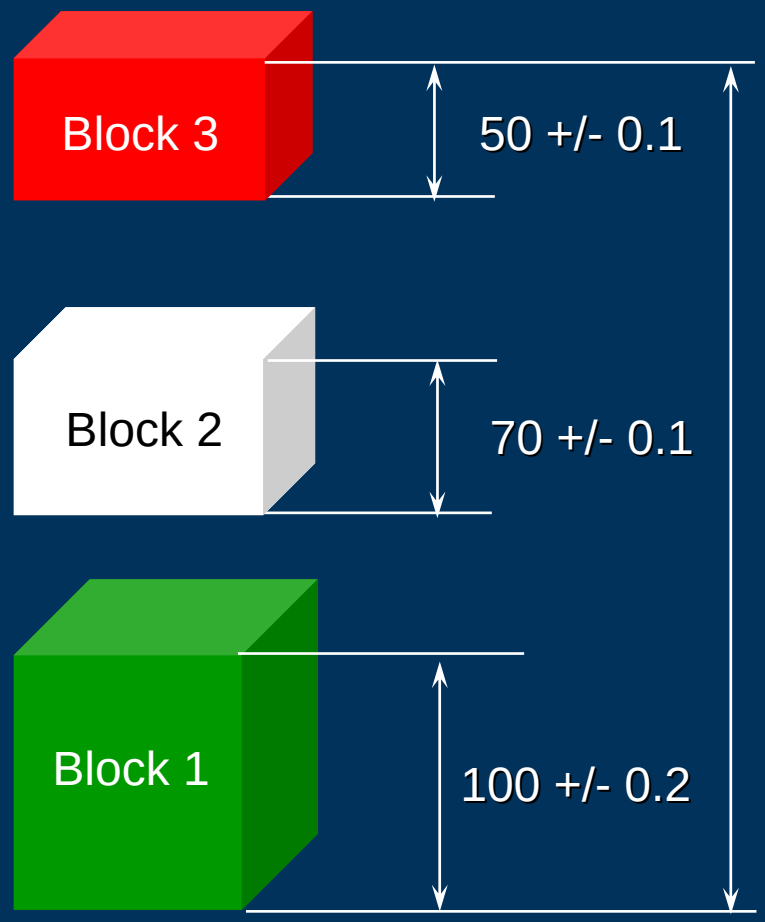
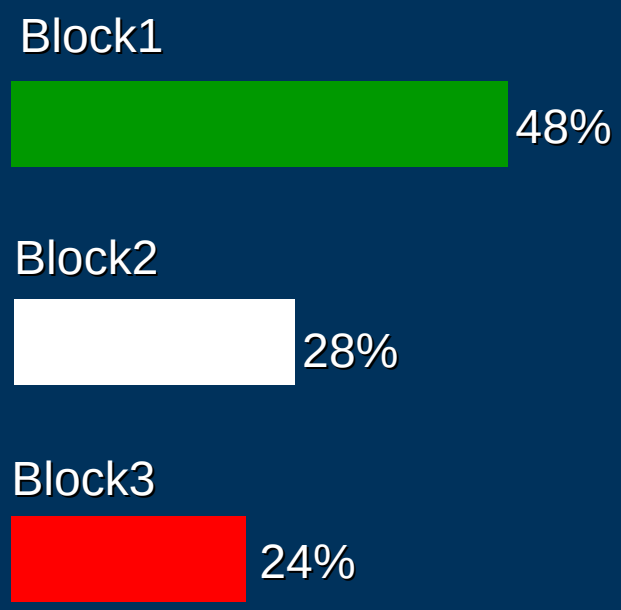
Contributor results



$220^{+0.21}_{-0.15}$



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Comparing 3D variation analysis vs. hand calculation

- In term of:
- Accuracy
- Realism
- Flexibility

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(In)Accuracy /1

- Difficulty in handling complex geometry
- Difficulty in handling hundreds of tolerances
- 1D or 2D Problems Ignore Effects in 3D space
- GD&T, which has significance only in 3D is notably absent
- Difficulty in handling multiple design constraints on a single feature

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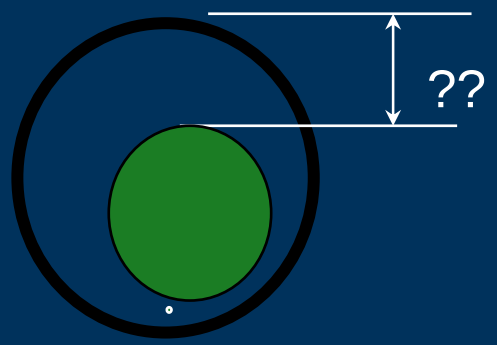
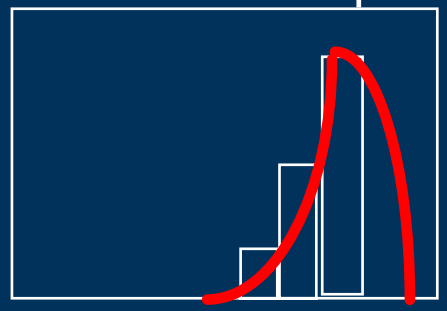
(In)Accuracy /2

- Normal Inputs *always* yield Normal Outputs

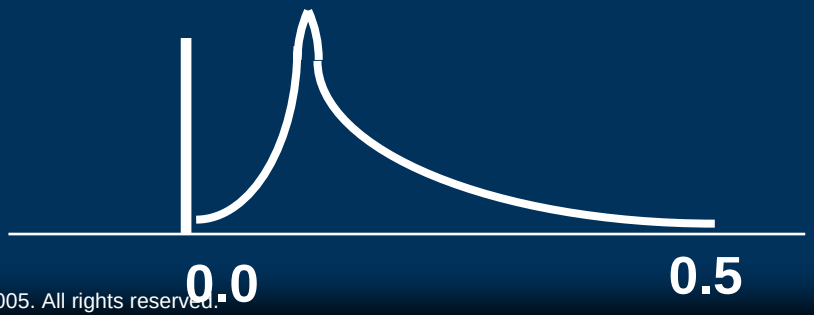
Floating of a pin in a hole



Clearance between pin and hole



- All tolerances are normally distributed (i.e from tests, shop floor data ...)



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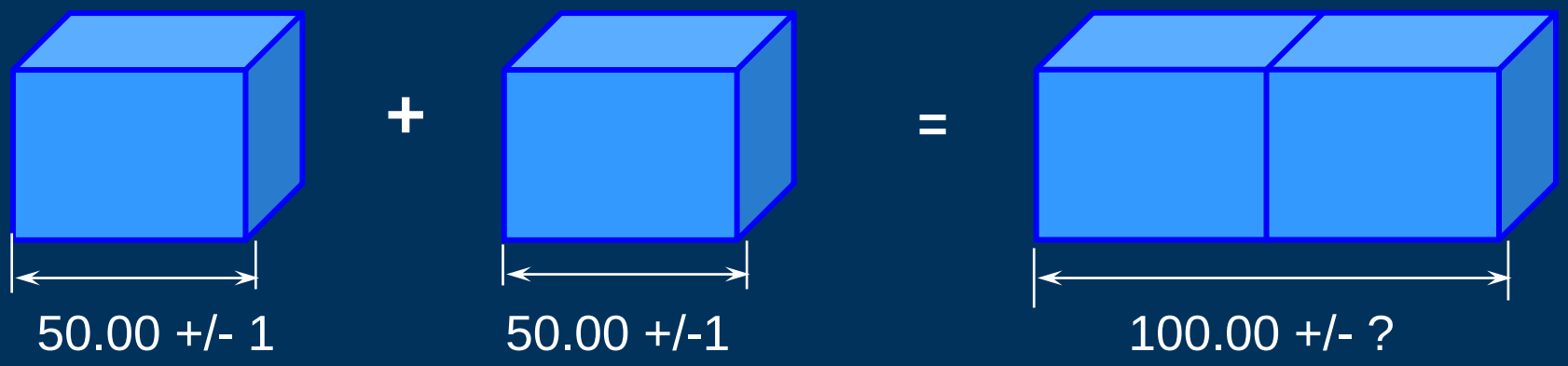
Realism /1

- Statistical variability in manufacturing



- Worst Case: 100 +/- 2.0 (Limit Stack)
- RMS Method: 100 +/- 1.414
- Monte Carlo: 100 +/- 1.03

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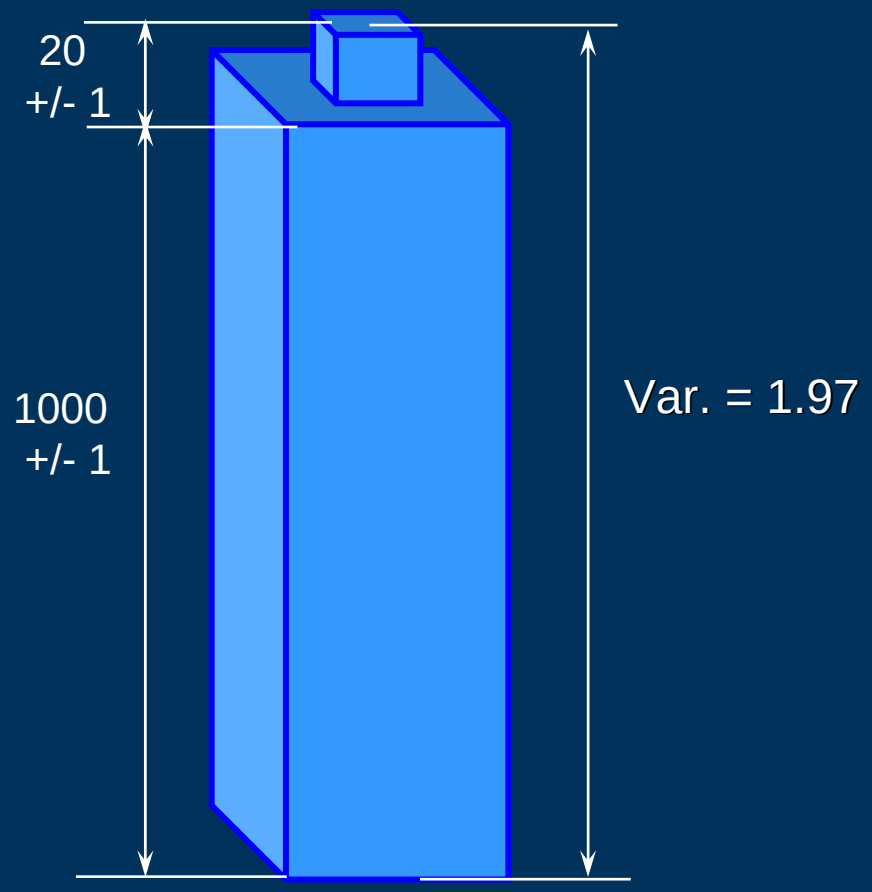
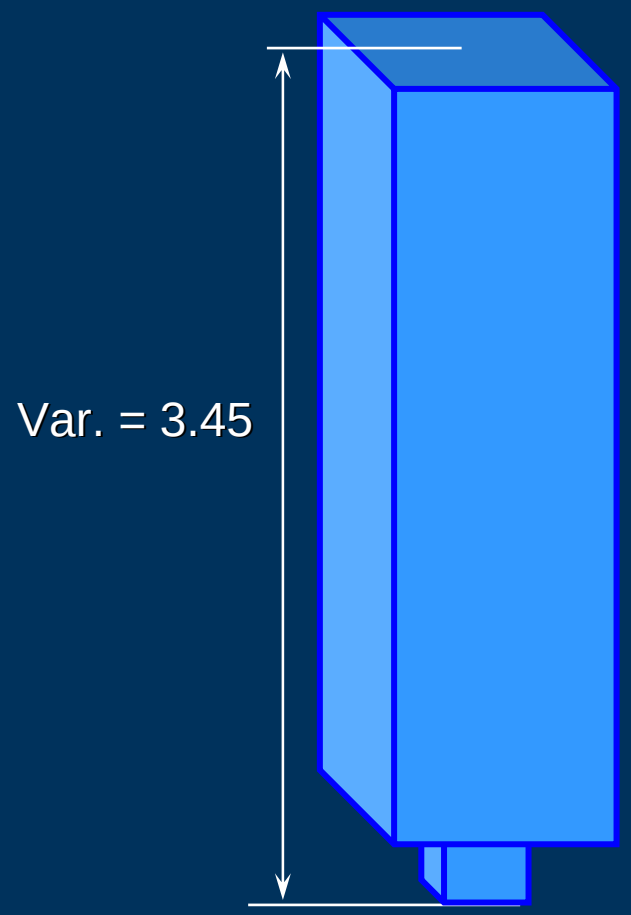
Realism /2





- Variation will be different in these case due to assembly order of sequence

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Flexibility

- What-if analysis is fairly complex
- Contributor calculations is impossible
- Extremely time consuming
- Extremely simplified

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Some Industrial Examples

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Fiat

- Division: Product & Process Engineering
- Location: Torino (Italy)
- Users: process engineers mainly dedicated to variation analysis
- Usage: Full simulation of entire car (BIW & FA), checking most critical key characteristics for aesthetic (i.e. door flushness, door gaps) and functional (i.e. location of engine mounting points).
- Level of usage: high
- Benefit: unquantified reduced number of problems in prototyping and initial production

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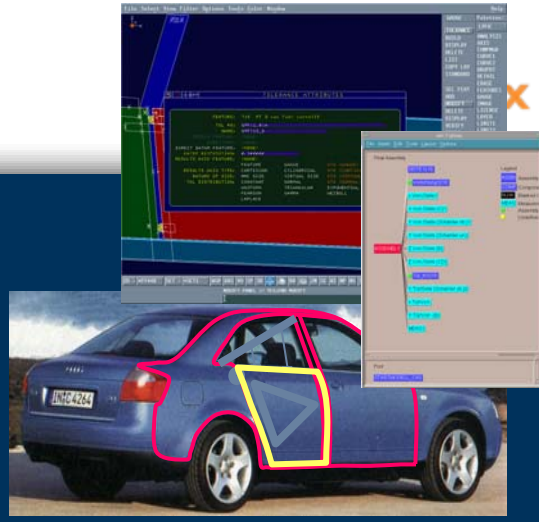
Magna



- Division: Magna Steyr (vehicle engineering)
- Location: Graz (Austria)
- Users: process engineers
- Usage:
  - -gaps and flushness of BIW subassemblies such as doors, fenders
  - -rear axle alignments (toe, camber angles)
- Benefit: reduced development time through early identification of critical parameters (such as tolerances or assembly operations) that leads to assembly optimization along with prediction of process capabilities

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Bosch

- Division: diesel injector
- Location: Stuttgart (Germany)
- Users: designer
- Usage:
  - During design to avoid destructive tests (calculation of critical characteristics such as minimum wall thickness)
  - To change design/process after quality issues
- Benefit:
  - Faster time to market in particular when adopting new manufacturing technology
  - Avoid building physical prototypes
  - Less customer complaints

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Karmann

- Division: Roof Systems, BIW, Final Assembly
- Location: Osnabruck (Germany)
- User: simulation engineer
- Usage:
  - Roof mechanism (alignments, gaps, flushness between roof and BIW, in different positions of the mechanism)
  - Clearance between sheet metal parts and safety roll bar
- Benefit:
  - Shorten development time by demonstrate Process Capability without building physical prototypes
  - Shorten development time by finding critical features to improve assembly process in the early designing. I.e. evaluation of casting tolerances vs. pressing tolerances

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Valeo

- Division: HVAC (Heating, Ventilation and Air Conditioning
- Location: Auburn Hills, MI (USA)
- Users: pre-development system engineers
- Usage: check interfaces between HVAC system and interior components
- Benefit:
  - Reduce number of PPDR (Product or Process Deviation Request)
  - Capability to perform a 3D tolerance analysis calculation, in comparison with an approximated 2D manual calculation. This results in a higher customer satisfaction, due to higher reliability of the calculation.

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