UNIVERSITY OF TWENTE.

DIGITAL TWINS IN MATERIAL FORMING

TON VAN DEN BOOGAARD

TODAY'S BUZZ WORDS

Big Data
Data analytics
Industry 4.0
Machine Learning
Factory of the future
Digital Twins
5G
Cyber Physical Systems
Internet of things
Smart Factories
Artificial Intelligence
Autonomous systems
Digitization

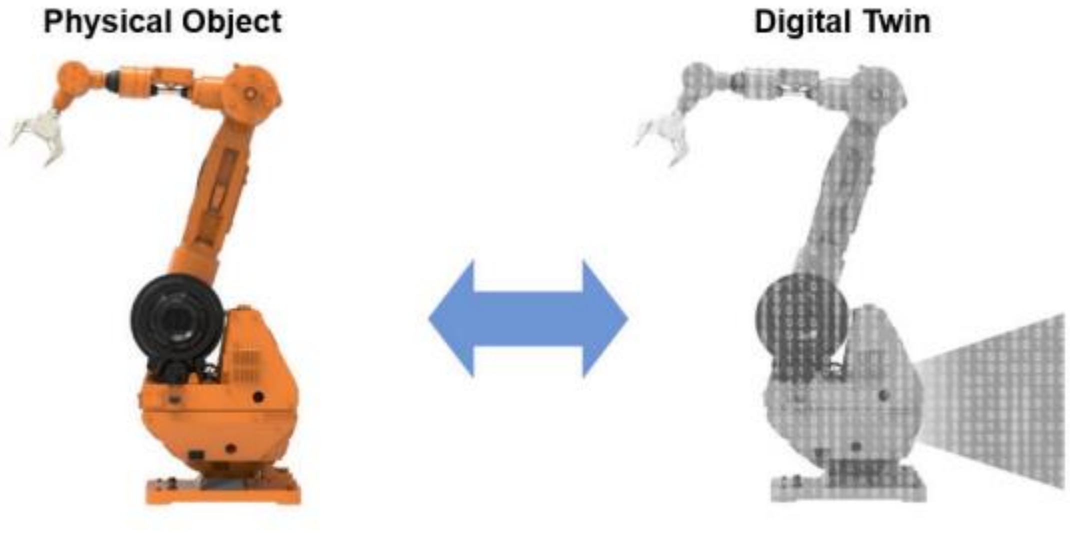
Zero-defect manufacturing
First time right production
Flexible production
Mass customization

WHAT IS A DIGITAL TWIN?

DIGITAL TWIN

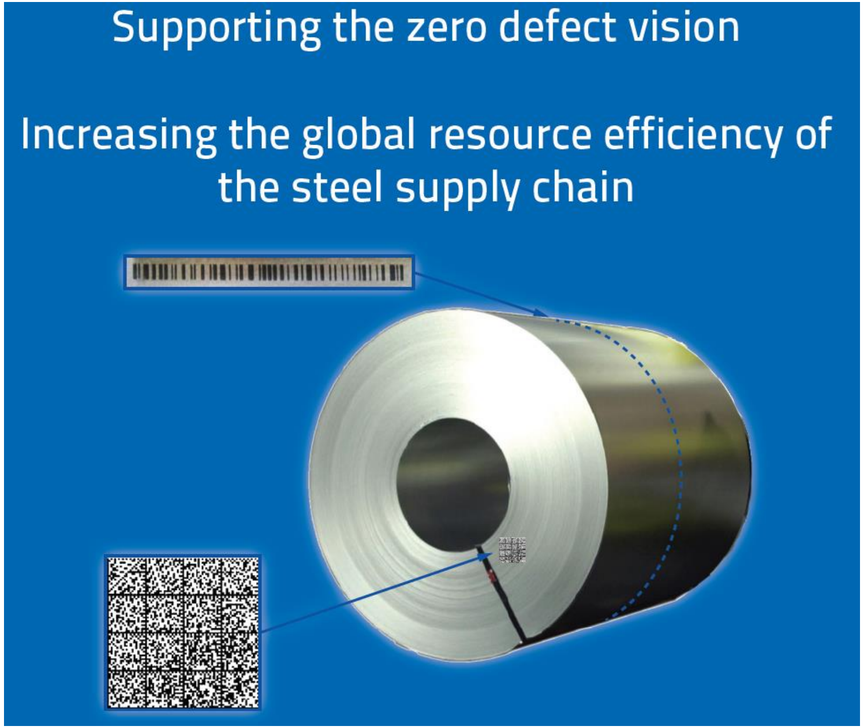
- "A digital twin is a real time digital replica of a physical device" (Bacchiega, 2017)
- “Using a digital copy of the physical system to perform real-time optimization” (Söderberg, R., Wärmefjord, K., Carlson, J. S., & Lindkvist, L. ,2017)
- “Digital twins are software representations of assets and processes that are used to understand, predict, and optimize performance in order to achieve improved business outcomes” (General Electric, webpage)

A DIGITAL TWIN AS REPLICA



Source: Gartner

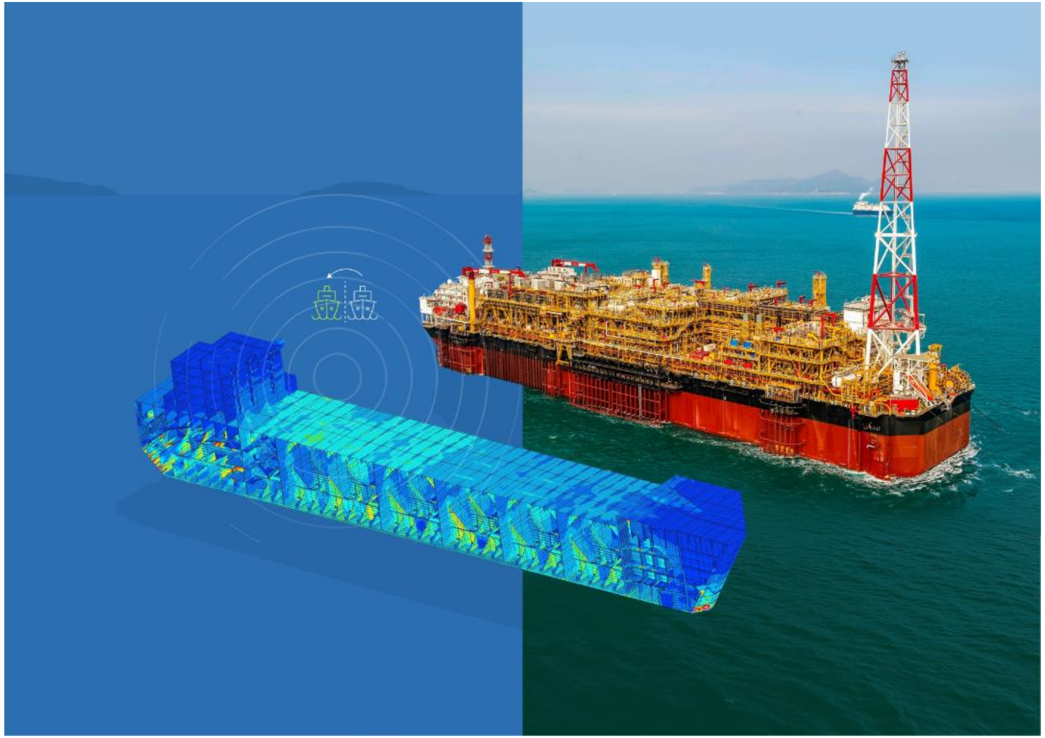
QUALITY TRACKING SYSTEM FOR STEEL COILS



EUROFER
The European Steel Association

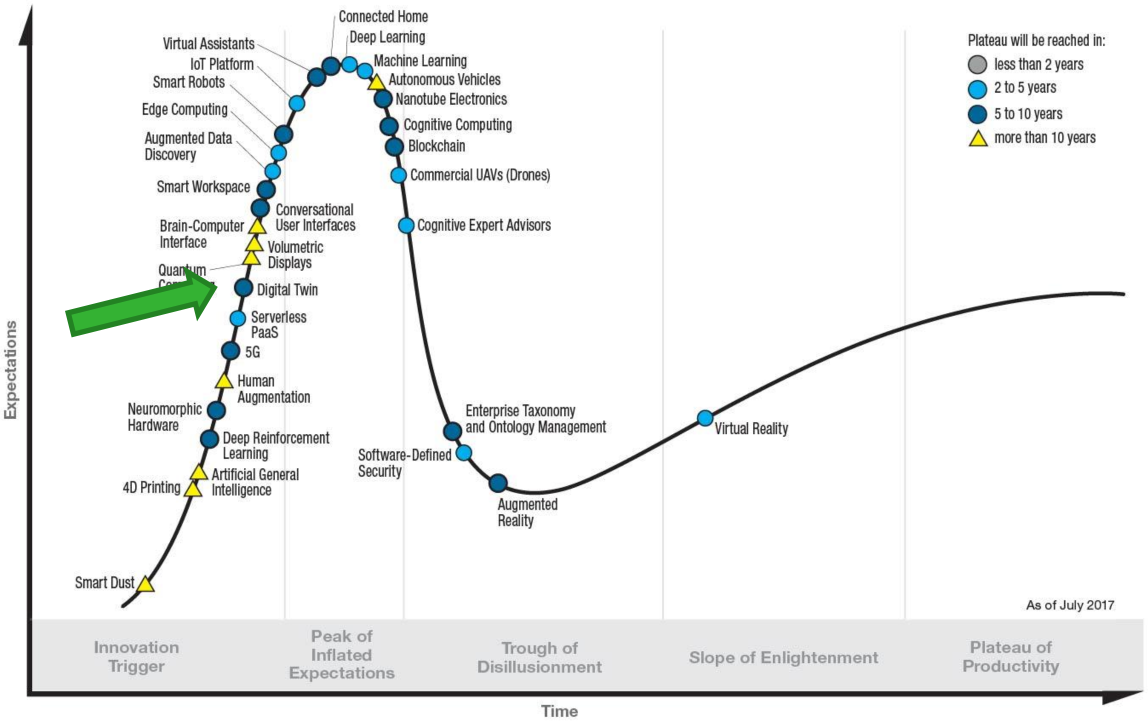
ArcelorMittal thyssenkrupp TATA STEEL voestalpine SALZGITTER FLACHSTAHL

A MODEL AS DIGITAL TWIN



businesswire.com

Gartner Hype Cycle for Emerging Technologies, 2017

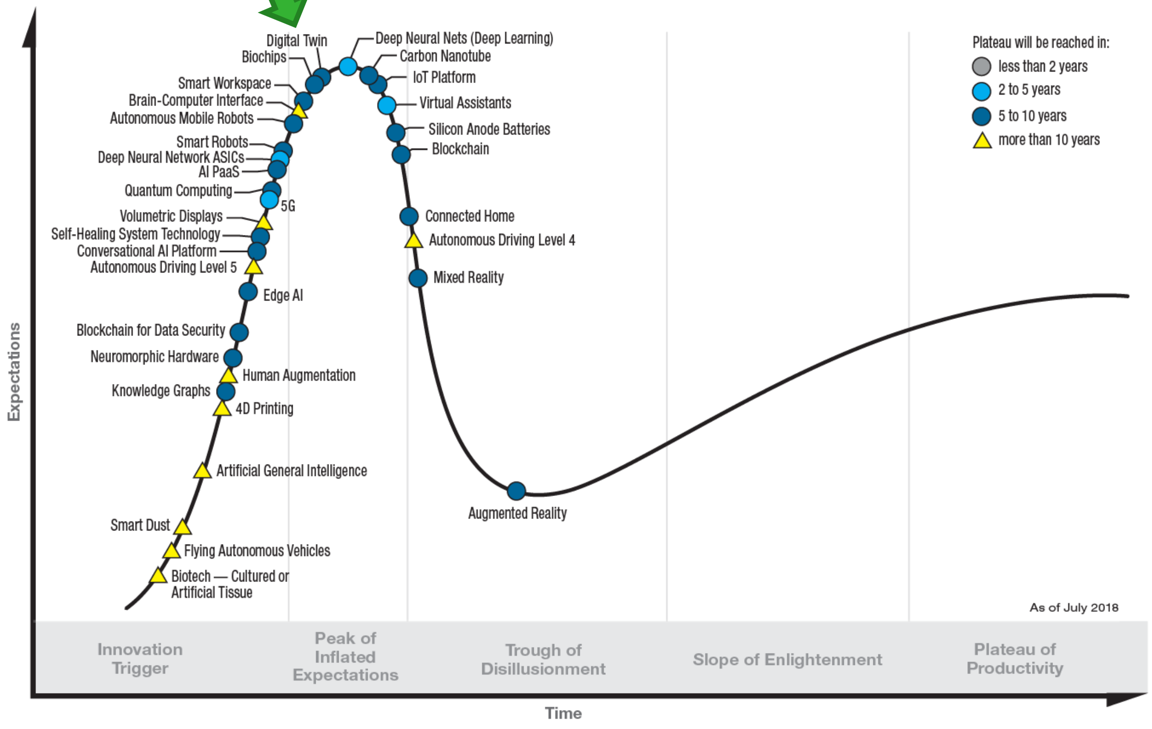


gartner.com/SmarterWithGartner

Source: Gartner (July 2017)

Gartner

Hype Cycle for Emerging Technologies, 2018

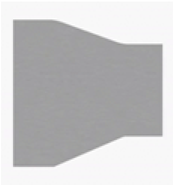


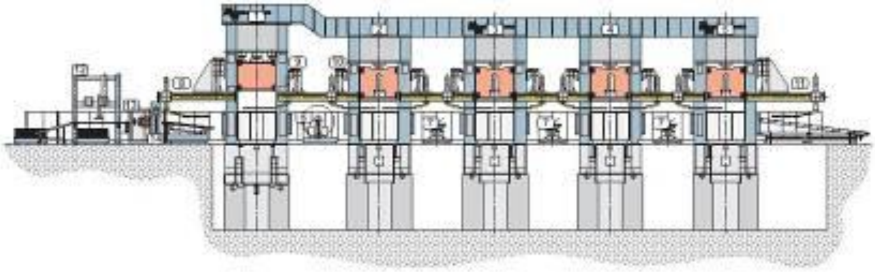
gartner.com/SmarterWithGartner

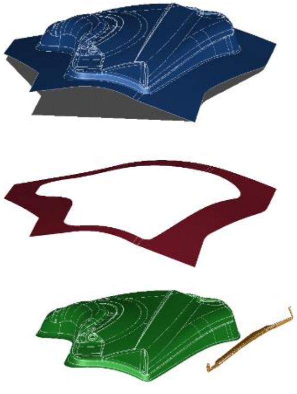
Source: Gartner (August 2018)

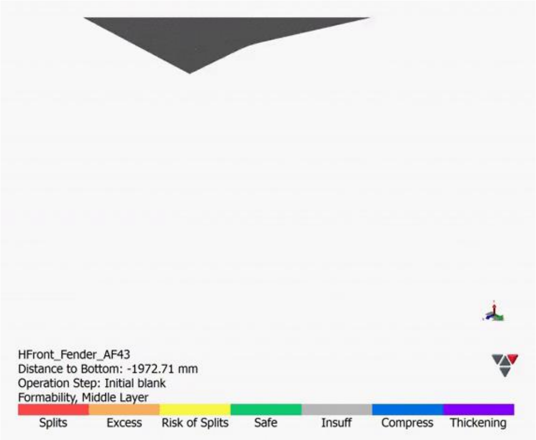
Gartner

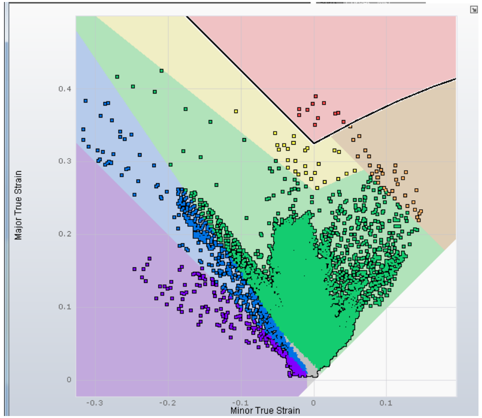
MODELLING OF PART MANUFACTURING



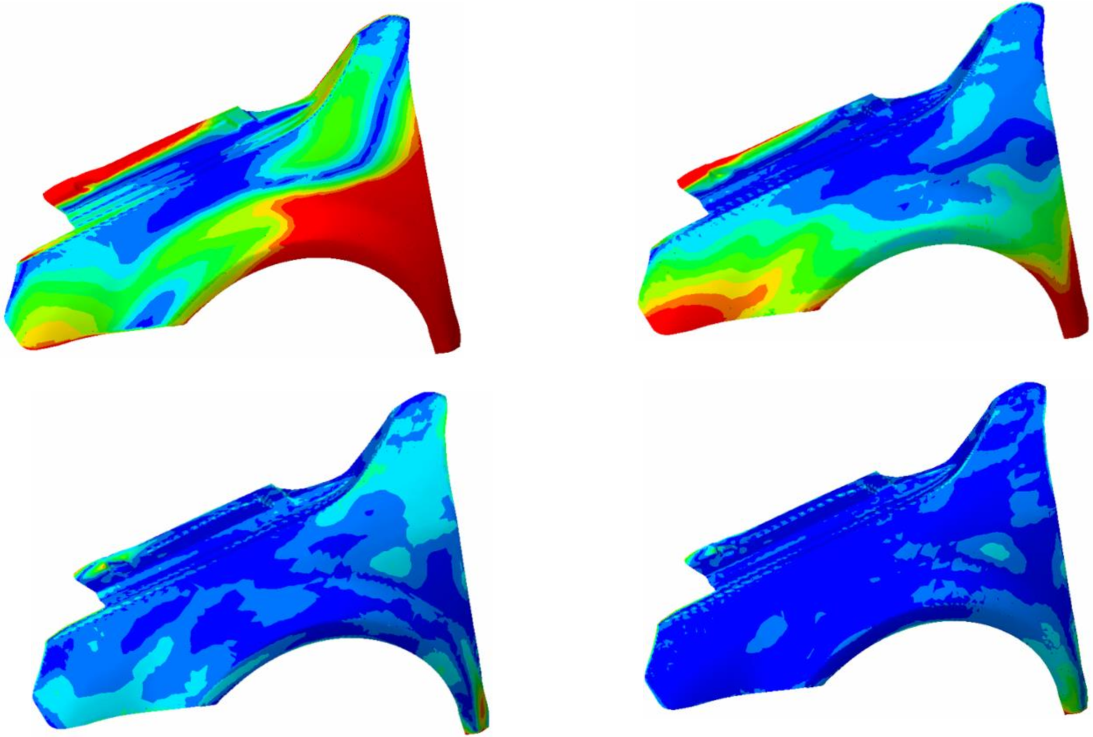




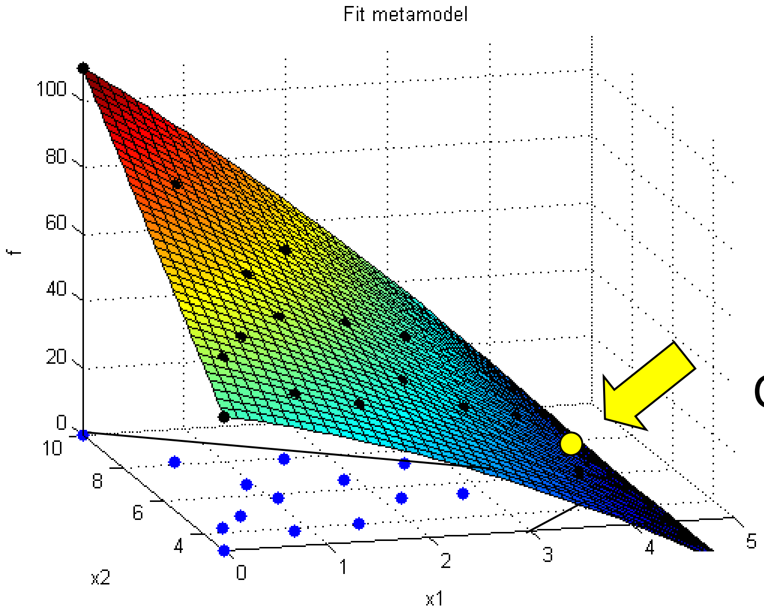




DIE COMPENSATION FOR SPRING BACK

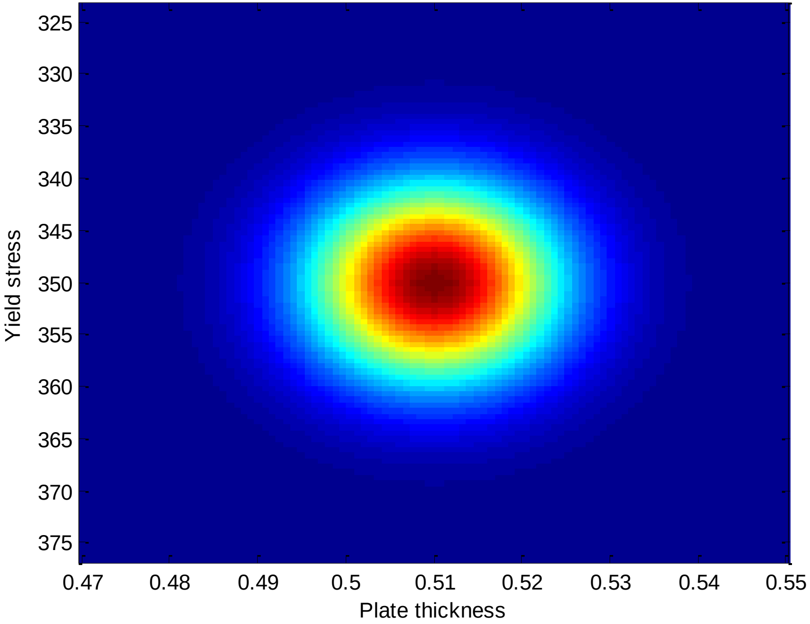


APPROXIMATE OPTIMIZATION



Constrained optimum

JOINT PROBABILITY DISTRIBUTION



ROBUST PROCESS OPTIMIZATION

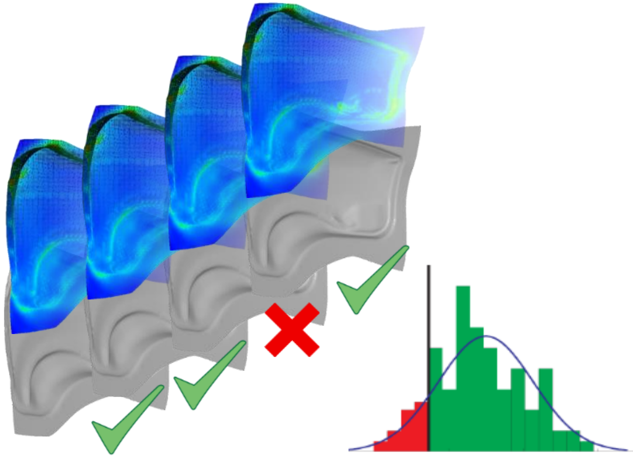
MATERIAL

PROCESS

PRODUCTS

Jan Harmen Wiebenga

materials innovation institute

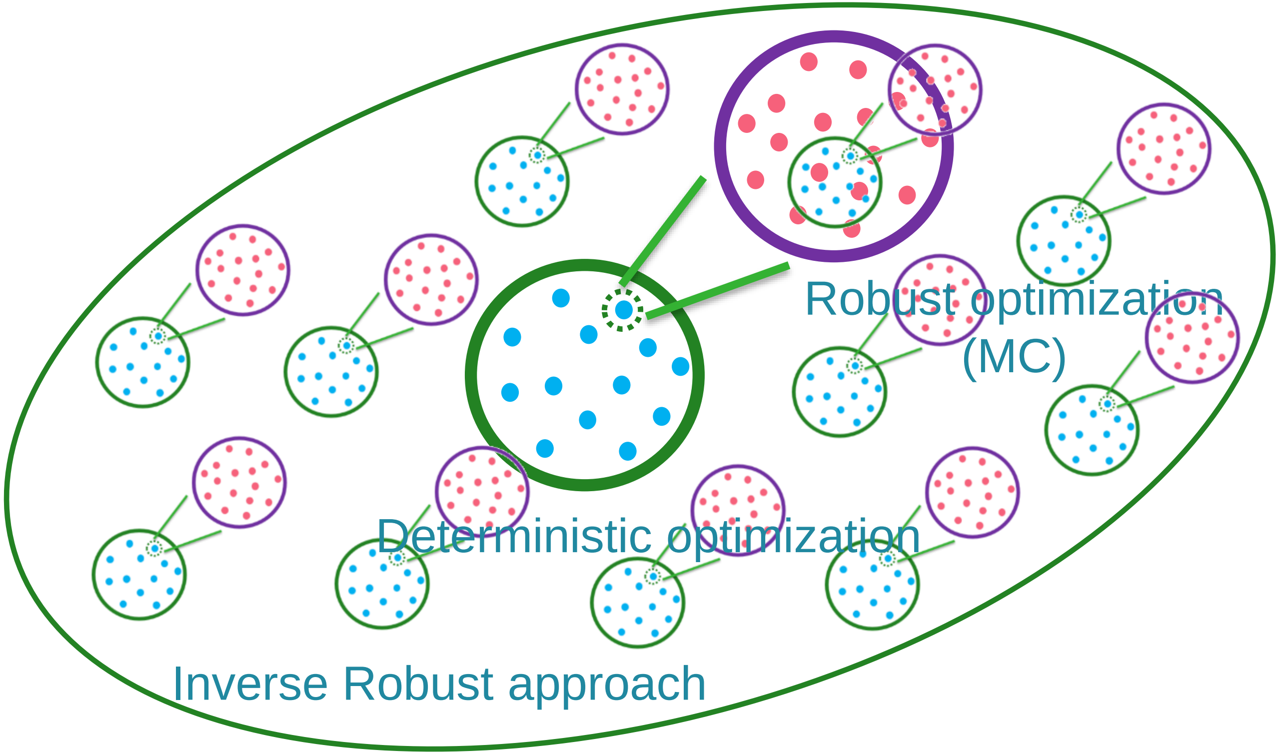


Scatter material properties

Variation process conditions

Product robustness

INCREASING COMPLEXITY



ANALYTICAL STATISTICAL MOMENTS

$$\mu_r(\mathbf{x}) = \int r(\mathbf{x},\mathbf{z})\mathcal{N}(\mathbf{z})d\mathbf{z} = \int r(\mathbf{x},\mathbf{z}) \prod_{q=1}^{n}[\mathcal{N}(z_q)dz_q] \; = \int \left\{ a_0 + \sum_{i=1}^{N}[a_i \prod_{P=1}^{M} b_{iP}(X_P)] \right\} \prod_{q=1}^{n}[\mathcal{N}(z_q)dz_q]$$

$$= a_0 + \sum_{i=1}^{N} \left\{ a_i \prod_{p=1}^{m} b_{ip}(x_p) \prod_{q=1}^{n}[\int b_{iq}(z_q)\mathcal{N}(z_q)dz_q] \right\} \; = a_0 + \sum_{i=1}^{N} \left\{ a_i \prod_{p=1}^{m} b_{ip}(x_p) \prod_{q=1}^{n} C1_{iq} \right\}$$

$$\sigma_r^2(\mathbf{x}) = \int [r(\mathbf{x},\mathbf{z}) - \mu_r(\mathbf{x})]^2 \mathcal{N}(\mathbf{z})d\mathbf{z} \;\; = \int r(\mathbf{x},\mathbf{z})^2\mathcal{N}(\mathbf{z})d\mathbf{z} - 2\mu_r(\mathbf{x}) \int r(\mathbf{x},\mathbf{z})\mathcal{N}(\mathbf{z})d\mathbf{z} + \mu_r(\mathbf{x})^2 \int \mathcal{N}(\mathbf{z})d\mathbf{z}$$

$$= \int [\sum_{i=1}^{N}\sum_{j=1}^{N} a_i a_j \prod_{P=1}^{m+n} b_{iP}(X_P) b_{jP}(X_P)] \prod_{q=1}^{n}[\mathcal{N}(z_q)dz_q] - \sum_{i=1}^{N}\sum_{j=1}^{N}[a_i a_j \prod_{p=1}^{m} b_{ip}(x_p) b_{jp}(x_p) \prod_{q=1}^{n} C1_{iq} C1_{jq}]$$

$$= \sum_{i=1}^{N}\sum_{j=1}^{N} a_i a_j \prod_{p=1}^{m} b_{ip}(x_p) b_{jp}(x_p) [\prod_{q=1}^{n} C2_{ijq} - \prod_{q=1}^{n} C1_{iq} C1_{jq}]$$

$$C1_{iq} = \int b_{iq}(z_q)\mathcal{N}(z_q)dz_q \; = \int e^{-\theta_q^2(z_q - z_{iq})^2} (\frac{1}{\sigma_q\sqrt{2\pi}} e^{-\frac{(z_q-\mu_q)^2}{2\sigma_q^2}}) dz_q \; = \sqrt{\frac{1}{2\sigma_q^2\theta_q^2 + 1}} \; e^{\frac{(2\theta_q^2 z_{iq}\sigma_q^2 + \mu_q)^2 - 2\theta_q^2 z_{iq}^2 \sigma_q^2 (2\sigma_q^2\theta_q^2+1) - \mu_q^2(2\sigma_q^2\theta_q^2+1)}{2\sigma_q^2(2\sigma_q^2\theta_q^2+1)}}$$

$$C2_{ijq} = \int b_{iq}(z_q) b_{jq}(z_q)\mathcal{N}(z_q)dz_q \;\; = \frac{1}{\sqrt{4\sigma_q^2\theta_q^2 + 1}} e^{\frac{-\theta_q^2(2\theta_q^2 z_{iq}^2\sigma_q^2 + z_{iq}^2 + 2\theta_q^2 z_{jq}^2 \sigma_q^2 + z_{jq}^2 + 2\mu_q^2 - 4\sigma_q^2\theta_q^2 z_{iq} z_{jq} - 2z_{iq}\mu_q - 2z_{jq}\mu_q)}{(4\sigma_q^2\theta_q^2+1)}}$$

INVERSE ROBUST PROCESS OPTIMIZATION

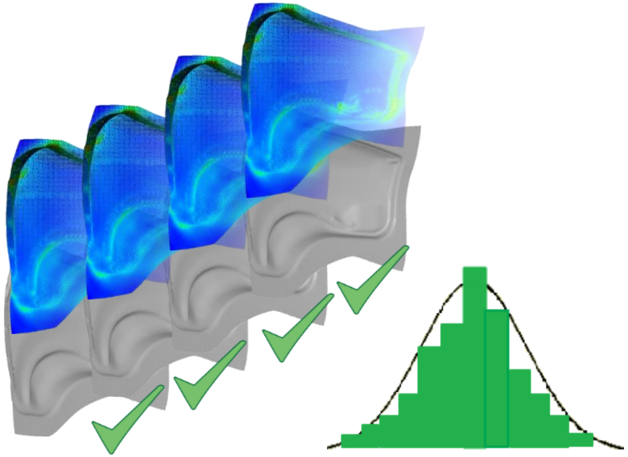
MATERIAL

PROCESS

PRODUCTS

Omid Nejadseyfi

materials innovation institute



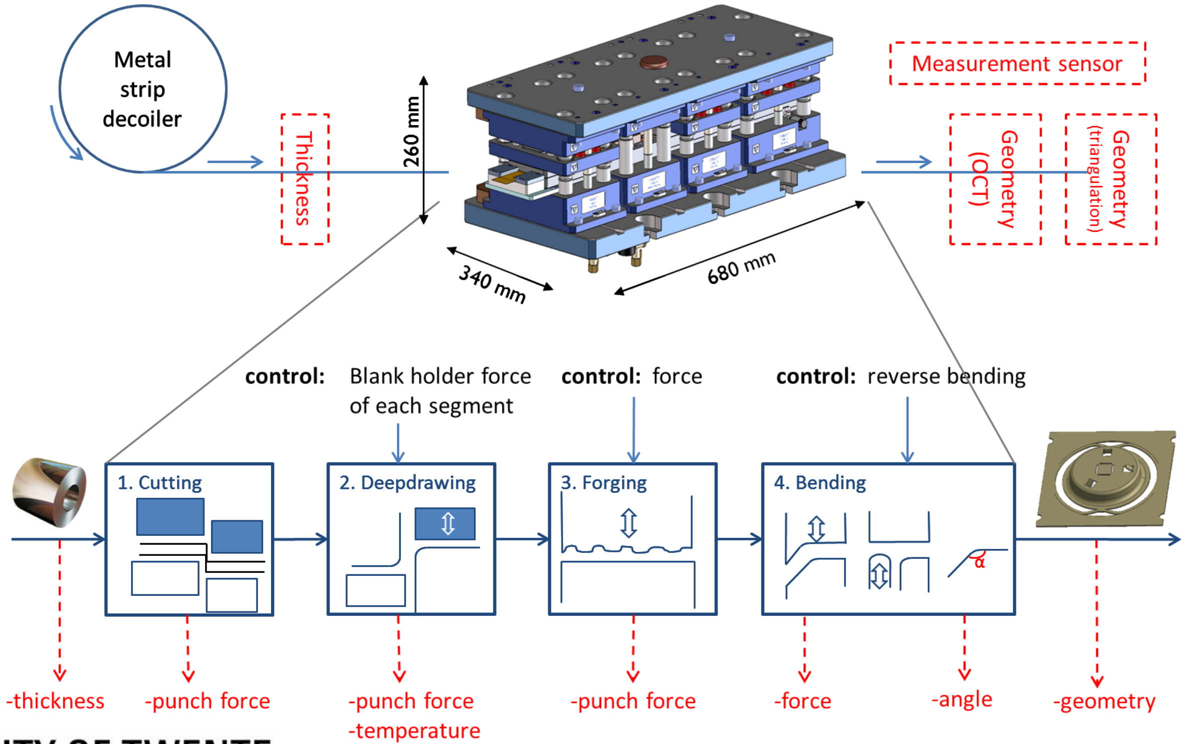
Scatter material properties

Variation process conditions

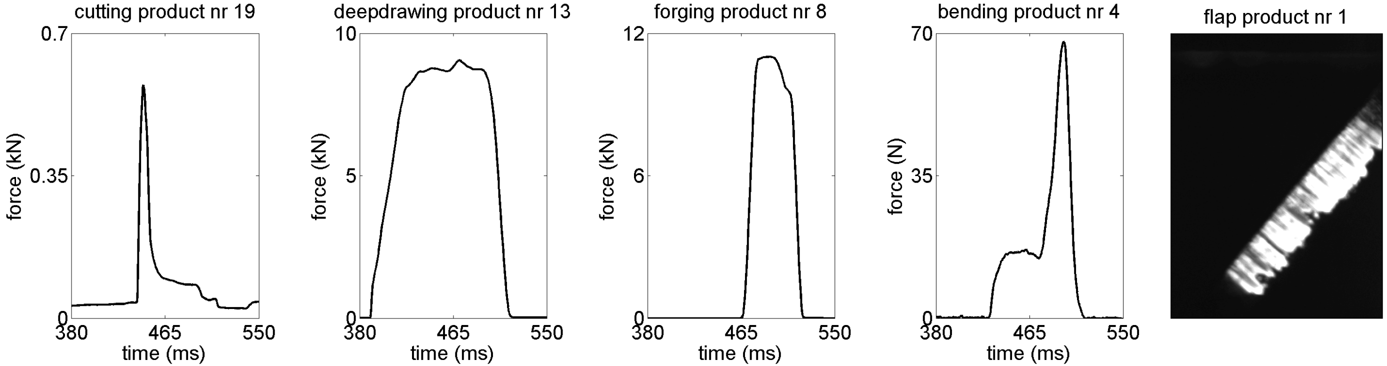
Product robustness

MODEL BASED PROCESS CONTROL

Jos Havinga



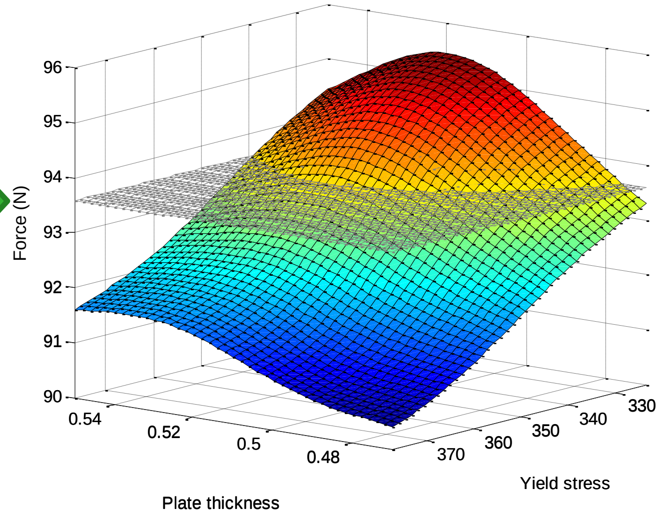
FORCE MEASUREMENTS

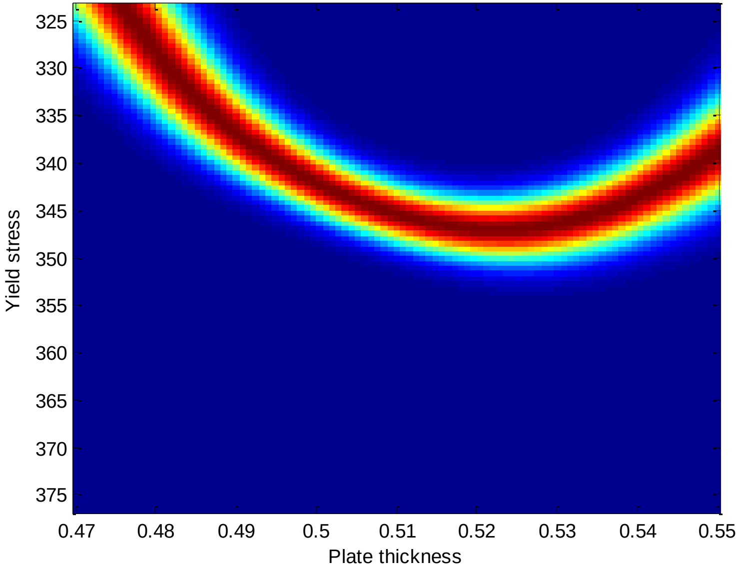


RELATION PUNCH FORCE AND NOISE PARAMETERS

MEGaFiT

1) Metamodel

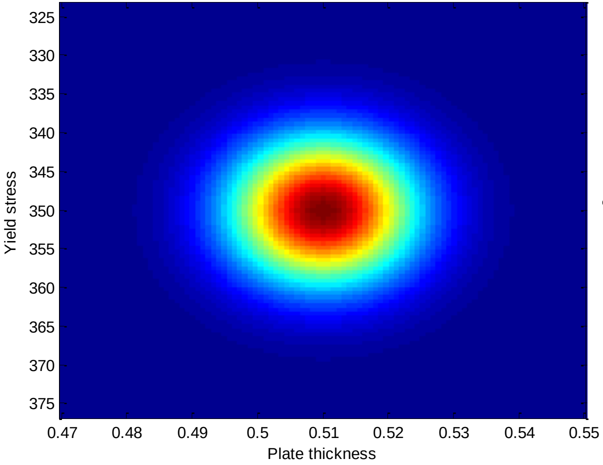




2) Measurement

BAYESIAN STATISTICAL APPROACH

Prior probability



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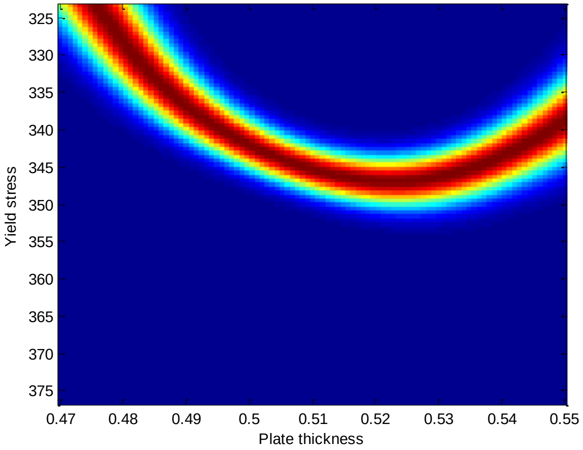
Observation



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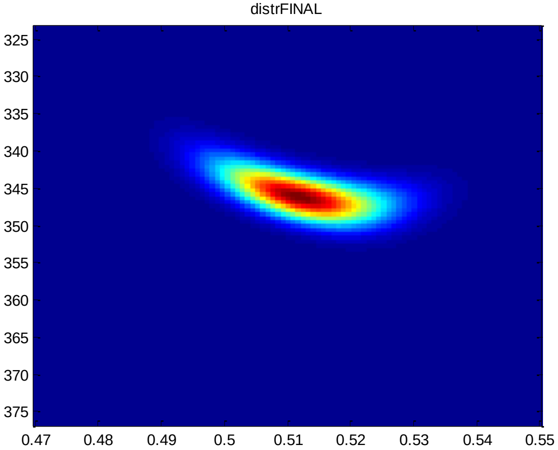
Posterior probability



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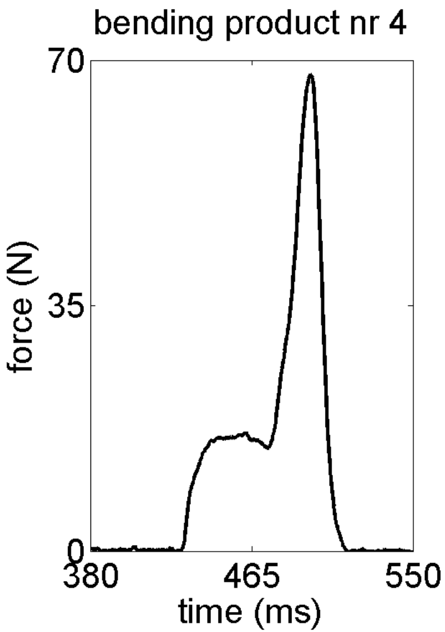
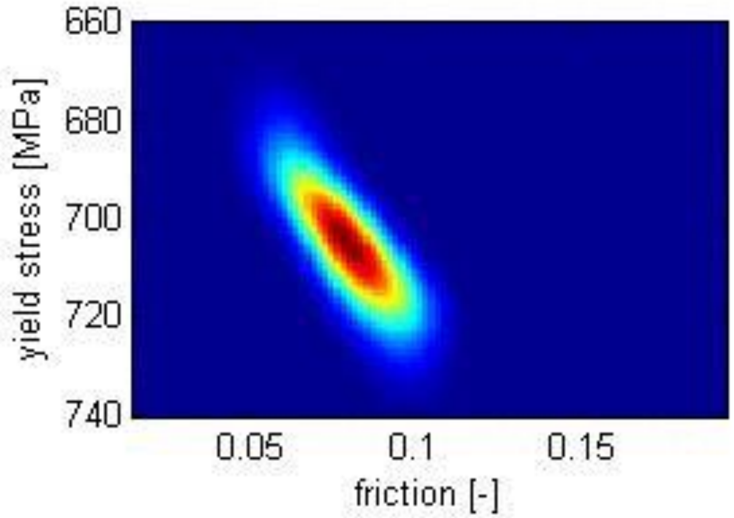
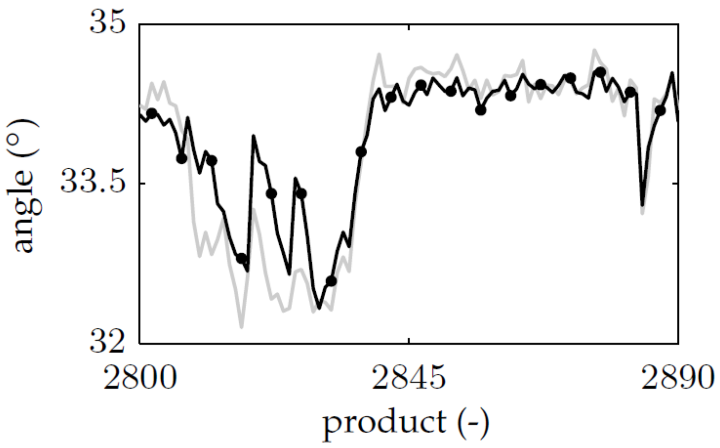
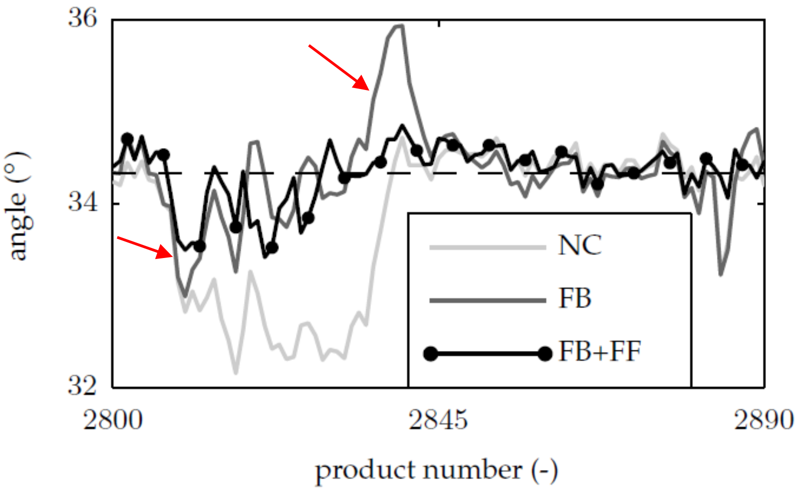
CONTROL BASED ON POSTERIOR PROBABILITY





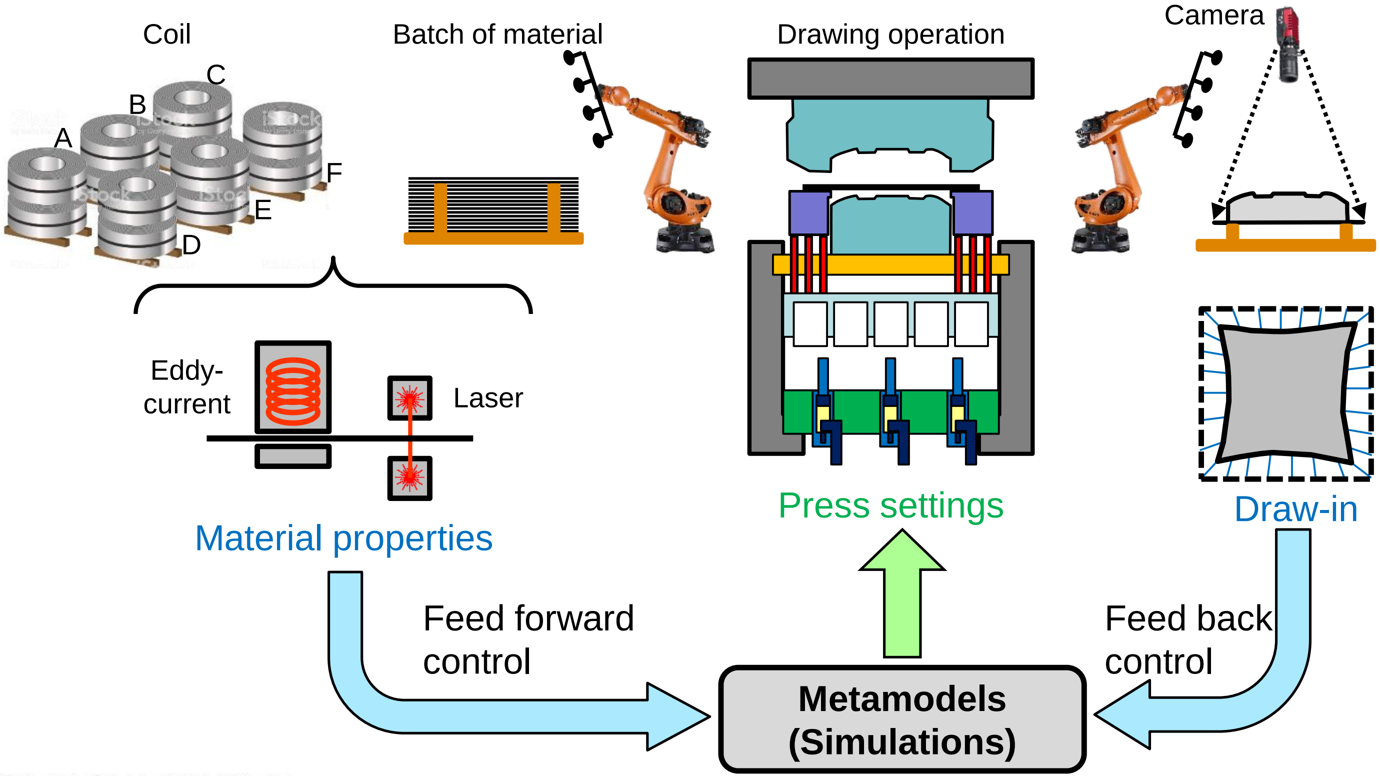
MODEL BASED CONTROL
PREDICTED EFFECTIVENESS





PROCESS CONTROL FOR DEEP DRAWING PROCESS

DAVID HARSCH (ETH)



inspire

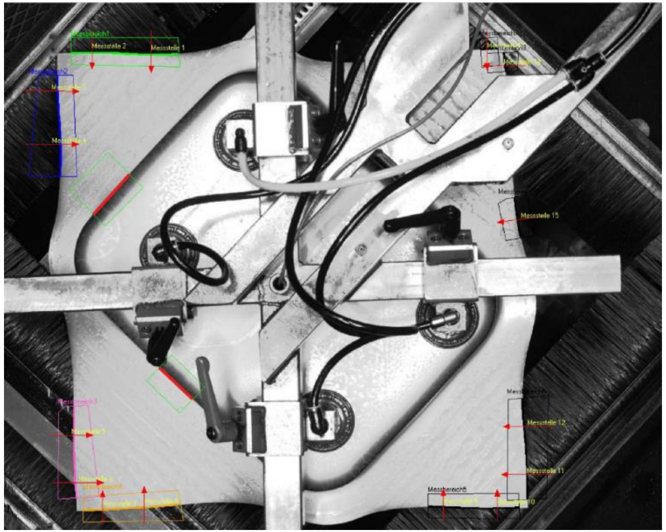
FRANKE

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Institut für Virtuelle Produktion
Institute of Virtual Manufacturing

OPTICAL DRAW-IN MEASUREMENT

- Measurement is done in the re-lubrication station.
- Draw-in is calculated through the software, based on an image taken from above.



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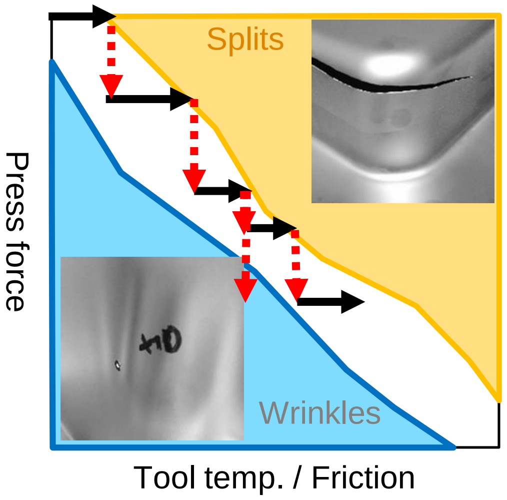
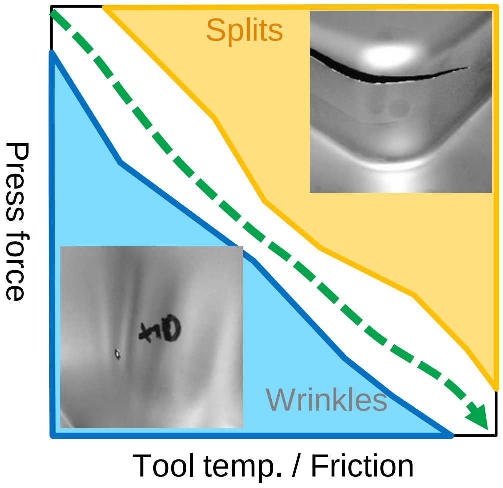
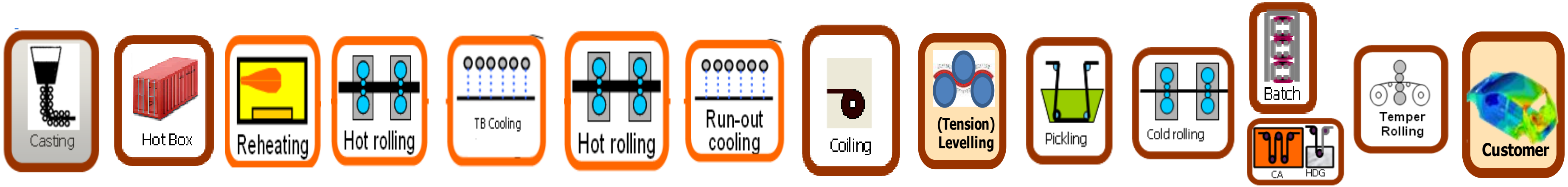
EXPERIENCE VS. PROCESS CONTROL



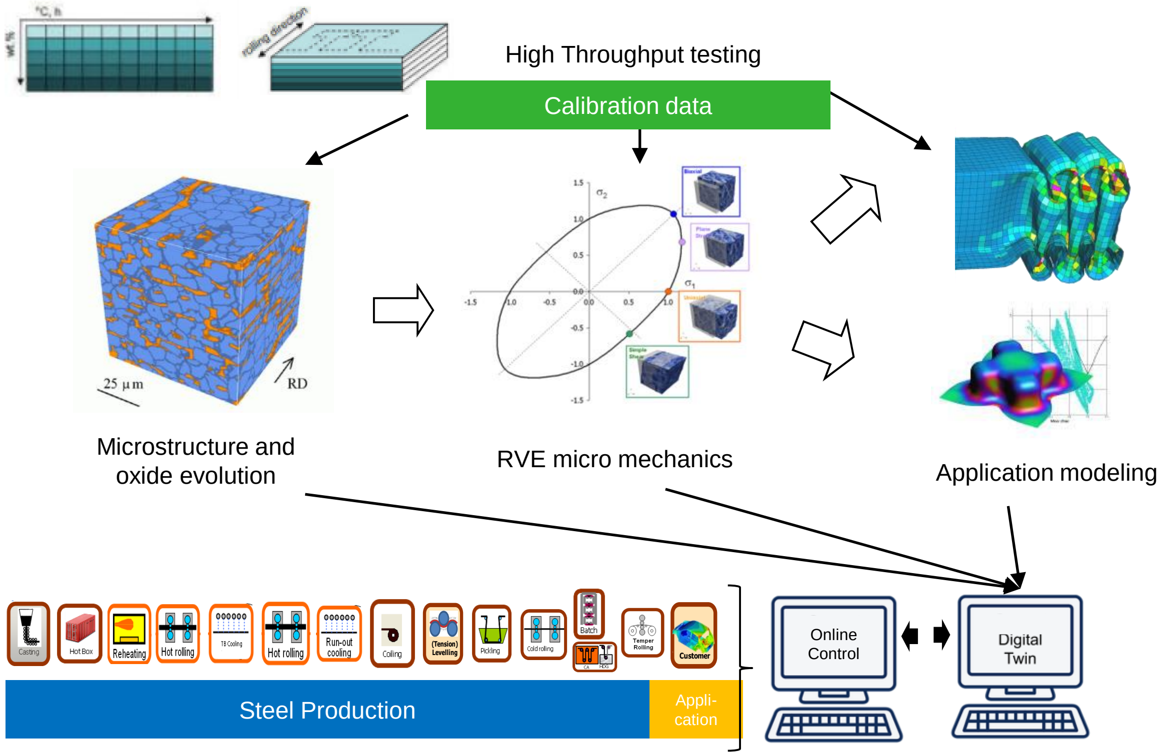


(David Harsch, ETH)

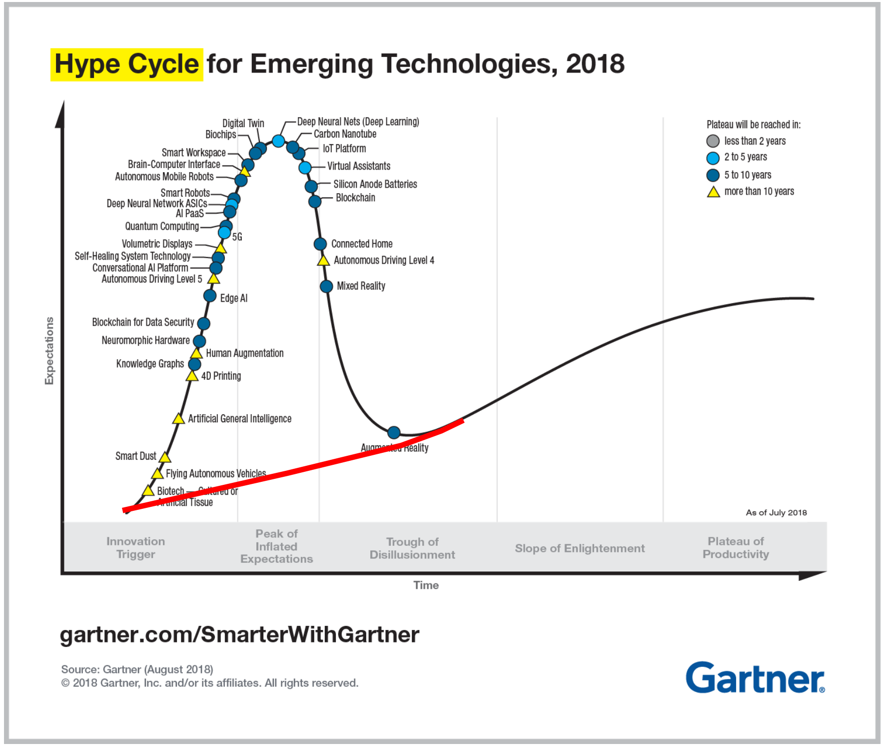
DIGITALLY ENHANCED NEW STEEL PRODUCT DEVELOPMENT (DENS)

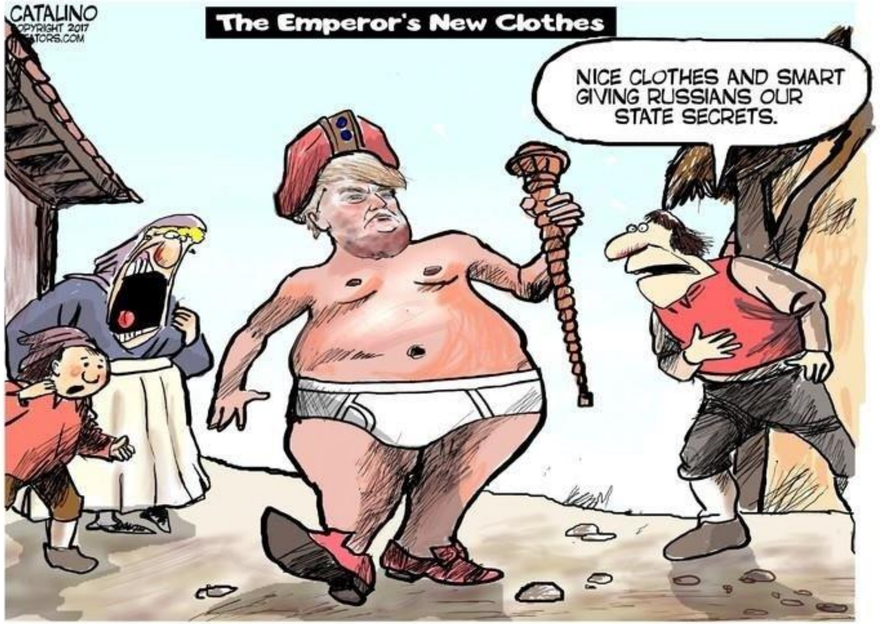


DIGITALLY ENHANCED NEW STEEL PRODUCT DEVELOPMENT (DENS)



ARE DIGITAL TWINS *THE EMPEROR'S NEW CLOTHES*?





THANKS TO:

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Leonardo Schneider (ETH)

…

David Harsch (ETH)

Jörg Heingärtner (Inspire AG)

Kees Bos (Tata Steel)

Eisso Atzema (Tata Steel)

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