Toward the Development of a Real Digital Twin for Automotive Steel Stamping

Jason A Ryska

Director, Manufacturing Technology
Development – Ford Motor Company

Great Designs in Steel, May 22, 2024

Education

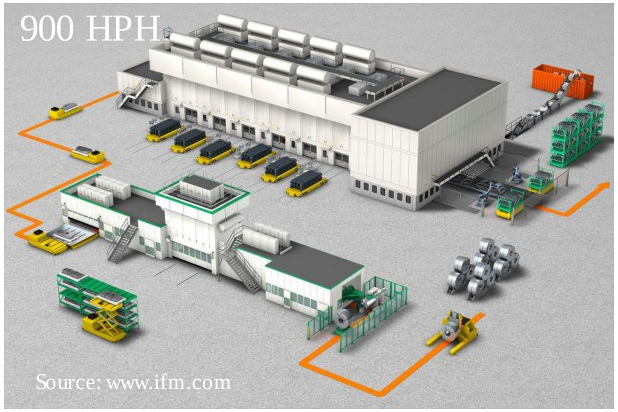
- Ph.D, 2024, Automotive Systems and Mobility, University of Michigan
- M.B.A 2005, Michigan State University
- M.S. 1997, Manufacturing Systems, Oakland University
- B.S. 1995, Mechanical Engineering, Oakland University

Professional Experience

- Ford Motor Company (2016 to present)
  - Director, Manufacturing Technology Development,
  - Chief Engineer, Global Stamping Engineeing
- FCA (1995-2016)
  - Autodie LLC, VP and COO
  - General Manager Stamping Operation
  - Plant Manager
    - Vehicle Assembly
    - Stamping

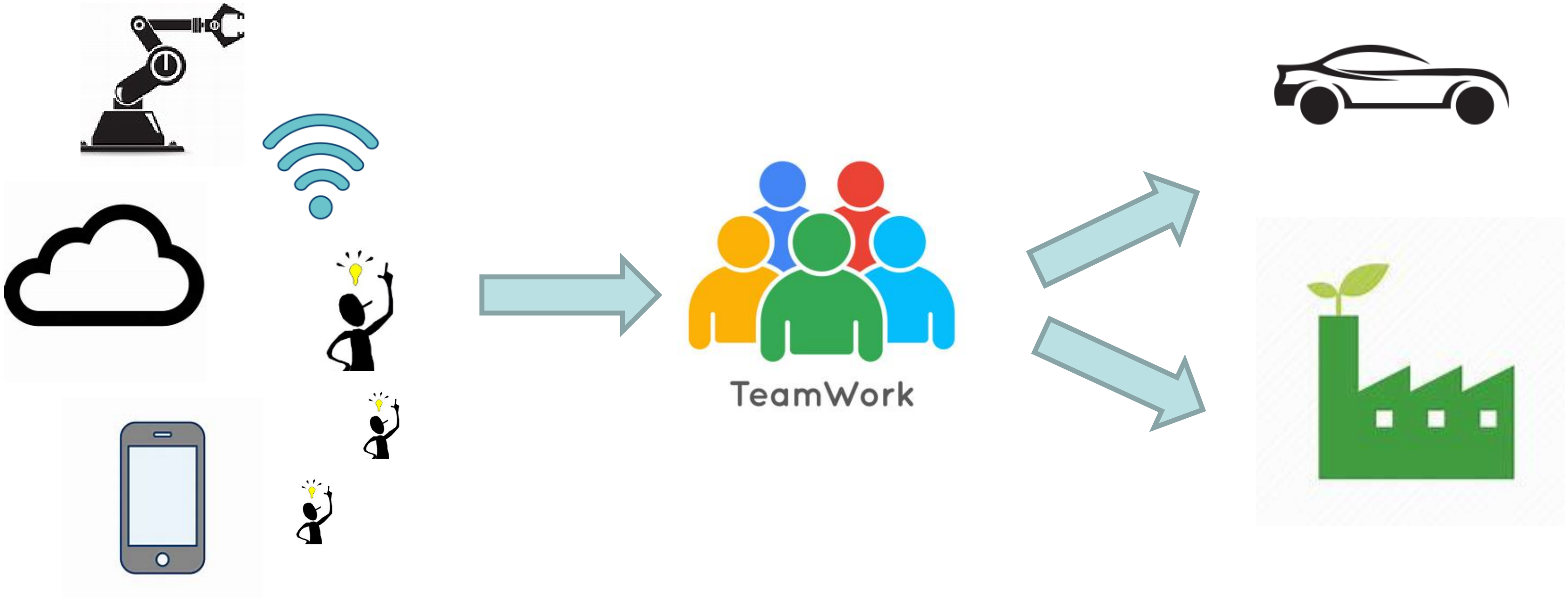
Stamping Industry 1975, 1995, 2024, Beyond..

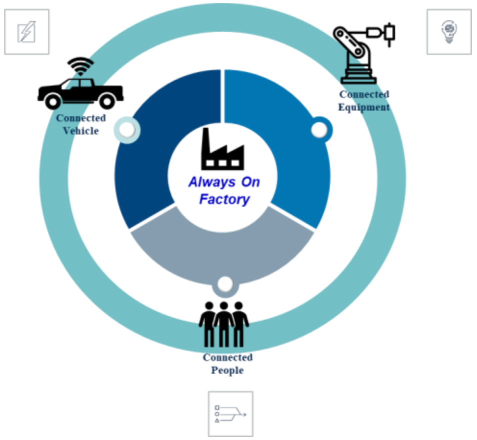
Source: https://www.maxwill-ind.com



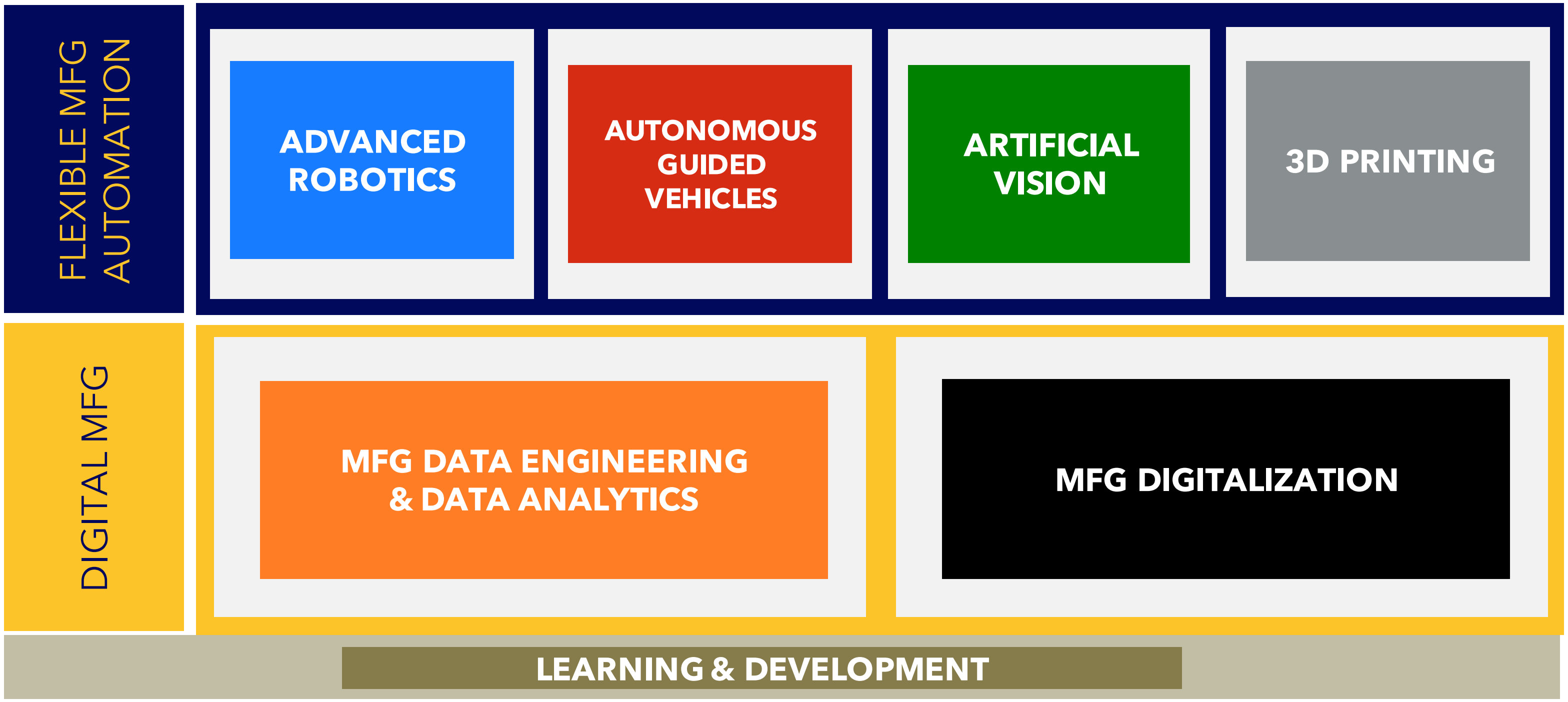
Source: www.ifm.com

Manufacturing Technology Development Center





Manufacturing Innovation Pillars



FLEXIBLE MFG AUTOMATION

ADVANCED ROBOTICS

AUTONOMOUS GUIDED VEHICLES

ARTIFICIAL VISION

3D PRINTING

DIGITAL MFG

MFG DATA ENGINEERING & DATA ANALYTICS

MFG DIGITALIZATION

LEARNING & DEVELOPMENT

Product Driven Organization
breaking the Silos of the Manufacturing Areas and Departments

Introduction: Survey of Digital Twin in Manufacturing

George Ayoub,
Associate Professor,
Director of the
Human Centered
Engineering Design
Program

Abdullah Chehade,
Associate Professor,
Industrial and
Manufacturing
Systems
Engineering

Ossama Modad,
Phd Candidate

Ford

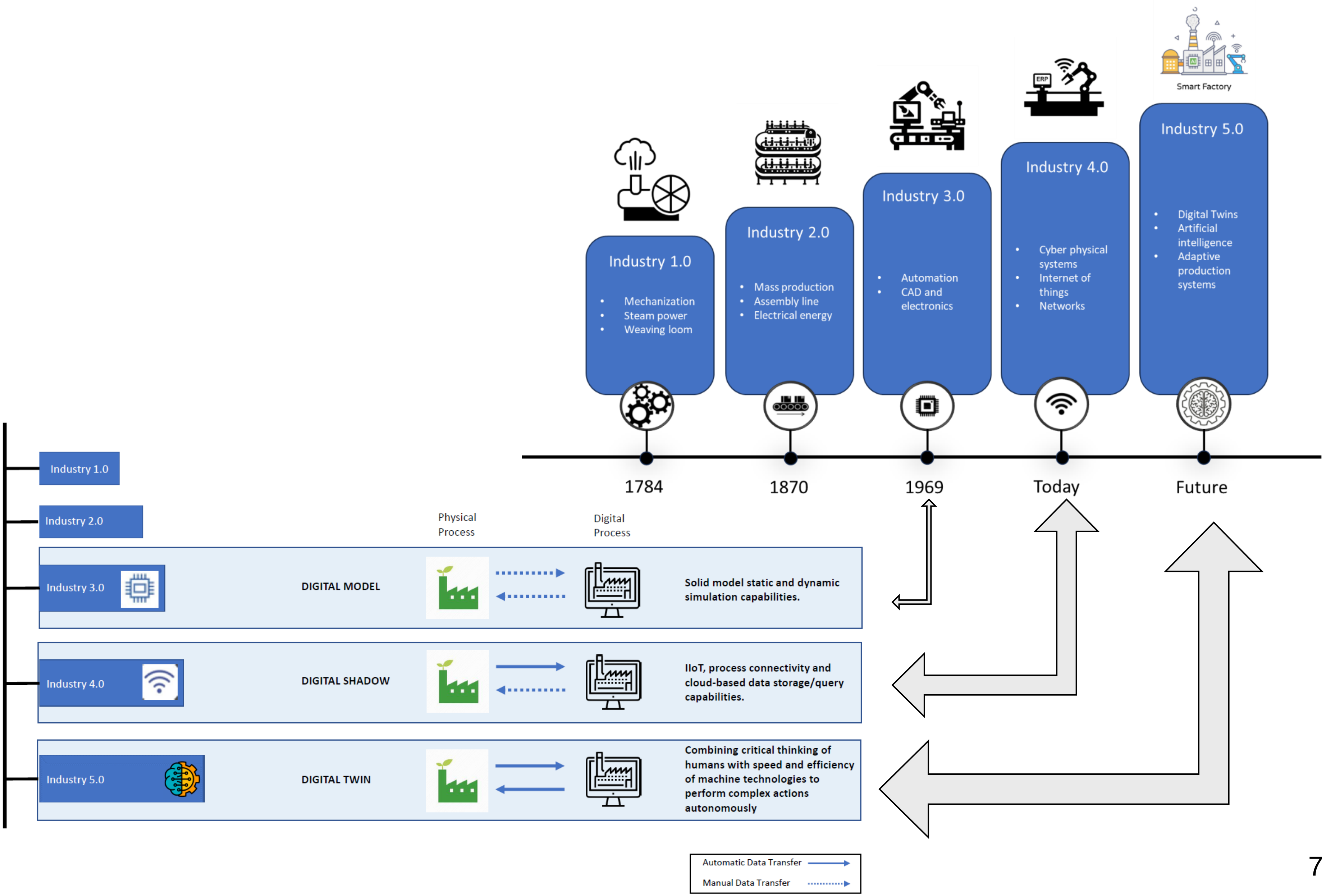
DEARBORN

Introduction: Survey of Digital Twin in Manufacturing

In his work, Grieves describes a DT as "a virtual representation of a physical product that contains information about the physical product" and its end goal is manufacturing excellence. According to Grieves, the DT consists of three components, (1) the physical product, (2) accurate digital representation of the physical product, and (3) bidirectional data flow between the physical and digital objects.

M. Grieves, "Digital twin: manufacturing excellence through virtual factory replication," *White Pap.*, vol. 1, no. 2014, pp. 1–7, 2014.

Introduction: Survey of Digital Twin in Manufacturing



Smart Factory

Industry 1.0
- Mechanization
- Steam power
- Weaving loom

1784

Industry 2.0
- Mass production
- Assembly line
- Electrical energy

1870

Industry 3.0
- Automation
- CAD and electronics

1969

Industry 4.0
- Cyber physical systems
- Internet of things
- Networks

Today

Industry 5.0
- Digital Twins
- Artificial intelligence
- Adaptive production systems

Future

Industry 1.0

Industry 2.0

Physical Process

Digital Process

Industry 3.0 — DIGITAL MODEL — Solid model static and dynamic simulation capabilities.

Industry 4.0 — DIGITAL SHADOW — IIoT, process connectivity and cloud-based data storage/query capabilities.

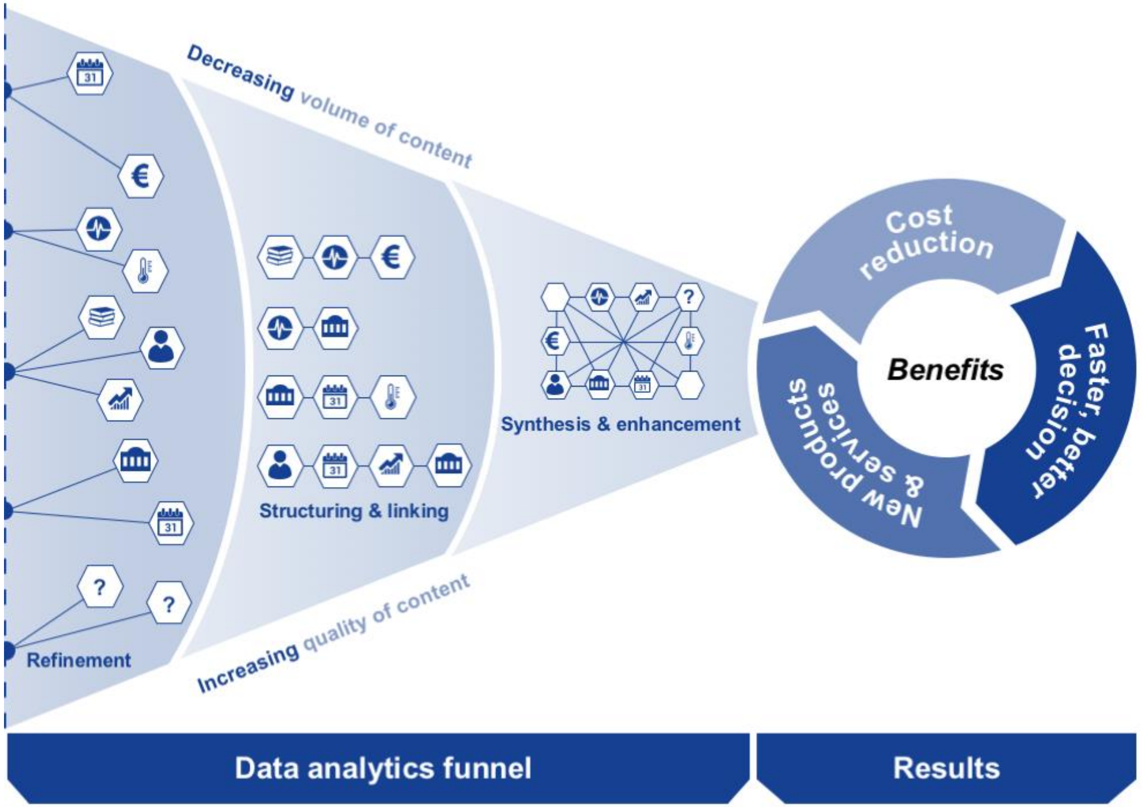
Industry 5.0 — DIGITAL TWIN — Combining critical thinking of humans with speed and efficiency of machine technologies to perform complex actions autonomously

Automatic Data Transfer ──►

Manual Data Transfer ·········►

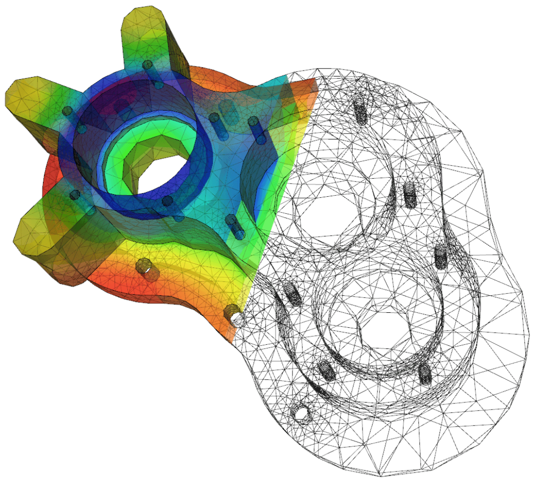
Introduction: Survey of Digital Twin in Manufacturing

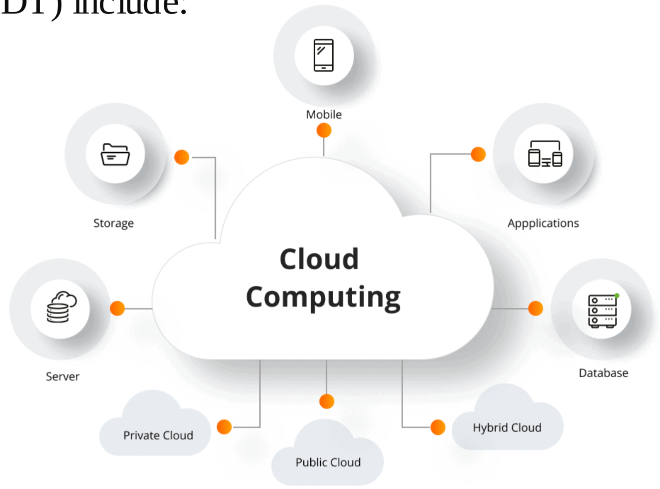
Technological advancements that enable the implementation of Digital Twins (DT) include:

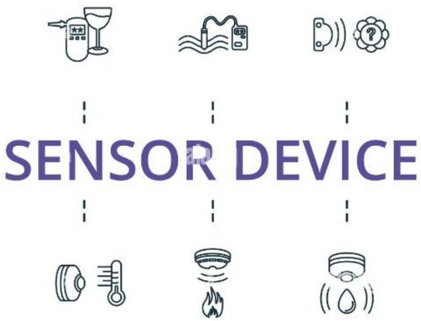


Introduction: Survey of Digital Twin in Manufacturing

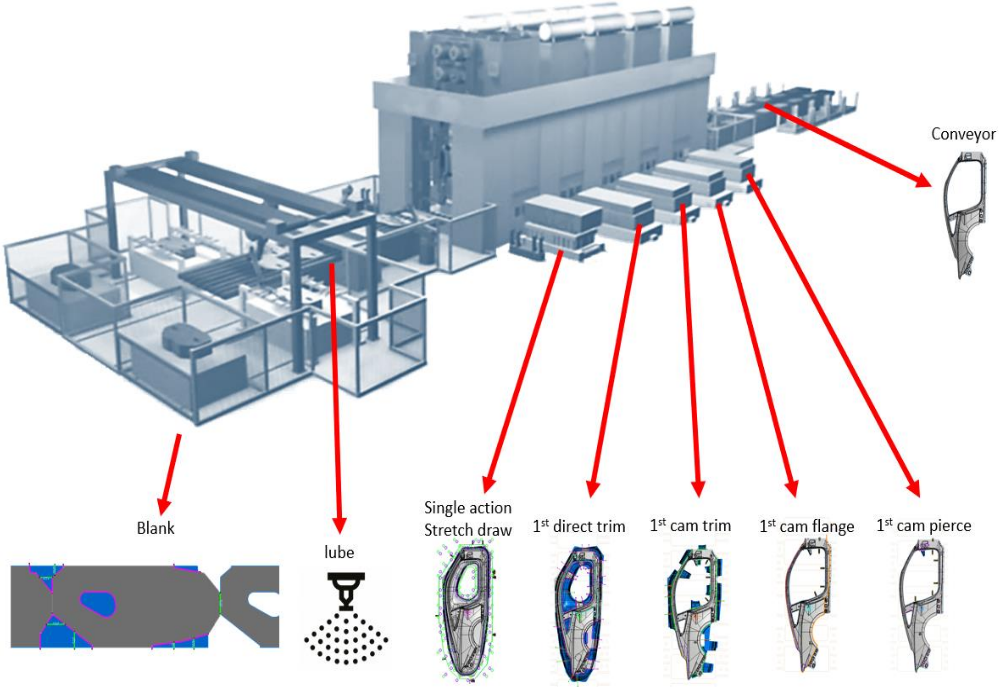
Technological advancements that enable the implementation of Digital Twins (DT) include:

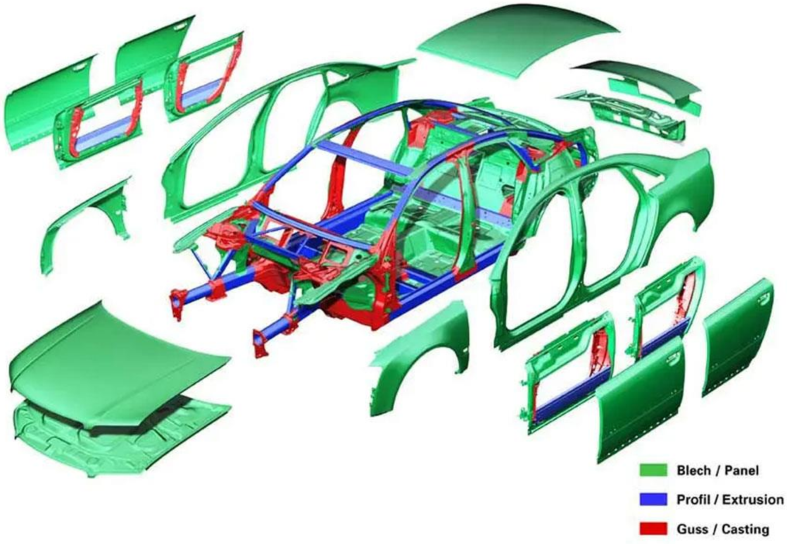




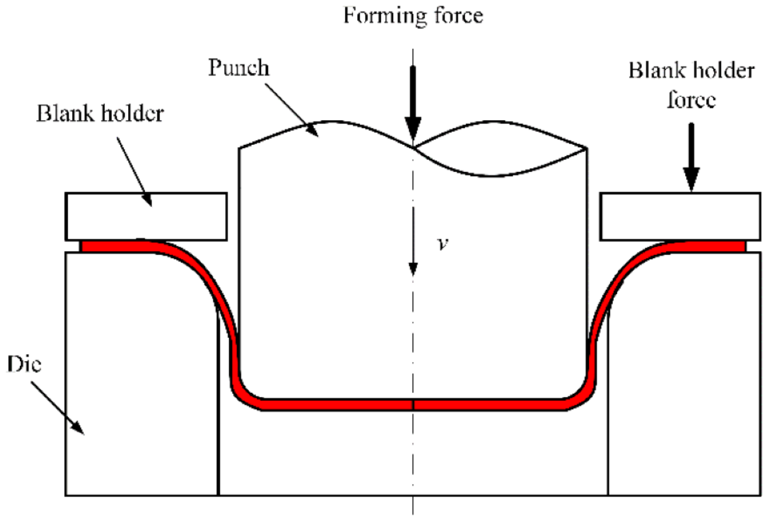


Toward a Sheet Metal Forming DT



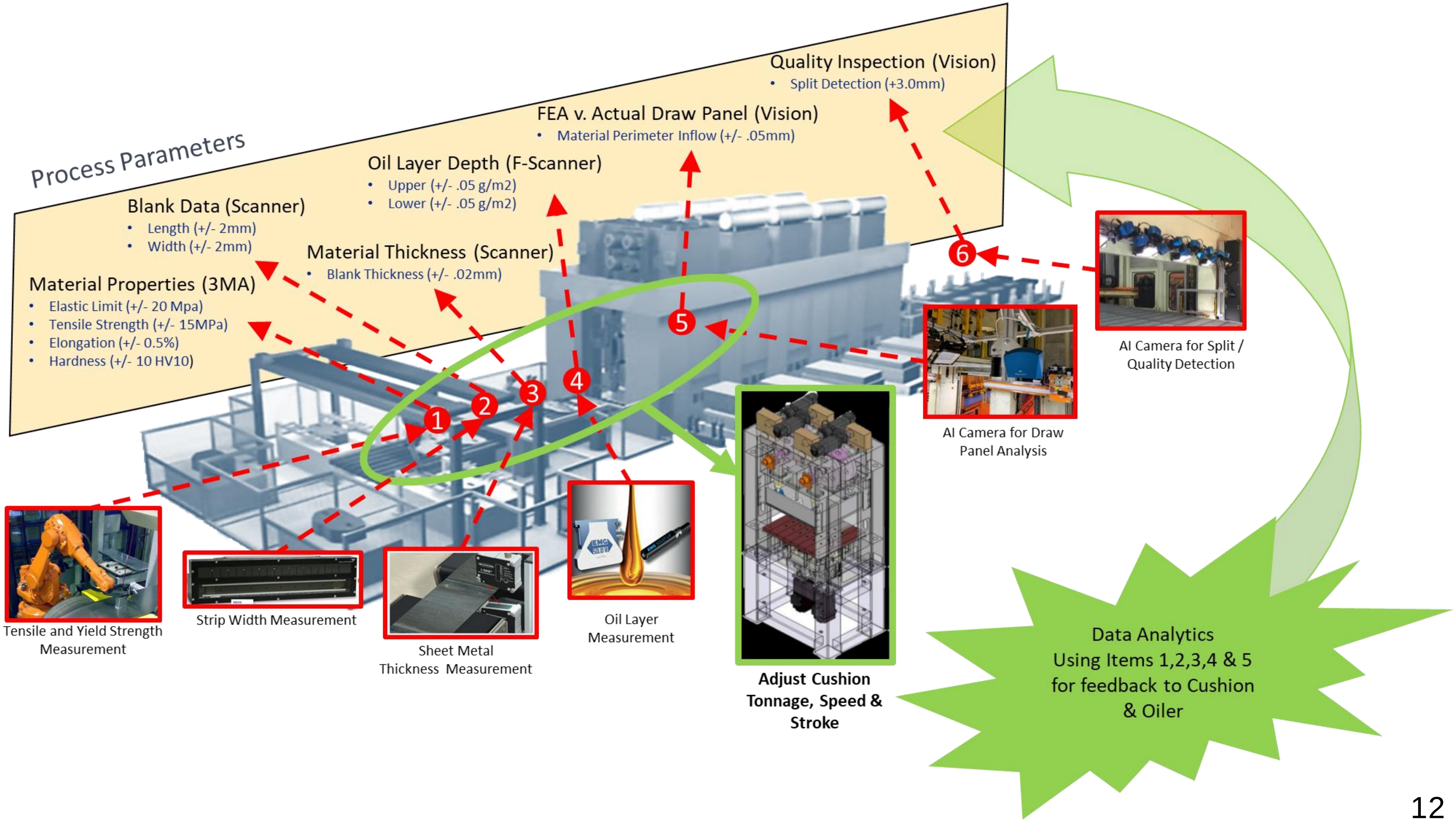


Toward a Sheet Metal Forming DT



Sheet metal properties	Material composition, deformation history, temperature. Yield and tensile strengths, hardness. Flow stress for different loading conditions (different strains, strain rates, temperatures, microstructures). Mechanical anisotropy. Ductility as function of process temperature. Strain rate, applied load.
Tool/equipment	Geometric attributes and surface finish of the tool. Tool material and properties. Force applied by the tool
Tool/material interface	Friction at the tool/material interface. Lubricant type, temperature, and film thickness. Lubricant thermal properties.
Zone of deformation	Deformation mechanisms. Material flow, velocity of flow. Stress, strain, and damage profiles post deformation.
Product geometry and properties	Final product geometry (dimensions, thickness uniformity, surface finish and tolerances). Final product mechanical properties

Toward a Sheet Metal Forming DT (data collection)



Process Parameters

Blank Data (Scanner)
- Length (+/- 2mm)
- Width (+/- 2mm)

Material Properties (3MA)
- Elastic Limit (+/- 20 Mpa)
- Tensile Strength (+/- 15MPa)
- Elongation (+/- 0.5%)
- Hardness (+/- 10 HV10)

Oil Layer Depth (F-Scanner)
- Upper (+/- .05 g/m2)
- Lower (+/- .05 g/m2)

Material Thickness (Scanner)
- Blank Thickness (+/- .02mm)

FEA v. Actual Draw Panel (Vision)
- Material Perimeter Inflow (+/- .05mm)

Quality Inspection (Vision)
- Split Detection (+3.0mm)

Tensile and Yield Strength Measurement

Strip Width Measurement

Sheet Metal Thickness Measurement

Oil Layer Measurement

Adjust Cushion Tonnage, Speed & Stroke

AI Camera for Draw Panel Analysis

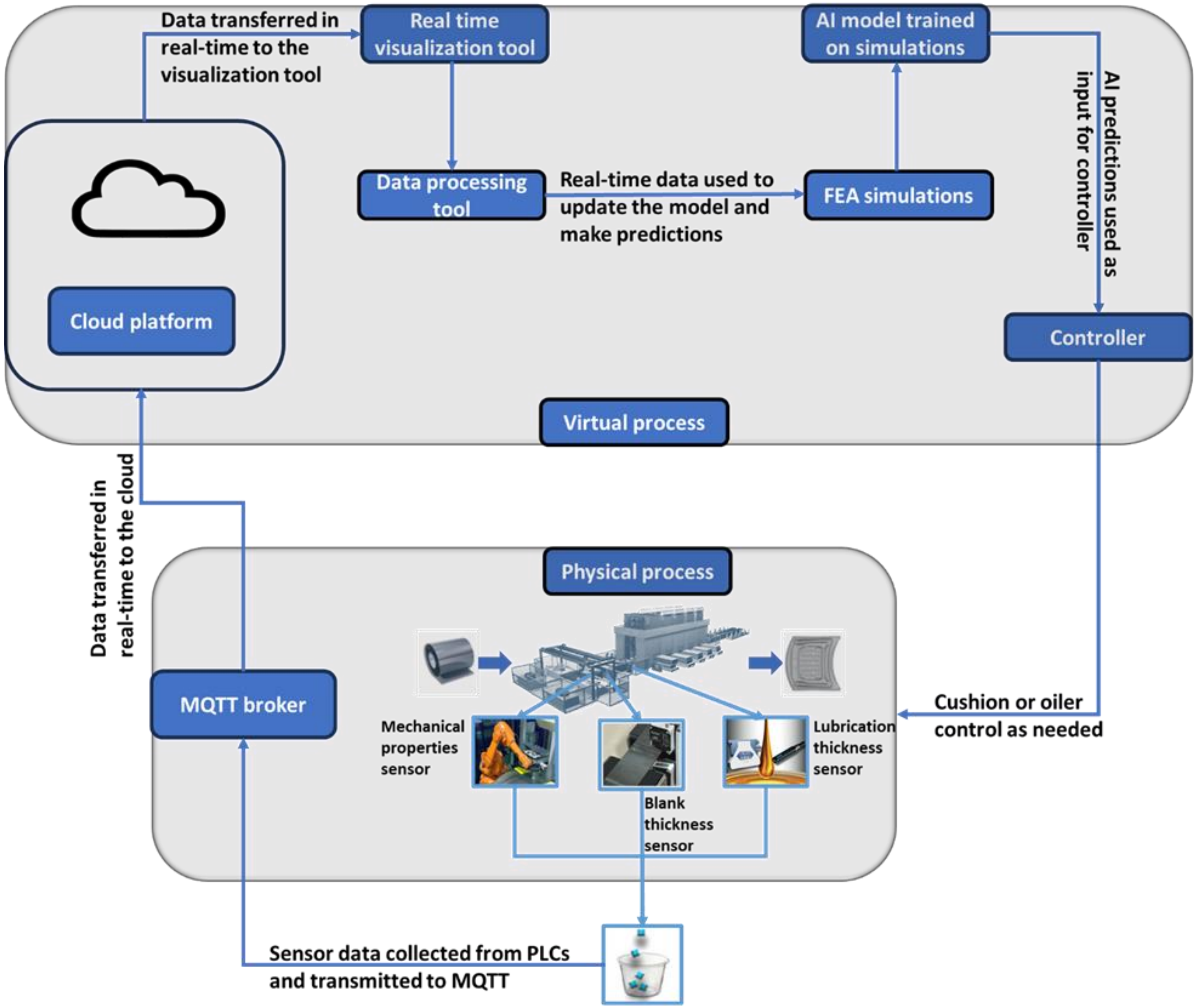
AI Camera for Split / Quality Detection

Data Analytics Using Items 1,2,3,4 & 5 for feedback to Cushion & Oiler

Toward a Sheet Metal Forming DT (data collection)

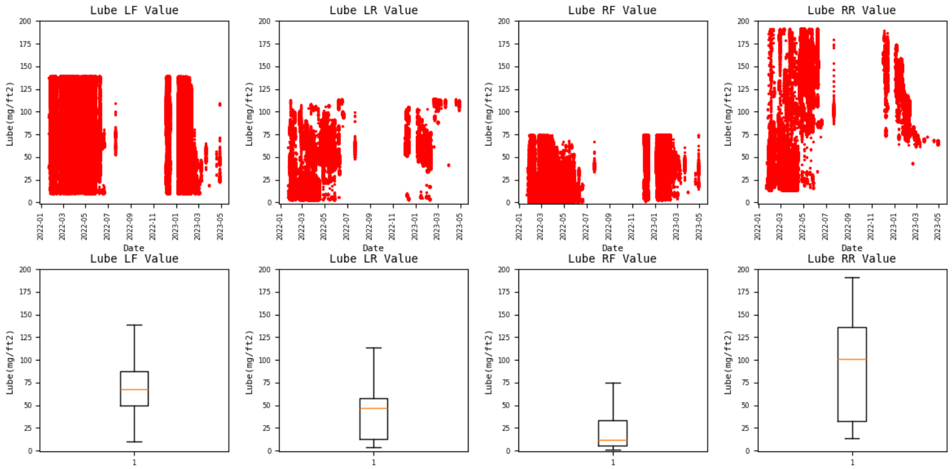
S.No.	Parameter	Method	Measurement Error
1)	Mechanical Properties		
1a)	Tensile Strength	Fraunhofer 3MA	± 15 MPa
1b)	Elastic Limit		± 20 MPa
1c)	Percent Elongation		± 0.5%
2)	Material Thickness	Banner Laser Scanner	± 0.02 mm
3)	Lubrication	Fraunhofer F-Scanner	± 0.05 g/m^2
4)	Slide Force in ton	Siemens Process PLC	--
5)	Cushion Force in ton	Siemens Process PLC	--
6)	Blank Draw In	Selmatec Vision	± 0.05 mm

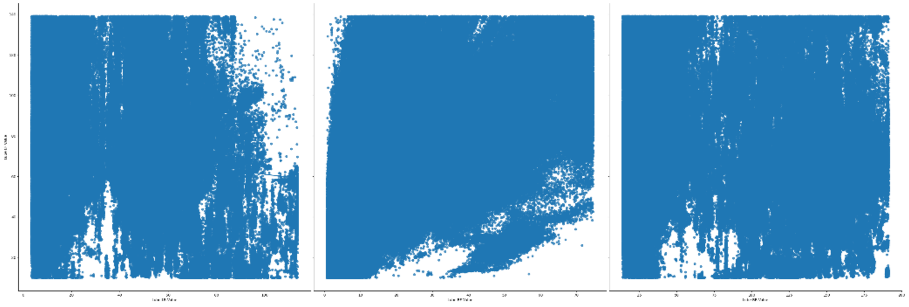
Toward a Sheet Metal Forming DT (system architecture)

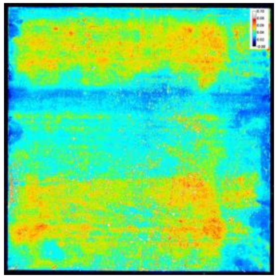


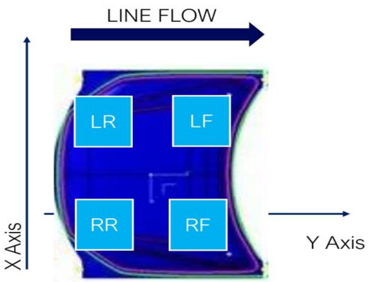
DT Algorithms for Sheet Metal Forming

Lubrication





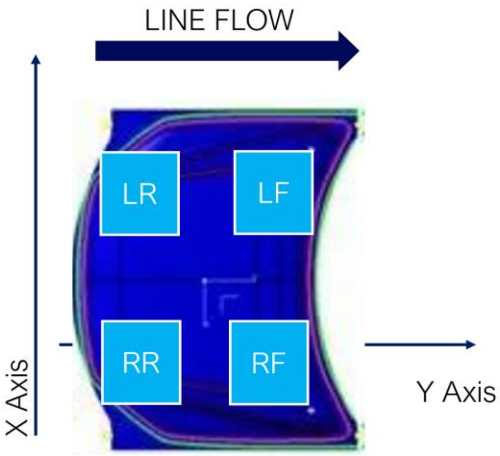


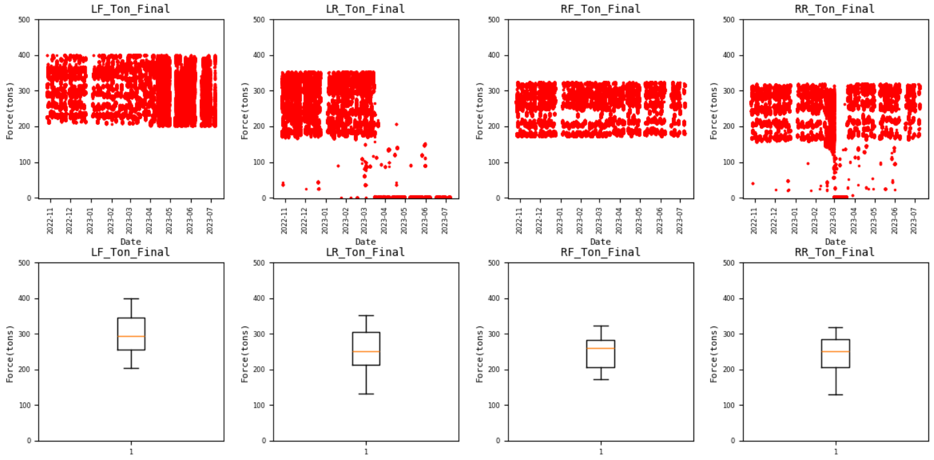


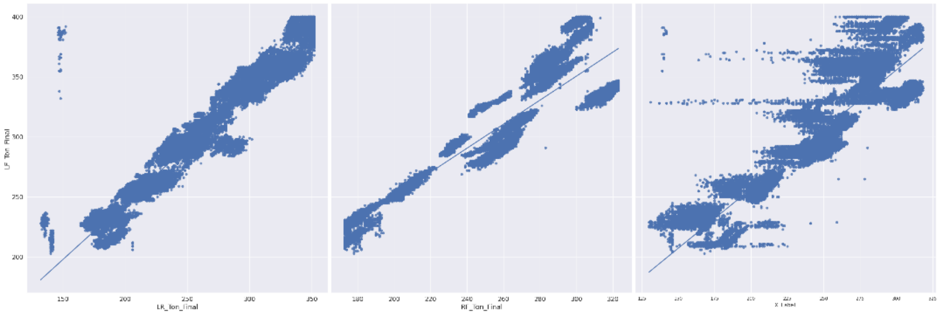
```
               Model  Mean Squared Error  Root Mean Squared Error  R-squared
0              Lasso          629.172017                25.083302   0.265408
1              Ridge          629.136262                25.082589   0.265450
2      Decision Tree          130.950817                11.443374   0.847108
3   Nearest Neighbor           75.017186                 8.661246   0.912413
4      Random Forest           72.088616                 8.490502   0.915833
5                MLR          629.136262                25.082589   0.265450
The Random Forest model had the lowest mean squared error of 72.09.
```

DT Algorithms for Sheet Metal Forming

Press Force

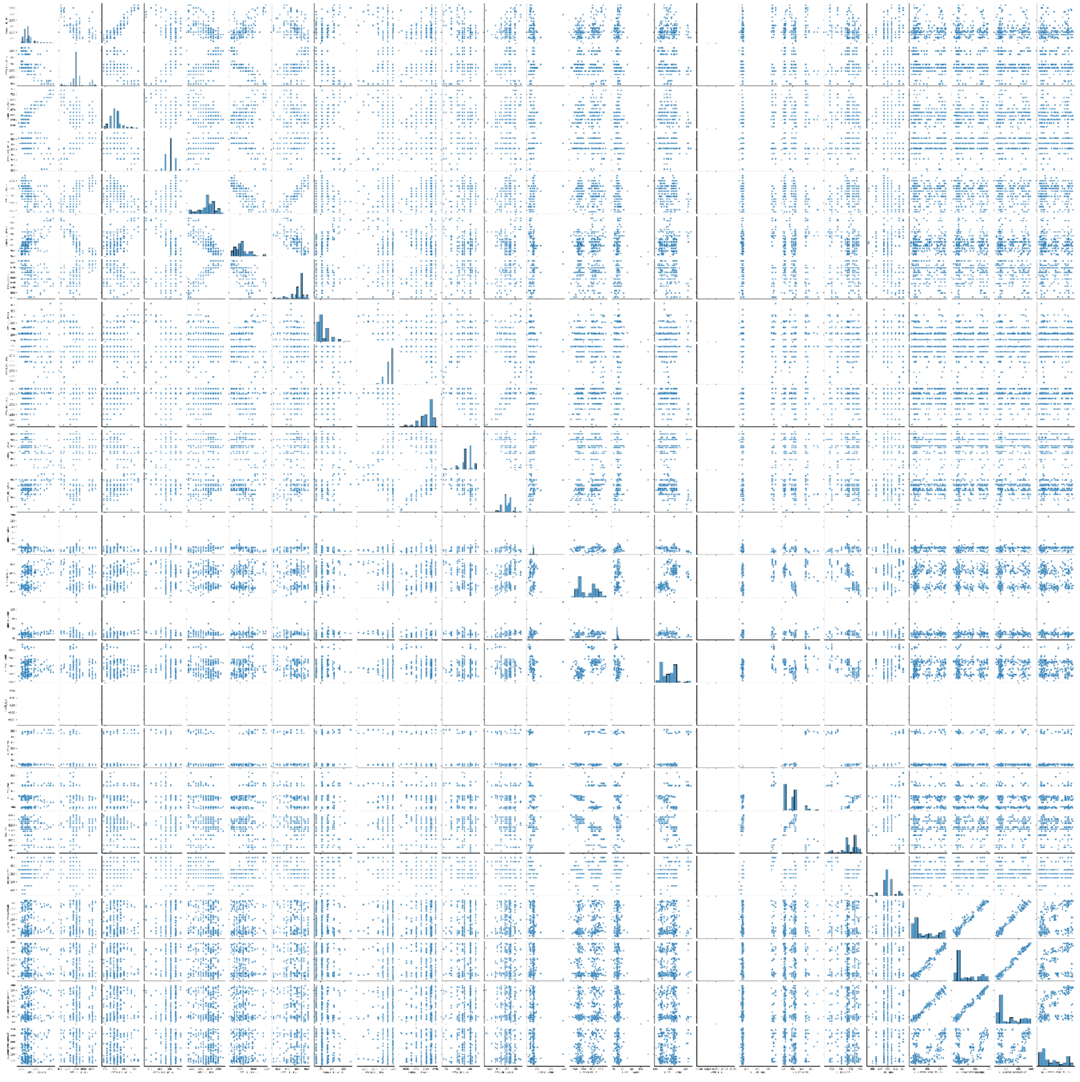






```
                Model  Mean Squared Error  Root Mean Squared Error  R-squared
0               Lasso           70.222500                 8.379887   0.972224
1               Ridge           70.248109                 8.381414   0.972214
2       Decision Tree            3.784588                 1.945402   0.998503
3    Nearest Neighbor            3.770542                 1.941788   0.998509
4       Random Forest            3.429267                 1.851828   0.998644
5                 MLR           70.248109                 8.381415   0.972214
The Random Forest model had the lowest mean squared error of 3.43.
```

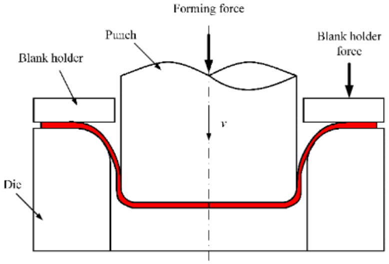
DT Algorithms for Sheet Metal Forming



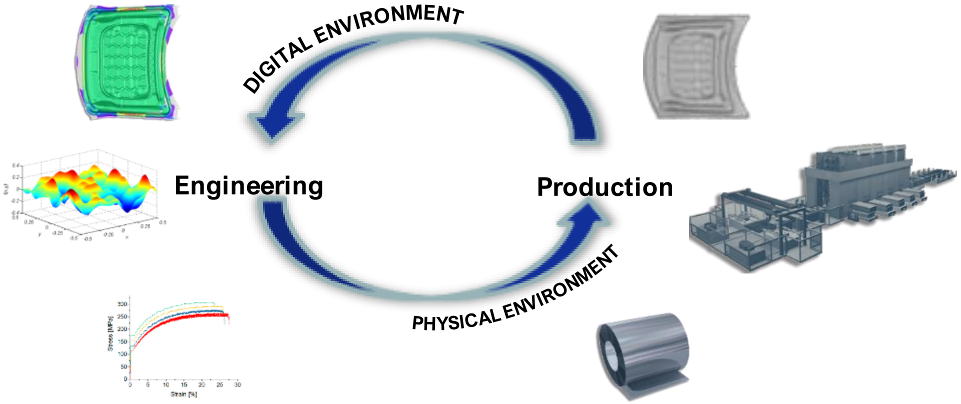
DT Algorithms for Sheet Metal Forming

$$DV_{1..16} = f\ (Y, BT_{1..3}, L_{1..4}, BF_{1..4}, PF_{1..4})$$

DV = Draw vector (material flow)
Y = Yield strength
BT = Blank thickness
L = Lubrication
BF = Blank holder force
PF = Press force



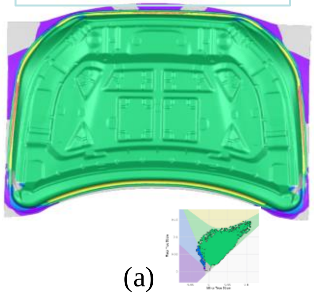
Anticipated Stamping Lifecycle Benefits



Significance of Friction – Autoform Simulation

Formability = Pass

Friction coefficient = 0.11

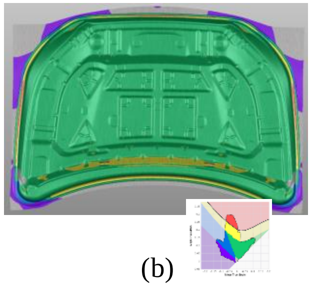


(a)

Baseline friction / tuned beads optimized restraining force

Formability = Fail

Friction coefficient = 0.15

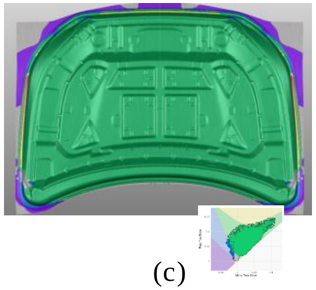


(b)

Higher friction; same restraining force as in (a)

Formability = Pass

Friction coefficient = 0.15

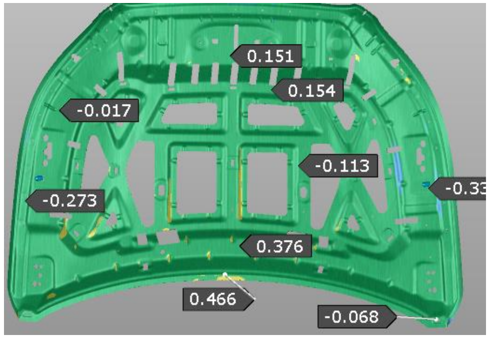


(c)

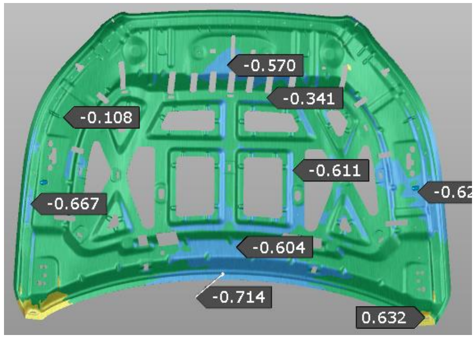
Higher friction; optimized restraining force

Friction (without restraining force adjustment) has a significant effect on formability
(example above shows > 10% change in strains)

Low friction (f=0.11)



High friction (f=0.15)



Friction (without restraining force adjustment) has a significant effect on panel springback (up to several mm)
(example above shows dimensional change upto ~1.2 mm change)

Summary

- We have provided a clear definition of the DT and differentiates it from Industry 4.0. The enabling technologies such as IoT, big data, AI/ML, and finite element modeling that contribute to the realization of DT have been discussed.

- An automotive production stamping servo 2500-ton XL-Tandem line was selected and fitted with sensors to collect production data.

- To realize the vision of a true DT in sheet metal forming, it can be accomplished by following a systematic progression from the digital model (DM) to the digital shadow (DS), and ultimately to the full-fledged digital twin with bi-directional data flows.

- A data Architecture has been implemented and algorithm to analyze the date are being tested.

- Algorithm to automatically cleanse and interpolate the data are being tested.

Future Work

- AI/ML based algorithms will be used with the primary objective of reducing variation in part quality and help achieving zero manufacturing defects.

- Algorithm using a hybrid approach that combines finite element (FE) modeling with data-driven techniques will be used for minimizing the error between simulation results and measured manufacturing process output.

- A full-fledged digital twin with bi-directional data flows will be implemented and tested.

- CHALLENGES

  - Data serialization. Part ID versus Timestamp.
  - Post processing, null values, flyers.
  - Image capture.
  - Sensor development and trigger strategy.

Thank You!