Changeable production by utilizing digital twins

10th IFAC Conference on Manufacturing Modelling, Management and Control
Prof. Dr.-Ing. Gisela Lanza
Are we living in a time of increasing disruption and uncertainty?
Disruptive political and economic events since 1990

- Dotcom bubble
- Terrorist attacks at 9/11
- Global financial crisis
- Annexation of Crimea by the Russian Federation
- COVID-19 pandemic
- China-USA trade war
- Russian invasion of Ukraine
Challenges of today's production environment

Volatile markets require rapid responses

Uncertainty characterizes production operations

Complexity due to individualized mass production

Ambiguity of requirements for production

Industry 4.0 enables competitive production operations in the VUCA world. A Digital Twin unites and utilizes the enablers of Industry 4.0 and decreases uncertainty to operate efficiently in the VUCA world.

Digital Twin of Product and Production

Definition

Digital Twin (DT)

+ Digital Shadow (DS)

Instantiation

Digital Master (DM)

Digital Twin of Product and Production

Definition

**Digital Master (DM)**

**Product Twin**

**Production Twin**

Digital Twin of product and production

Definition

Digital Master (DM)

+ Digital Shadow (DS)

Connection

Real-time capability enables ad-hoc updating of the digital twin

Supplying product and process models with high quality data

Valid depiction of production as a starting point for analyses and forecasts

Retrospect: Digital twin Keynote at CIRP CAT 2022 by Kristina Wärmefjord

Digital twins


"At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin”

Gieves & Vickers, 2017
Digital Master for production system

Improve decision quality by enhanced digital models

Digital Master (DM)

+ Digital Twin (DT)

+ Connection

+ Digital Shadow (DS)

Discrete-event simulation (DES) as the basis for the digital master of a production system

Sophisticated simulation models allow for detailed and reliable foresight in production systems. However, conventional simulation models are rigid in regard of expanding the digital master.

Ingenieurs, V.D. VDI 3633 Simulation von Logistik-, Materialfluss- und Produktionssystemen; Beuth: Düsseldorf, Germany, 1996
The trend of product individualization and ever-shorter product life cycles requires flexible and changeable production systems.
The trend of product individualization and ever-shorter product life cycles requires flexible and changeable production systems.
Ontology enhanced digital master

Semantics are helpful to further improve versatility

The ontology allows to model real production systems by mapping the assets of the production system to the simulation in an abstract way. This results in a higher flexibility of the digital master.

May, Kiefer, Kuhnle, Lanza (2022): Ontology-based Production Simulation with OntologySim
Use case: Agil production for circular manufacturing

Remanufacturing is characterized by a high degree of uncertainty
Especially product disassembly is impeded by uncertain product specifications. Production planning is either ineffective or inefficient due to a high number of anomalies and unpredictable events.

Source: C-ECO, Bosch, bz-berlin
Use case: Agil production for circular manufacturing

Definition of an agile remanufacturing system

Uncertain type and quantity of used products

Detailed inspection immediately before disassembly

Flexible material flow

Diverging material flow

Alternative sequence of operations

Product condition influences:
- Operation times
- Product routings
- Regeneration rates
- Required production capacity

Capacity demand fluctuations - Compensation through reconfiguration at system and cell level

Many complexities within the disassembly system, such as the condition of discarded products, are mapped in a digital master to overcome uncertainty and improve production planning and control.

Source: [1] Inderfurth & Langella (2006), agiprobot.de
Use case: Agil production for circular manufacturing
Improving material requirements planning in remanufacturing

Simulation-based material requirements planning based on a digital master respecting the condition of used products increases planning accuracy and decreases stock level at high delivery reliability.
Use case: Agil production for circular manufacturing
Implementation of the real production system

Focus: Disassembly of electrical drives
Digital Shadow of production system
Supporting acceptance by automatic instantiation

Digital Twin (DT) + Connection

+ Digital Shadow (DS)

Digital Master (DM)

By connecting heterogenous data sources and digital shadow with a standardized adapter, the interoperability can be guaranteed.

Source: Leonard Overbeck (2021),
By following an iterative adaption approach with consideration of new data, it can be guaranteed that the digital shadow represents the current state of the real production system.

Source: Leonard Overbeck (2021),
Example of a simulation model of a production system based on real production data

Source: Leonard Overbeck (2021), Software: Tecnomatix Plant Simulation
Evaluation of simulation results with historic data shows a valid representation of the real system.

Production volume represented by a variety of variants (Reference: Produced pieces from August '19 to April '20)

- Variant 1
- Variant 2

Source: Leonard Overbeck (2021),
Metrics to validate the digital shadow with the real production

<table>
<thead>
<tr>
<th>Metric</th>
<th>Total Output and OEE</th>
<th>Dynamics</th>
<th>Distributions</th>
<th>Resource utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>Mapping the core function of the production system</td>
<td>Dynamics of the model in the period under consideration</td>
<td>Stability of the system in reality and simulation</td>
<td>Internal processes in the system</td>
</tr>
<tr>
<td>Example</td>
<td><img src="image1" alt="Output SIM" /> <img src="image2" alt="Output REAL" /> <img src="image3" alt="OEE SIM" /> <img src="image4" alt="OEE REAL" /></td>
<td><img src="image5" alt="Time" /> <img src="image6" alt="Output" /></td>
<td><img src="image7" alt="SIM REAL" /></td>
<td><img src="image8" alt="SIM REAL" /></td>
</tr>
</tbody>
</table>

By comparing the simulation model and reality with respect to metrics, the validity of the digital shadow can be determined.

Source: Leonard Overbeck (2021),
Digital Twin
Vision for the future

Digital Twin (DT)
+ Digital Shadow (DS)

Outlook: Daydreaming Engine

Data Interfaces between models and Production Data Lake will enable Digital Twins. Interoperability of Models will enable additional value. Therefore, a Daydreaming Engine layer has to be implemented.


Supply Chain Optimization


Production Data Lake

Digital Twin: Single Production Plant by Discrete Event Simulation [7]

Daydreaming Engine
Vision of the digital twin for changeable production systems in the future

Conclusion

Automated Modeling
- Automatic Generation
- Continuous Synchronization
- High validity / accuracy of the model

Multiple Models
- Simultaneous use of different modeling techniques
- All models rely on the same data and can be used synergistically

Faster deployment
- Virtual commissioning
- Automated deployment of changes to the production

Decision support
- Planning and assessment of reconfigurations
- Integration of planning and control tools
Thank you for your attention!

10th IFAC Conference on Manufacturing Modelling, Management and Control

Gisela Lanza
Tel.: +49 721 608-44017; Mail: gisela.lanza@kit.edu
Sources