Novel applications in assessing manufacturing and assembly of complex composite structures
A pace towards Industry 4.0 in composite manufacturing

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Introduction

Institute of Composite Structures and Adaptive Systems
Prof. Dr.-Ing. M. Wiedemann

Our Professional Competences – Bricks of the Process Chain of High Performance Lightweight Structures

We align our research along the entire process chain for building adaptable, tolerant, efficiently manufactured light weight structures.

For excellent results in the basic research and industrial application.

Department of Composite Technology
Dr. -Ing. M. Kleineberg

Tailored manufacturing concepts

From the idea via processes to prototypes

• New technologies for manufacturing
• Hybrid manufacturing
• Assembly
• Repair
• Process automation

Process Assessment
Dr. -Ing. P. Hilmer, A. Al-Lami

Process development

Process analysis

Process assessment
Motivation
benefit assessment

Idea → Realization → Benefits

Design → Manufacturing → Assembly → Operation → End-of-Life

Simplified product life-cycle
**Motivation Industry 4.0**

The term ‘Industry 4.0’ describes the integration of product development, production, logistics and customers within intelligent networks. Materials and precursor products, production machines and consumer products will connect with the digital network and be modelled in a virtual world.

Production processes, logistics, sales, service and entire business models can be simulated on a computer to evaluate and assess their viability.

Source: DLR, Industry 4.0, Industry of the future
Assessment models

<table>
<thead>
<tr>
<th>Criterions</th>
<th>Bottom-up</th>
<th>Top-down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data quality</td>
<td>🎉</td>
<td>😞</td>
</tr>
<tr>
<td>Single technology evaluation</td>
<td>🎉</td>
<td>😞</td>
</tr>
<tr>
<td>Data collection effort</td>
<td>😞</td>
<td>😞</td>
</tr>
<tr>
<td>Recurring Cost (RC)</td>
<td>😞</td>
<td>😞</td>
</tr>
<tr>
<td>Non-Recurring Cost (NRC)</td>
<td>😞</td>
<td>🎉</td>
</tr>
</tbody>
</table>

Eco-Efficiency Assessment Model

Technical cost analysis

Decision support tools

Business case estimation

Data

Decision

Experiences

Bottom-up

Top-down
Eco-Efficiency Assessment Model (EEAM) description

Designed and developed by DLR
- Based on the Life Cycle Assessment (LCA): ISO 14040:2006
- Gate-to-Gate: Manufacturing and Assembly
- Combined framework of LCA and BPMN
Eco-Efficiency Assessment Model (EEAM) framework
Conventional data collection

Inventory analysis

Conventional data collection
- Dedicated data collector
- Dependent data quality
- Time consuming data collection
- Offline data mining
- Offline assessment
- Automation is required for digitalization
Concept of Smart Work Station (SWS) principles

System boundary

Matter

Energy

Principles

Nothing comes from nothing
Lucretius c. 99 BC – c. 55 BC
Source: Bloomsbury

Mass–energy equivalence
Einstein's 1905
Source: Springer

Law of mass conservation
Lavoisier 1774
Lomonosov 1756
Source: Springer
Concept of Smart Work Station (SWS) principles implementation

<table>
<thead>
<tr>
<th>Adaptation</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>- System:</td>
<td>UP</td>
</tr>
<tr>
<td>- System boundaries:</td>
<td></td>
</tr>
<tr>
<td>- Physical:</td>
<td>Work station</td>
</tr>
<tr>
<td>- Time:</td>
<td>UP duration</td>
</tr>
<tr>
<td>- Technical:</td>
<td>UP Inputs</td>
</tr>
</tbody>
</table>

Manufacturing/ Assembly (M&A)

Unit Process (UP) 1  Unit Process (UP) n

Product

System boundary

Benefits

Smart Work Station (SWS)
Smart Work Station (SWS) in manufacturing and assembly of composites description

<table>
<thead>
<tr>
<th>Matter</th>
<th>Energy</th>
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<tbody>
<tr>
<td>Fiber</td>
<td>Electricity</td>
</tr>
<tr>
<td>Matrix</td>
<td>Equipment</td>
</tr>
<tr>
<td>Supplies</td>
<td>„Labor“</td>
</tr>
</tbody>
</table>

- Mass
- Power

Physical system boundary: Work station

Inputs:
- Electricity
- Fiber
- Matrix
- Supplies
- Equipment
- Labor

Unit process (Es)

Outputs:
- Product
- Carbon footprint
- Waste
- Cost impact
- € „RC“

Time boundary „time window“

- Time
- Mass
- Power

Matter Energy

- Electricity
- Fiber
- Matrix
- Supplies
- Equipment
- Labor

Unit process (Es)
Functionality of Smart Work Station (SWS)
nmatter: materials

Digital scale system
- Fiber holder integrated scale system (Cutter)
- Mold integrated scale system (preforming, bagging, ..)
- Scale-integrated matrix vessels
- Dedicated mini-platform scale for each supply material
- Or/ universal work mini-platform scale for all supplies with barcode detector to identify the supplies

Source: HBM
Functionality of Smart Work Station (SWS)
energy: electricity & equipment

Digital electric meter system
- Defined electricity source of each work station
- Defined electricity source of each equipment
- Dedicated electric meter for each equipment
Functionality of Smart Work Station (SWS) energy: labor work

**Digital work time detection**
- Cells oriented work station to detect the work efforts (in case of more than one worker)
- Video camera with motion detection functionality for each cell
- Infra-red camera with thermal detection (allowed by German works council)
- Labor work is measured as simplified input (either yes or no: no effort measurement)
Smart Work Station (SWS) example

Manufacturing of fiber reinforced polymers (FRP)

Cutting  Preforming  Bagging  Infusion  Tempering  Demolding

UPs: Technical system boundary

Physical work stations

Example of CFRP

Physical system boundary

Matter  Energy

Mass  Time  Power

Time boundary "time window"

t
Results of Smart Work Station (SWS) example of materials data

- Matter
  - Fiber
  - Matrix
  - Supplies

**Example**
- Preforming
- Bagging

**Graph:**
- **Mass: g**
- **Time: min**
- **Cumulative**

- Fiber
- Vacuum Bag
- Tacky-Tape
- Adhesive tape
- Breather
- Cleaning tissue
- Copper pipe
- Vacuum film
- Cotton gloves

These data are estimated and not collected.
Results of Smart Work Station (SWS) example of electricity & equipment data

<table>
<thead>
<tr>
<th>Energy</th>
<th>Electricity</th>
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</table>

Example

Preforming Bagging

Power: kW

Cumulative

Time: min

- Hot air blower
- Vacuum pump
- Preform System

These data are estimated and not collected
Results of Smart Work Station (SWS) example of labor work data

![Graph showing labor work data over time with estimated cumulative values.]

- **Energy**
  - Electricity
  - Equipment
  - „Labor“

**Example**

Preforming Bagging

These data are estimated and not collected.
Results of Smart Work Station (SWS) example of combined inputs

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Example

- Fiber
- Vacuum Bag
- Tacky-Tape
- Adhesive tape
- Breather
- Cleaning tissue
- Copper pipe
- Vacuum film
- Cotton gloves
- Hot air blower
- Vacuum pump
- Preform System
- Labor work

Preforming

Bagging

time: min
Benefits of Smart Work Station (SWS) benefit assessment & Industry 4.0

Industry 4.0

SWS data collection
- No data collector is required
- Independent & repeatable data quality
- "0" time consuming data collection (automated)
- Online data mining
- Online assessment
- Process automation is not a prerequisite
- Universal: process associated
Outlook
next steps in SWS

Realization
- Construction
- Development of digital interfaces
- Development of data collection software
- Validation intern
- Validation with partners

Enhancement
- Size extension: scale limitation
- Connection of work stations
- Development of accurate camera detection
- Data dual-use: product quality assurance
  (as designed vs. as manufactured)
Outlook
next steps in EEAM

SWS & EEAM
- Correlation of SWS & EEAM
- Online benefit assessment
- Parameterization
- Independent process definition based on parameterization

Eco-Efficiency Estimation Model (EEEM)
- Based on EEAM & parameterization
- Combining bottom-up (RC) with top-down (NRC)
- Benefit estimation in early design phase
- Design-to-Cost (DTC)
- Top-down based on bottom-up
- Design for Manufacturing and Assembly (DFMA)
Thank you for your attention!

For any further questions please don’t hesitate to contact me:

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