Eco-Efficiency and INDUSTRY 4.0
Concept for Smart Eco-Efficiency Assessment in Composite Production

Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES

Ali Al-Lami
Department of Composite Technology
Institute of Composite Structures and Adaptive Systems
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES
A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production
12th June 2019

Decision Makers

Composite Structures

Eco-Efficiency

DLR.de • Chart 2
Life-Cycle Stages

Design → Production → Operation → End-of-Life

Eco-Efficiency

Decision Makers

Composite Structures
Life-Cycle Stages

- Design
- Production
- Operation
- End-of-Life

Eco-Efficiency

Composite Structures

Decision-Makers
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES
A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production • 12th June 2019

Life-Cycle Stages
- Design
- Production
- Operation
- End-of-Life

Manufacturing • Assembly

Eco-Efficiency

Composite Structures
Life-Cycle Stages

- Design
- Production
- Operation
- End-of-Life

Key-Result-Indicators (KRI)

- Direct Cost
- Carbon Footprint

Eco-Efficiency

Decision Makers

Composite Structures

- Manufacturing
- Assembly

Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES> A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production > 12th June 2019
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES
A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production
12th June 2019

Decision Makers
Key Result Indicators (KRI)
Direct Cost
Carbon Footprint

Decision Support System (DSS)

Composite Structures
Eco-Efficiency

Life-Cycle Stages
Design
Production
Operation
End-of-Life
Manufacturing
Assembly
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES

Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production

12th June 2019

Decision-Makers

Key-Result-Indicators (KRI)

Direct Cost

Carbon Footprint

Eco-Efficiency

Composite Structures

Life-Cycle Stages

Design

Production

Operation

End-of-Life

Manufacturing

Assembly

Decision Support System (DSS)
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES

A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production

12th June 2019

Decision-Makers

Key-Result-Indicators (KRI)

\[ \alpha \times \lambda = \theta \]

Direct Cost
Carbon Footprint

Eco-Efficiency

Composite Structures
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES> A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production > 12th June 2019

Life-Cycle Stages

- Design
- Production
- Operation
- End-of-Life

Manufacturing Assembly

Key-Result-Indicators (KRI)

- Direct Cost
- Carbon Footprint

Decision Support System (DSS)

Decision Makers

Characterization Factors

Eco-Efficiency

Composite Structures

\[ \alpha \times \lambda = \theta \]
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES

Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production

12th June 2019

Decision-Makers

Key-Result-Indicators (KRI)

Direct Cost

Carbon Footprint

Eco-Efficiency

Decision Support System (DSS)

α * λ = θ

Characterization Factors

Process Parameters

Life-Cycle Stages

Design

Production

Operation

End-of-Life

Manufacturing

Assembly

Composite Structures

DLR.de • Chart 2
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES

A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production

12th June 2019

Decision-Makers

Key-Result-Indicators (KRI)

Direct Cost

Carbon Footprint

Composite Structures

Decision Support System (DSS)

Eco-Efficiency

End-of-Life

Operation

Production

Life-Cycle Stages

Design

Manufacturing

Assembly

α * λ = θ

Eco-Efficiency Assessment Model (EEAM)

Process Parameters

Characterization Factors

DLR.de • Chart 2
Production Volume

Degree-of-Automation (DoA)

Degree-of-Customization

Decision-Makers
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES
A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production
12th June 2019

Decision-Makers

Degree-of-Automation (DoA)

Degree-of-Customization

Production Volume

R&Ds

SMEs

Universities

DLR.de • Chart 3
Decision-Makers

Degree of Automation (DoA)

Production Volume

Degree of Customization

R&Ds

SMEs

Universities

Manufacturers
Production Volume

Technology Readiness Level (TRL); Process Maturity (PM); Industries; Applications;

For Different:
Technology Readiness Level (TRL);
Process Maturity (PM);
Industries;
Applications;

Decision-Makers

Degree-of-Automation (DoA)

Degree-of-Customization

R&Ds
SMEs
Universities
Manufacturers
Production Volume

Technology Readiness Level (TRL);
Process Maturity (PM);
Industries;
Applications;
For Different:

Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES> A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production > 12th June 2019

Degree-of-Automation (DoA)

Degree-of-Customization

Decision-Makers

For Different:
Technology Readiness Level (TRL);
Process Maturity (PM);
Industries;
Applications;
Locations

R&Ds
SMEs
Universities
Manufacturers

DLR.de  •  Chart 3
Production Volume

Technology Readiness Level (TRL);
Process Maturity (PM);
Industries;
Applications;

For Different:

- Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES
- A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production
- 12th June 2019

Decision-Makers

Degree of Customization

Degree of Automation (DoA)

Locations

R&Ds
SMEs
Universities
Manufacturers

For Different:

Technology Readiness Level (TRL);
Process Maturity (PM);
Industries;
Applications;
Locations
For Different:

- Technology Readiness Level (TRL);
- Process Maturity (PM);
- Industries;
- Applications;
- Locations

Decision Makers

Degree-of-Automation (DoA)

Degree-of-Customization

Concept of Smart-WorkShop (SWS)

Production Volume

R&Ds

SMEs

Universities

Manufacturers

Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES: A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production > 12th June 2019
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES

A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production

12th June 2019
Different Techniques, DoA, Industrialization, ...

 Reality
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES
A. Al-Lami
Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production
12th June 2019

DLR.de • Chart 6
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES  
A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production  
12th June 2019

Conceptual Model

Discretization, Unit Process (UP)

UP1: Preparing  
UP2: Cutting  
UP3: Preforming  
UP4: Trimming  
UP5: Curing  
UP6: Demolding
Conceptual Model

Elementary Flows (Inputs)

$UP_1$: Preparing $UP_2$: Cutting $UP_3$: Preforming $UP_4$: Trimming $UP_5$: Curing $UP_6$: Demolding

$UP_2$: Cutting $UP_3$: Preforming $UP_1$: Preparing $UP_5$: Curing $UP_6$: Demolding $UP_4$: Trimming
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES

A. Al-Lami

Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production

12th June 2019

Conceptual Model

Elementary Flows (Inputs)

Material

Energy

UP₁: Preparing
UP₂: Cutting
UP₃: Preforming
UP₄: Trimming
UP₅: Curing
UP₆: Demolding

UP₂: Cutting
UP₃: Preforming
UP₁: Preparing
UP₅: Curing
UP₆: Demolding
UP₄: Trimming
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES

A. Al-Lami

Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production

12th June 2019

Conceptual Model

Elementary Flows (Inputs)

Material
- Fiber
- Matrix
- Core Material
- Ancillaries

Energy
- Labor
- Equipment
- Energy
- Facility

UP₁: Preparing
UP₂: Cutting
UP₃: Preforming
UP₄: Trimming
UP₅: Curing
UP₆: Demolding
Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES

A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production

12th June 2019

Conceptual Model

Elementary Flows (Inputs)

What? How much? When? Where?

Conceptual Model

4.0 INDUSTRY

UP₁: Preparing
UP₂: Cutting
UP₃: Preforming
UP₄: Trimming
UP₅: Curing
UP₆: Demolding

UP₂: Cutting
UP₃: Preforming
UP₁: Preparing
UP₅: Curing
UP₆: Demolding
UP₄: Trimming
Conceptual Model

Sensor Nodes

What? How much? When? Where?

4.0 INDUSTRY

Optical Detection
Mass Measurement
Thermal Detection
Energy Measurement

UP₁: Preparing
UP₂: Cutting
UP₃: Preforming
UP₄: Trimming
UP₅: Curing
UP₆: Demolding

UP₁: Preparing
UP₂: Cutting
UP₃: Preforming
UP₄: Trimming
UP₅: Curing
UP₆: Demolding
**Data Processing Algorithms, Process Matrix**

**Mathematical Model**

\[ a_{ij} = f(r_{ij}, b_{ij}, c_{ij}, q_{ij}, \Pi_{ij}, \alpha_{ij}, Y_{ij}, \Omega_{ij}) \]

\[ a_{ij} = f(r_{ij}, b_{ij}, c_{ij}, q_{ij}, \Pi_{ij}, \alpha_{ij}, Y_{ij}, \Omega_{ij}) \]

\[ a_{ij} = f(r_{ij}, b_{ij}, c_{ij}, q_{ij}, \Pi_{ij}, \alpha_{ij}, Y_{ij}, \Omega_{ij}) \]

\[ a_{ij} = f(r_{ij}, b_{ij}, c_{ij}, q_{ij}, \Pi_{ij}, \alpha_{ij}, Y_{ij}, \Omega_{ij}) \]

\[ a_{ij} = f(r_{ij}, b_{ij}, c_{ij}, q_{ij}, \Pi_{ij}, \alpha_{ij}, Y_{ij}, \Omega_{ij}) \]

\[ a_{ij} = f(r_{ij}, b_{ij}, c_{ij}, q_{ij}, \Pi_{ij}, \alpha_{ij}, Y_{ij}, \Omega_{ij}) \]

\[ a_{ij} = f(r_{ij}, b_{ij}, c_{ij}, q_{ij}, \Pi_{ij}, \alpha_{ij}, Y_{ij}, \Omega_{ij}) \]

\[ a_{ij} = f(r_{ij}, b_{ij}, c_{ij}, q_{ij}, \Pi_{ij}, \alpha_{ij}, Y_{ij}, \Omega_{ij}) \]
Graphical User Interface (GUI), Real-Time Eco-Efficiency Assessment

Computerized Model

$\alpha \star \lambda = \theta$ (€ ⚪️)

Eco-Efficiency Assessment Model (EEAM)
Chart 11: Concept of Smart-WorkShop (SWS)

- Production Volume
- Degree-of-Automation (DoA)
- Degree-of-Customization

- R&Ds
- SMEs
- Universities
- Manufacturers

Composite Structures

Decision-Makers

Composites Convention 2019: FUTURE FACTORY FOR COMPOSITES> A. Al-Lami • Eco-Efficiency and Industry 4.0: a Concept for Smart Eco-Efficiency Assessment in Composite Production > 12th June 2019
Thank You

Please don’t hesitate to contact me

Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)
German Aerospace Center
Institute of Composite Structures and Adaptive Systems | FA-FVT | Lilienthalplatz 7 | 38108 Braunschweig | Germany

Ali Al-Lami, M.Sc.
Tel. 0049 531 295 2234
ali.al-lami@dlr.de
www.DLR.de
Literatures