

Oliver Mörth

Institute of Innovation and Industrial Management

Graz University of Technology

Design for Lifecycle-Uncertainties

Guideline for the conceptual design of powertrain systems and their elements that enhance coping with uncertainties throughout the lifecycle

27. Techno-Ökonomie Kolloquium

02.07.2020

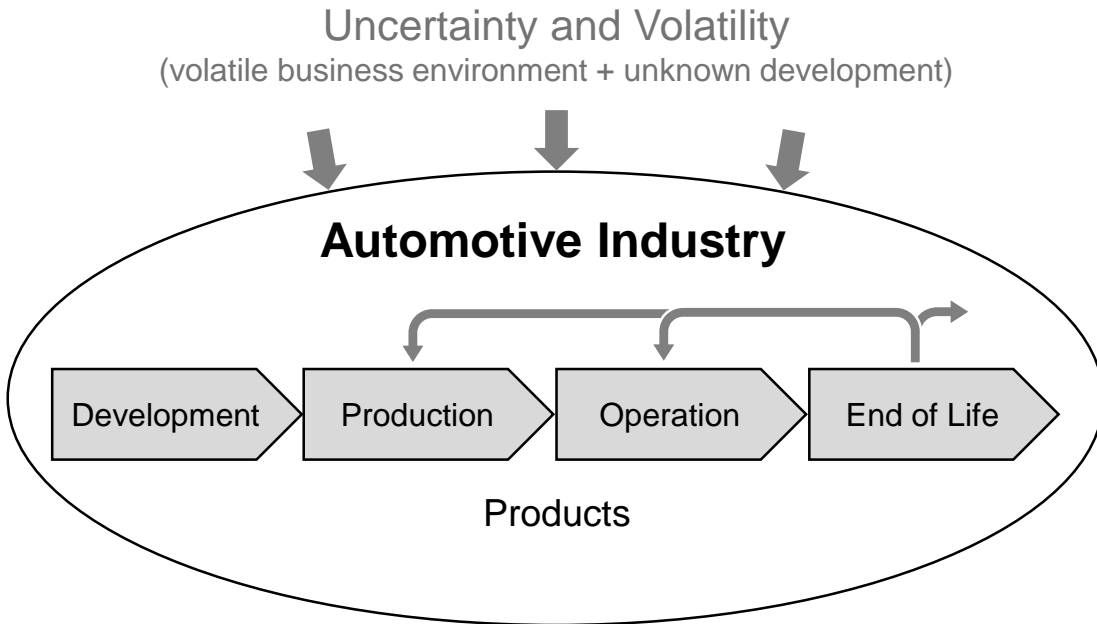


Agenda

- 1 Motivation
- 2 Problem Statement
- 3 Aim, Research Questions and Expected Outcome
- 4 Research Methodology
- 5 Relevant Research and References

Motivation

Initial Situation



Literature Perspective

- ▶ Changing customer requirements ^{1,2}
- ▶ Demand fluctuations, Supply disruptions, etc. ³
- ▶ Increasing vehicle variants ⁴
- ▶ Unknown future user needs or operating conditions ⁵
- ▶ ...

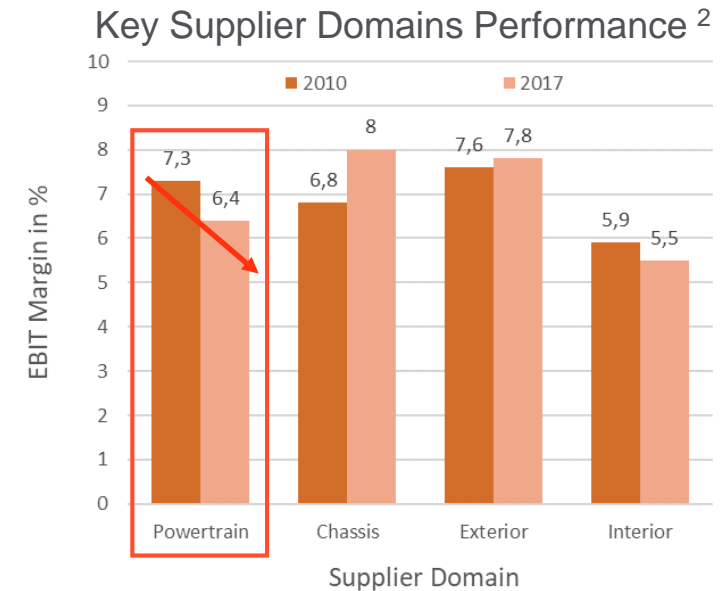
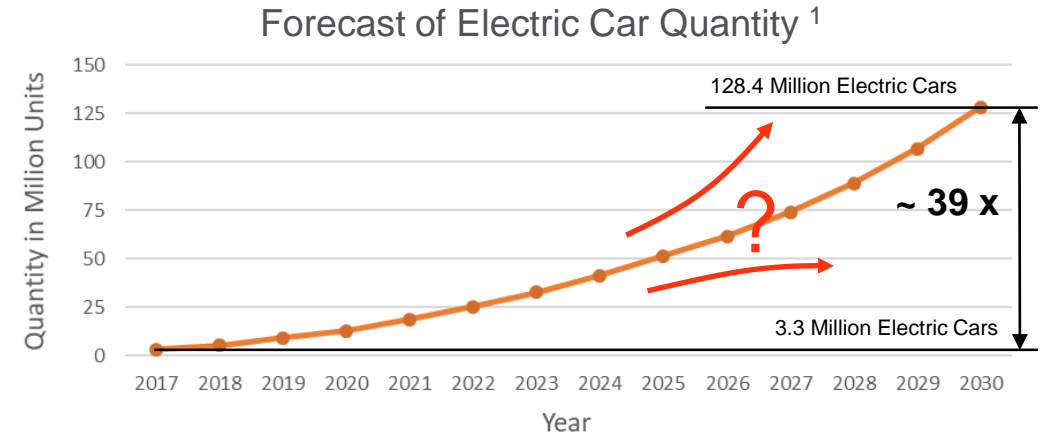
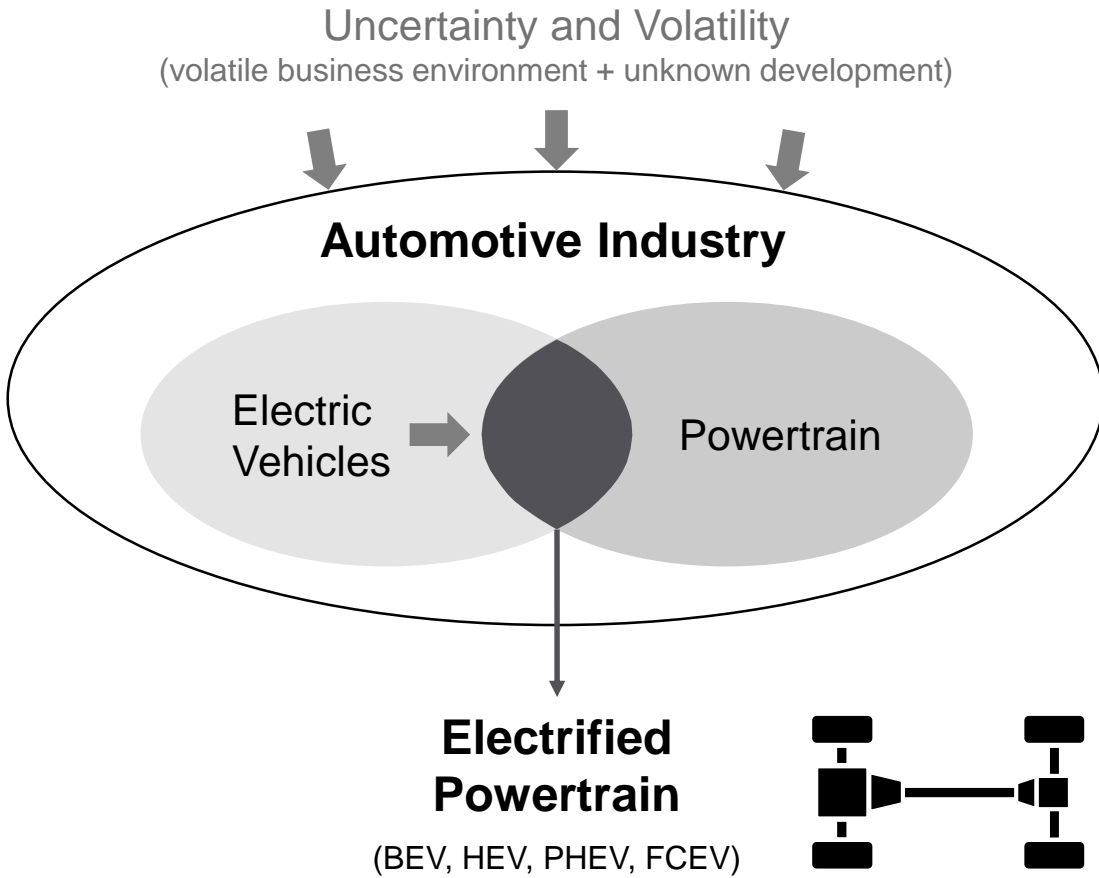
Industry Perspective*

- ▶ 25 meetings with 19 experts from industrial partner
- ▶ Relevant targets:
 - Alignment of product design with agile production
 - Adaptability of products on future requirements
 - Adaptability of product portfolio
 - Increased development efficiency and effectiveness
 - ...
- ▶ Within Development: Concept Phase highly critical
 - High influence on following phases
 - Limited information

¹ Book et al., 2017; ² Cooper & Sommer, 2016; ³ Ramsauer et al., 2017; ⁴ IEA, 2019; ⁵ Haberfellner & de Weck, 2005; * Industrial Partner: Engineering Company in the automotive industry

Motivation

Focus Definition



¹ IEA, 2019; ² Roland Berger & Lazard, 2017

State of Research & Research Gap

Agile-Systems Engineering

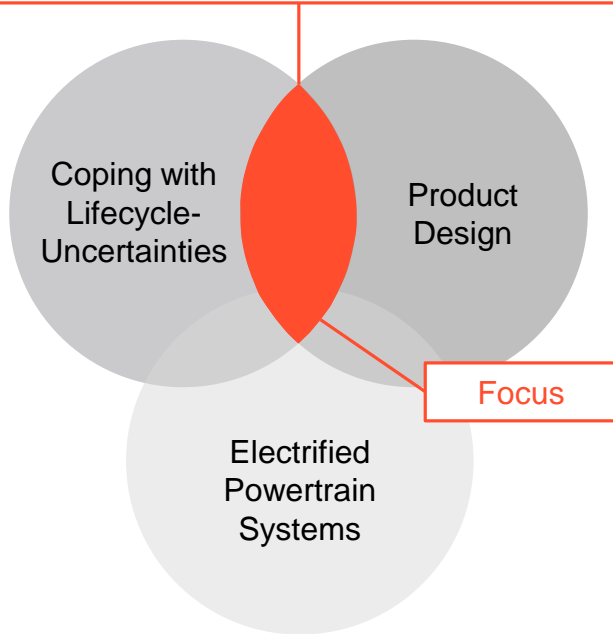
Engineering systems with embedded agility when prediction of future demand or functional requirements is limited. ¹

Flexibility in Engineering Design

Flexibility in the product to deal with uncertainty by providing new functions during their lifecycle. ²

Strategic Engineering

Designing products for an uncertain future to maximize lifecycle value by reducing risks and increasing opportunities. ³



Why Design for Lifecycle-Uncertainty?

- ▶ “Designers must not only consider how to meet specifications that will satisfy stakeholders today but also the trajectories of markets and technologies that will determine what it takes to satisfy stakeholders in the future.” ⁴
- ▶ “An uncertain future provides a range of opportunities and risks. We can deal with these eventualities and maximize our expected value if we build flexibility into product design.” ²
- ▶ “If there is bounded uncertainty in the future usage, it is a key interest in industry today to embed flexibility in product and system architecture.” ⁵

Limits of existing Approaches and recommended Further Research:

Life-Cycle Flexibility Framework ⁶	Flexible Product Platforms ⁷	Designing Flexible Product-Production-System ⁸
<ul style="list-style-type: none"> – Design poorly addressed (Focus on evaluating and managing options) – Case studies just result of "creative" thinking of the author → “Adaptions are required to make the framework applicable in practice” – A more systematic way of identifying where flexibility should be integrated 	<ul style="list-style-type: none"> – Lack of incorporation of basic requirements (from system to element) – Number of variants must be decided beforehand – Focus on uncertainties & changes during operation, not complete lifecycle 	<ul style="list-style-type: none"> – Focus on an element separate from the overall system – Only considering production but not entire lifecycle – Focus on variants → missing consideration of other uncertainties

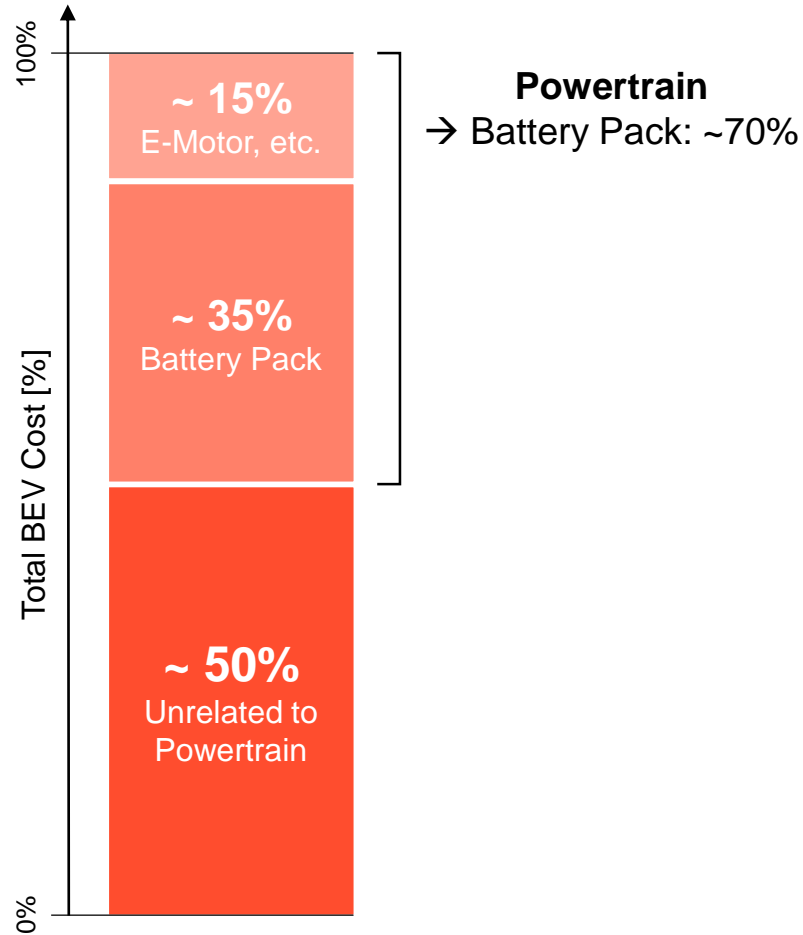
Research Gap:

Missing practically applicable guideline with the aim to systematically integrate an appropriate flexibility into the conceptual design of powertrain systems and their elements so that it enables coping with critical uncertainties throughout the lifecycle.

¹ Haberfellner & de Weck, 2005; ² Neufville & Scholtes, 2011; ³ de Weck, 2006; ⁴ Suh, de Weck & Kim, 2007; ⁵ Banerjee & de Weck, 2011; ⁶ McConnell, 2007; ⁷ Suh, 2005; ⁸ Sarovic, 2018

Critical Powertrain Element: The Battery Pack

Value of a Battery Pack¹



Preliminary Study

- ▶ Research Question:
 1. What powertrain elements are affected by critical* uncertainties & changes throughout their lifecycle?
 2. What are the reasons for that?
- ▶ Current Quantity of Interviews: 19

Problem Statement:

Within powertrain systems, especially battery packs are affected by critical uncertainties and resulting changes throughout their lifecycle.

An appropriate design defined in the concept phase enhances coping with them effectively and efficiently.

Current designs provide limited enhancement for coping with critical uncertainties throughout the lifecycle

* High impact in terms of cost & time, high occurrence probability, currently limited coping capability

¹ BCG, 2018; ² McKinsey & Company, 2019

Aim and Research Questions

AIM:
Development of a guideline to systematically integrate an appropriate flexibility into the conceptual design of powertrain systems and their elements considering the requirements of the vehicle.

RQ 1:

What are relevant design strategies and requirements on the design guideline to be practically applicable?

RQ 2:

How can critical uncertainties and changes throughout a lifecycle be systematically identified?



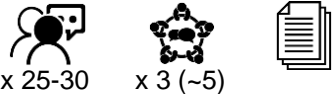

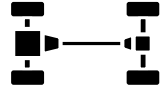
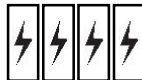

RQ 3:

How can an appropriate flexibility (what, how, for what price) be systematically defined and integrated into the conceptual design?

Expected Outcome

1. Practically applicable guideline to systematically integrate an appropriate flexibility into the conceptual design of powertrain systems and their elements so that they enable coping with uncertainties throughout the lifecycle while considering the requirements of the vehicle.
2. Verification of the guideline through its simultaneous application on electric vehicle battery pack design.
→ Incorporation of insights (e.g. requirements, specific methods) in guideline to ensure its practical applicability.
3. Overall evaluation of the guideline through its application on electrified powertrain system, fuel cell stack and connecting rod.

Design Research Methodology – from Blessing and Chakrabarti, 2009

Phase	Research Classification	Descriptive Study I	Prescriptive Study	Descriptive Study II
Aims	<ul style="list-style-type: none"> – Identification of current understanding – Overall Research Plan 	<ul style="list-style-type: none"> – Establishment of required design understanding – Definition of success factors 	<ul style="list-style-type: none"> – Development of support for design improvements – Verification of support 	<ul style="list-style-type: none"> – Evaluation of support – Derivation of overall conclusion
Activities	<ol style="list-style-type: none"> 1. Definition of the problem 2. Identification of overall topics of interest 3. Clarification of current understanding 4. Definition of aim, research questions and contribution 5. Selection of research type and design 	<ol style="list-style-type: none"> 1. Conduction of detailed literature review <ul style="list-style-type: none"> – Relevant design strategies – Guideline requirements (literature perspective) 2. Conduction of empirical study for DS I <ul style="list-style-type: none"> – Guideline requirements (industry perspective) 	<ol style="list-style-type: none"> 1. Realization of guideline <ul style="list-style-type: none"> – General requirements  x 10 – Relevant changes  x 25-30 – Coping requirements  x 25-30 x 3 (~5) – Conceptual Product Design  2. Verification of design guideline 	<ol style="list-style-type: none"> 1. Conduction of evaluation <ul style="list-style-type: none"> – Application of guideline <div style="display: flex; align-items: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg); border-right: 1px solid black; padding-right: 5px;">System</div>  </div> <hr/> <div style="display: flex; align-items: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg); border-right: 1px solid black; padding-right: 5px;">Element</div>  </div> <hr/> <div style="display: flex; align-items: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg); border-right: 1px solid black; padding-right: 5px;">Component</div>  </div>
Data Collection	Single Case Study (DS I, PS, DS II) <ul style="list-style-type: none"> – Engineering Company in the Automotive Industry 	Single unit of analysis: <ul style="list-style-type: none"> – Powertrain system 	Single unit of analysis: <ul style="list-style-type: none"> – Battery Pack 	Multiple units of analysis: <ul style="list-style-type: none"> – Powertrain system – Fuel Cell Stack – Connecting Rod

Agile Product Development

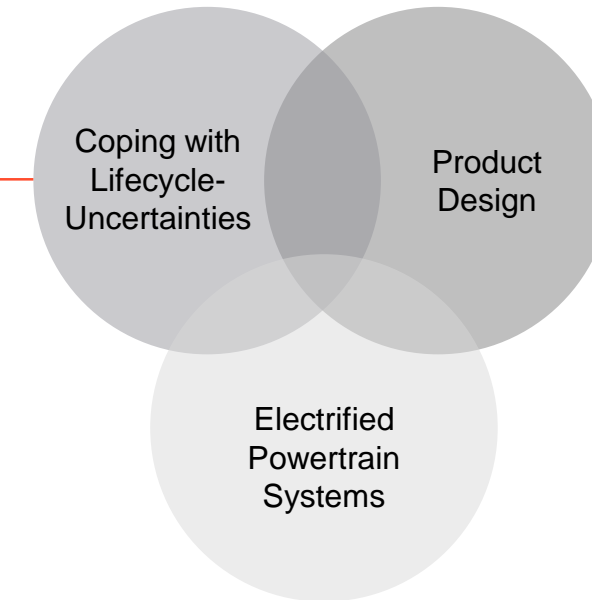
- H.P. Schnöll, 2015: Integrierte Produktentwicklung: Ein Vorgehensmodell zur kontextspezifischen Gestaltung des Produktentstehungsprozesses von Bauteilen aus Faserverbundkunststoffen
- Cooper RG, Sommer AF., 2016: Agile-Stage-Gate: New idea-to-launch method for manufactured new products is faster, more responsive
- Smith PG, 2007: Flexible Product Development
- Thomke S, Reinertsen D, 1988: Agile Product Development: Managing development flexibility in uncertain environments

Agile or Flexible Production & Customization

- Rabitsch C., 2016: Methodology for Implementing Agility in Manufacturing Companies
- Pointner A., 2018: Synchronizing Production Capacity with Market Demand Upswings in a Lean Production System
- Ramsauer C, Kayser D, Schmitz C., 2017: Erfolgsfaktor Agilität: Chancen für Unternehmen in einem volatilen Marktumfeld
- Holtewert P. Interchangeable Product Designs for the Increase of Capacity Flexibility

Flexibile Systems

- Haberkellner R, de Weck O, 2005: Agile SYSTEMS ENGINEERING versus AGILE SYSTEMS engineering
- Neufville R, Scholtes S, 2011: Flexibility in Engineering Design
- de Weck O, 2006: Strategic Engineering – Designing Systems for an Uncertain Future
- Banerjee P, de Weck, O, 2011: Flexibility Strategy – Valuing Flexible Product Options



Structure & Cost
Design Requirements
Standards
Lifecycle

Product Development and Design

- Ehrlenspiel K, Meerkamm H, 2013: Integrierte Produktentwicklung - Denkabläufe, Methodeneinsatz, Zusammenarbeit
- Ulrich K, 2011: Design is Everything?
- Schulz MD, 2014: Der Produktentstehungsprozess in der Automobilindustrie
- Eppinger S, Ulrich K, 2015: Product Design and Development

Product Architecture

- Ulrich K, 1995: The role of product architecture
- Lehnerd AP, Meyer MH, 1997: The power of product platforms
- Jose A, Tollenaere M, 2005: Modular and platform methods for product family design: literature analysis
- Gershenson JK, Prasad GJ, Zhang Y, 2003: Product modularity: definitions and benefits

Design Guidelines & Strategies

- Benabdellah AC, Bouhaddou I, Benghabrit A, Benghabrit O, 2019: A systematic review of design for X techniques from 1980 to 2018: concepts, applications, and perspectives
- Benabdellah AC, Benghabrit A, Bouhaddou I, Benghabrit O, 2020: Design for relevance concurrent engineering approach: integration of IATF 16949 requirements and design for X
- Arnette AN, Brewer B, 2014: Design for sustainability (DFS): The intersection of supply chain and environment
- Bralla JG, 1996: Design for Excellence
- Kuo T, Huang S, 2001: Design for manufacture and design for 'X': concepts, applications, and perspectives,

Oliver Mörth

Institute of Innovation and Industrial Management

Graz University of Technology

Thank You

Head of Institute

Christian Ramsauer

Univ.-Prof. Dipl.-Ing. Dr.techn.

Graz University of Technology

Institute of Innovation
and Industrial Management

Kopernikusgasse 24 / II

8010 Graz / Austria

Phone +43 316 873 7291

Fax +43 316 873 7791

E-Mail iim@tugraz.at

Web iim.tugraz.at