# Automation and Robotics in Remanufacturing

Dr. Sebastian Groß

iBT Institut für Betriebs- und Technologiemanagement
*Institute for Operations and Technology Management*

Umwelt-Campus Birkenfeld | HOCHSCHULE TRIER

# THE ENVIRONMENTAL CAMPUS.

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# SITUATION DESCRIPTION.


# A UNIQUE IDEA.


US Military Hospital

Foundation of the university

State of the art

# NUMBERS, DATA & FACTS.

STUDY PROGRAMS

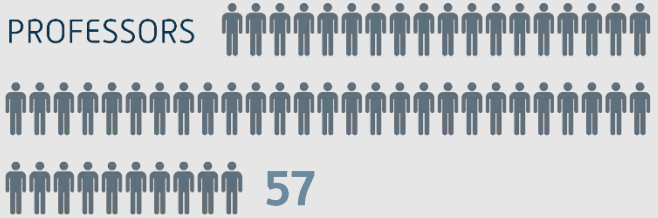

ZERO **EMISSION** CAMPUS

**02** **FACULTYS**

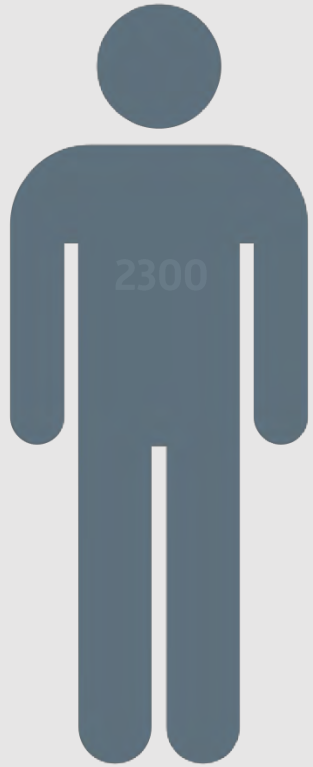
since **1996**

EMPLOYEES

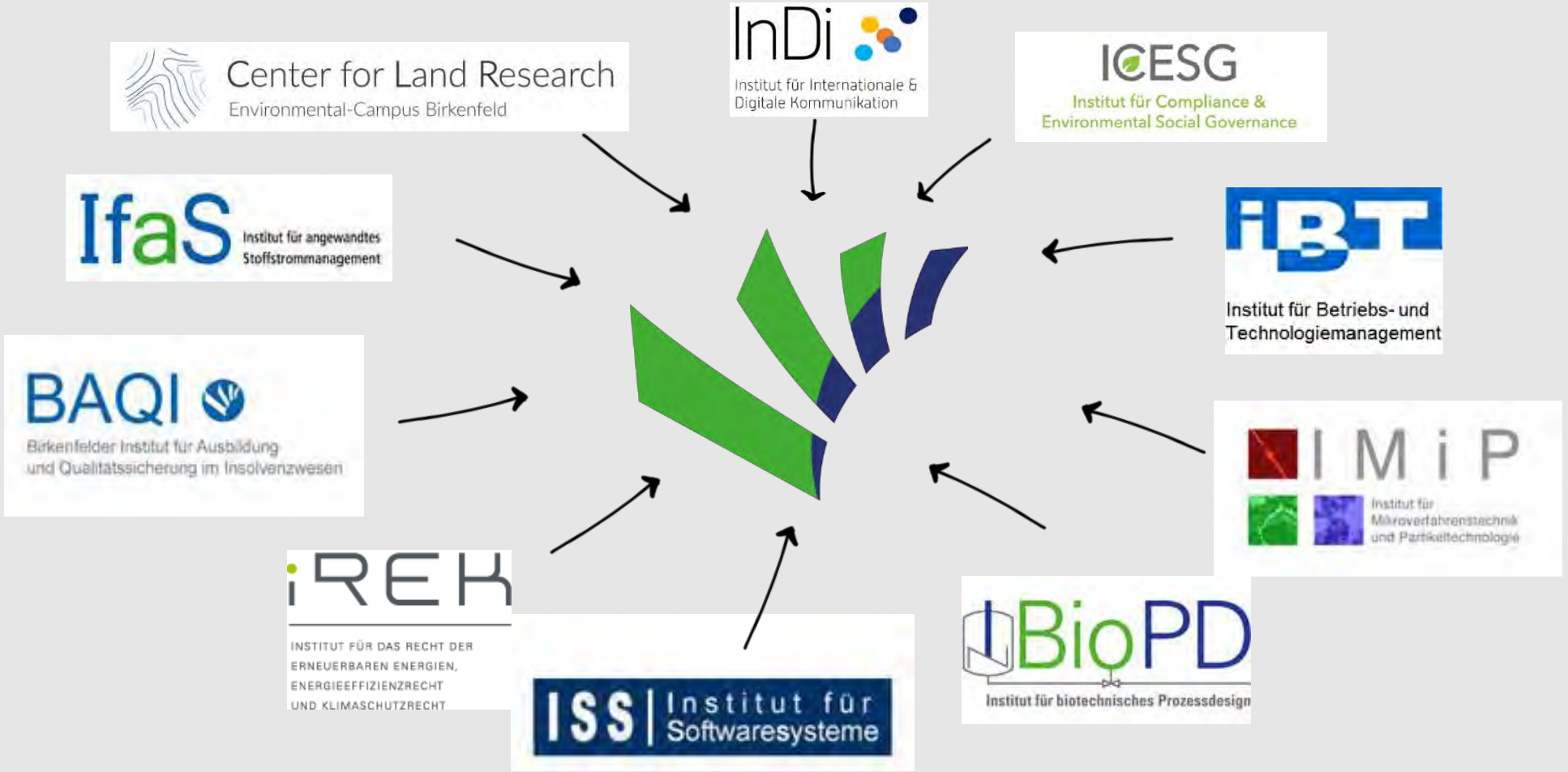

PROFESSORS




STUDENTS



# RESEARCH INSTITUTES AND COMPETENCIES.



# Working group
# Sustainable Production Processes and Industrial Robotics

# TUAS – Umwelt-Campus Birkenfeld
# Research areas

**Research profile of the TUAS**

| Applied material flow management | Life Sciences: Medical-, pharmaceutical- and biotechnology | Intelligent Technologies for Sustainable Development |
|---|---|---|

Prof. Dr.-Ing. Matthias Vette-Steinkamp

Sustainable Production Processes

Remanufacturing

Industrial Robotics

Assistance systems and human-machine interaction

At the UCB, a variety of research activities on the topic Industry 4.0 are undertaken.

# Remanufacturing

## Process technology

- Non-destructive and destructive disassembly technologies
- Automated cleaning and smart inspection procedures

## Planning and control

- Plant layouts and logistics concepts
- Simulation-based process planning and system technology selection
- Digital twin for online control of flexible remanufacturing systems

## Services

- Analysis of products regarding the possibilities for remanufacturing
- Execution of feasibility studies
- Technical and economic evaluation

# Industrial Robotic

## System Technologies

- Benchmarking and optimization of robot systems and components
- Development of new control and safety concepts
- Development of new process technologies

## Engineering

- Simulation-based layout, workspace and cycle time analyses
- Selection of components and integration into plant technology
- Optimization of robot applications

## Services

- Analysis of the legal situation and necessary standards
- Technical and economic evaluation
- Prototype implementation in application-oriented development environments

# Assistance systems and human-machine interaction

## Cognitive Assistance

- Worker guidance systems and assisted training workstations
- Fault detection and derivation of recommendations for action by expert systems

## Human-Machine Interaction

- User-oriented multimodal operation and interaction concepts
- Behavioral prediction and ad hoc action planner for the agile production environment
- Safe physical human-robot cooperation

## Smart Services

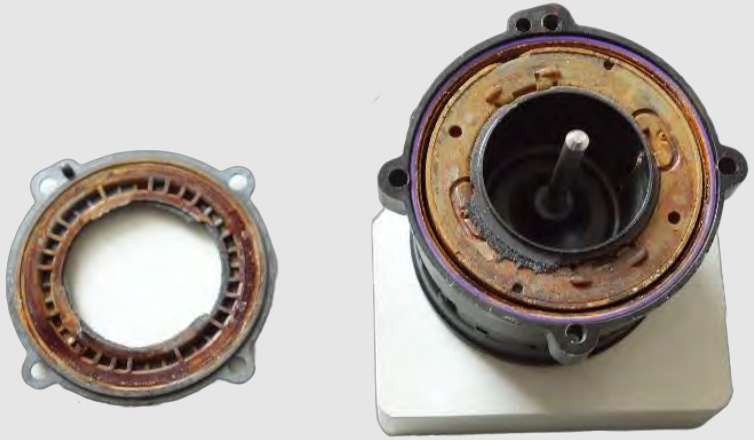
- I4.0-Retrofit of existing plants
- Block chain technologies for data integrity and smart contracts
- Analytical and AI-based feature recognition

# Remanufacturing process

1. Complete disassembly of the product
2. Cleaning of all parts
3. Inspection and sorting of the parts
4. Overhauling or replacing the parts
5. Reassembly of the product
6. Test

Picture source: Roboter Bosch GmbH

# Challenges in Remanufacturing



Picture source: Robert Bosch GmbH

Unknown Product State

Unpredictable Results of Inspection → Changes in the Process Plan

In general: Increasing Product Variety and Individualisation

**Individual Routing of Products through the (Re-)manufacturing System**

# Flexible (Re-)manufacturing System

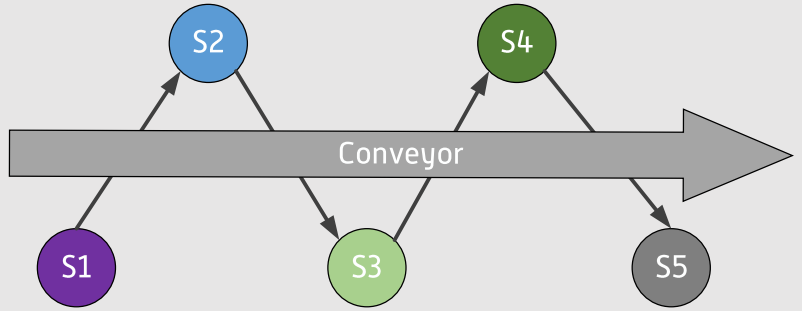
## Form of Manufacturing

Traditional Production Line

Flexible (Re-) manufacturing System

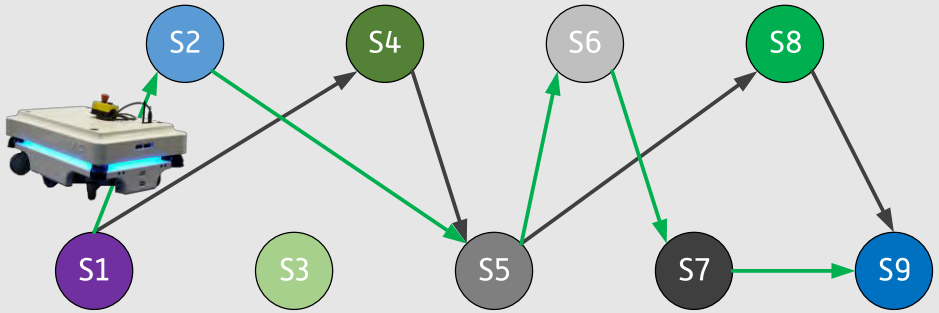
## Schematic Production Setup

### Traditional production line




Single route through the manufacturing system:
Product A: S1 -> S2 -> S3 -> S4 -> S5

### Flexible remanufacturing system




Multiple routes through the remanufacturing system:
Product A1: S1 -> S2 -> S5 -> S6 -> S7 -> S9
Product A2: S1 -> S4 -> S5 -> S8 -> S9

# Mega trends and the future of robotics

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# Megatrends in robotics

| Number | Megatrend |
|---|---|
| 1 | Robots need to be easily deployed and used:<br>Plug and play by end users |
| 2 | Make business more resillient:<br>Agile production and service delivery |
| 3 | Robots impact green digital:<br>Supporting the cicular economy, recycling, reducing waste, … |
| 4 | COVID-19 showed that transformation can be needed more rapidly than expected |

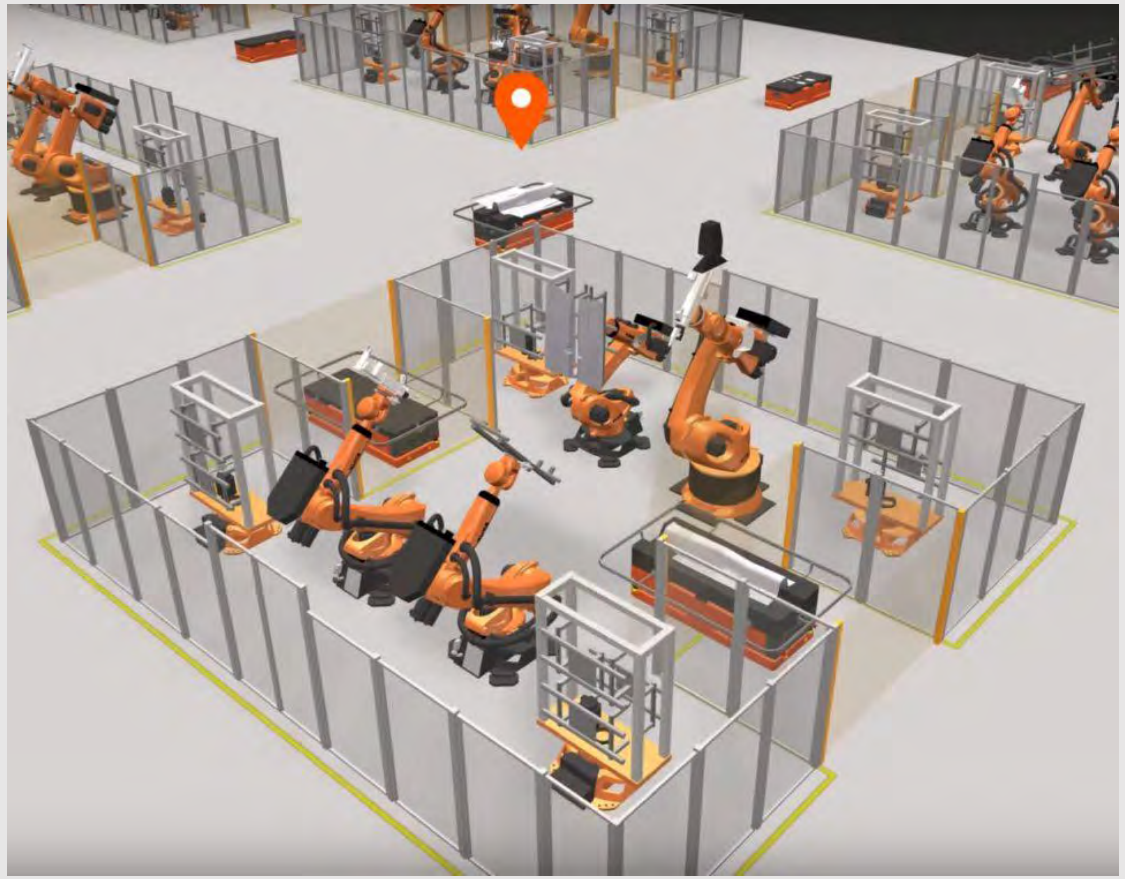
# Megatrend 1: Plug and play by end users

Picture source: ESSERT GmbH

Easy configuration of a robot cell through pre defined plug and play modules

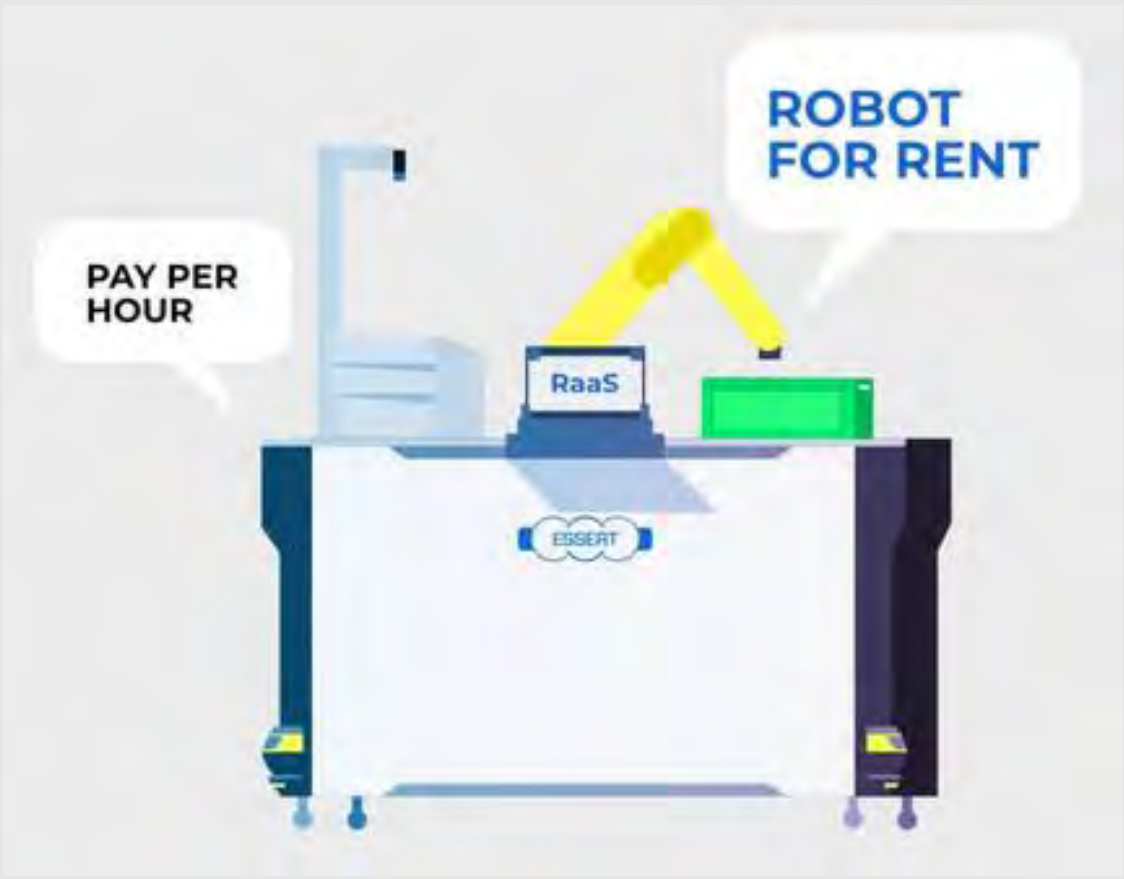
# Megatrend 2: Agile production and service delivery

## Agile matrix production



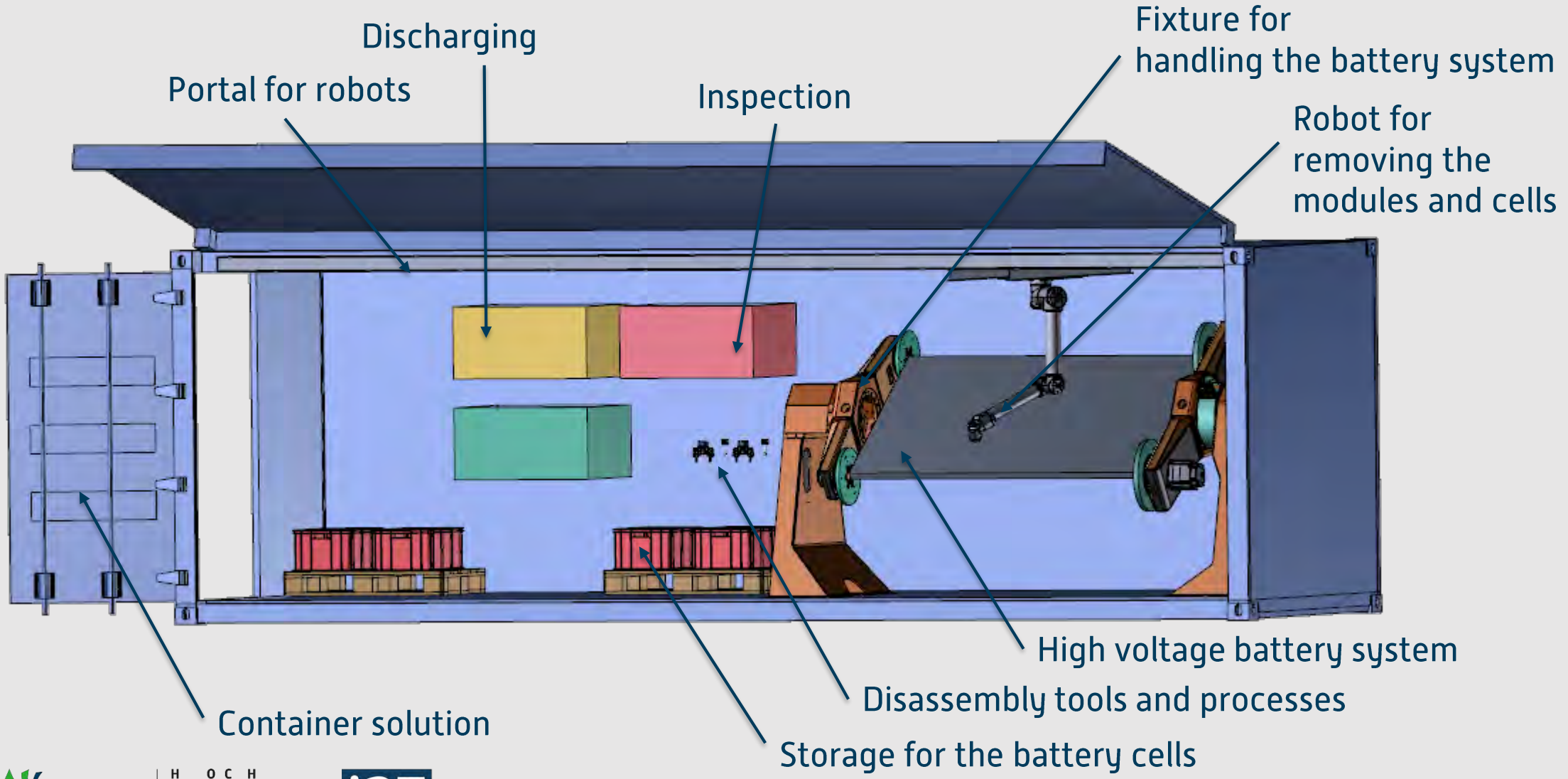
Picture source: KUKA AG

## Robot as a service




Picture source: ESSERT GmbH

# Megatrend 3:
# Supporting the cicular economy, recycling, reducing waste, ...



# Megatrend 4: COVID-19

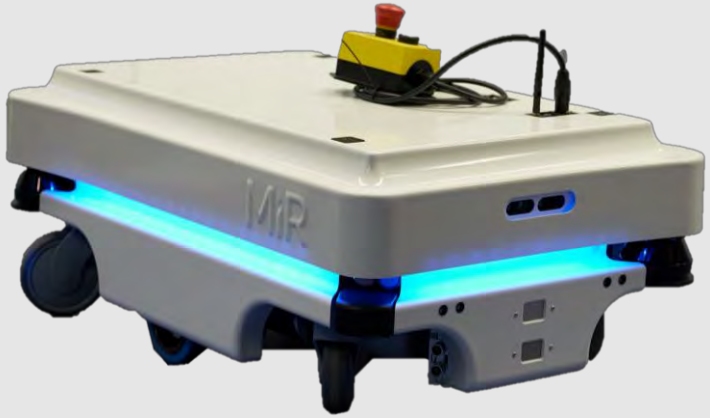
**Telepresence robot on the factory floor**

- Reduces the number of people required to work on-site → less contacts
- Enables untrained workers to solves difficult problems through automated expert guidance (expert systems) → Workers achieve higher added value

**Intralogistics through automated guided vehicles (AGVs)**

- AGVs eliminate unnecessary contact in and between work cells. Risk reduction of COVID-19 related shutdown.
- General: Material handling is the leading cause of compensable injuries in the American workplace [1].

Picture source: Doubel Robotic




[1] United States Department of Labor; Occupational Safety and Health Administration; Section VII: Chapter 1

# The future of robotics

| HRC-capable robot systems | Smart Devices |
| --- | --- |
|  |  |
| **Smart Services and IoT-Platforms** | **AI and Big Data** |
|  |  |

The human receives support in the Smart Factory and takes on the role of actor, sensor and decision maker.

# Current automation and robotization projects in remanufacturing

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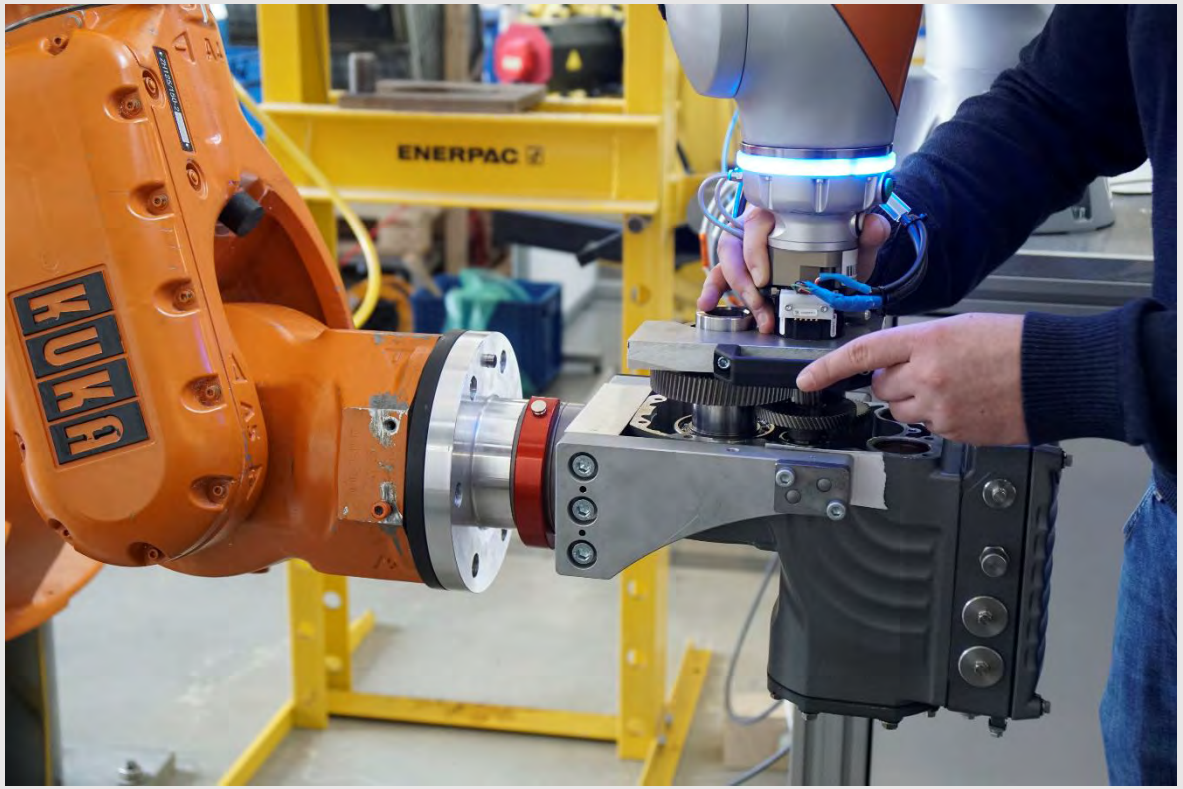
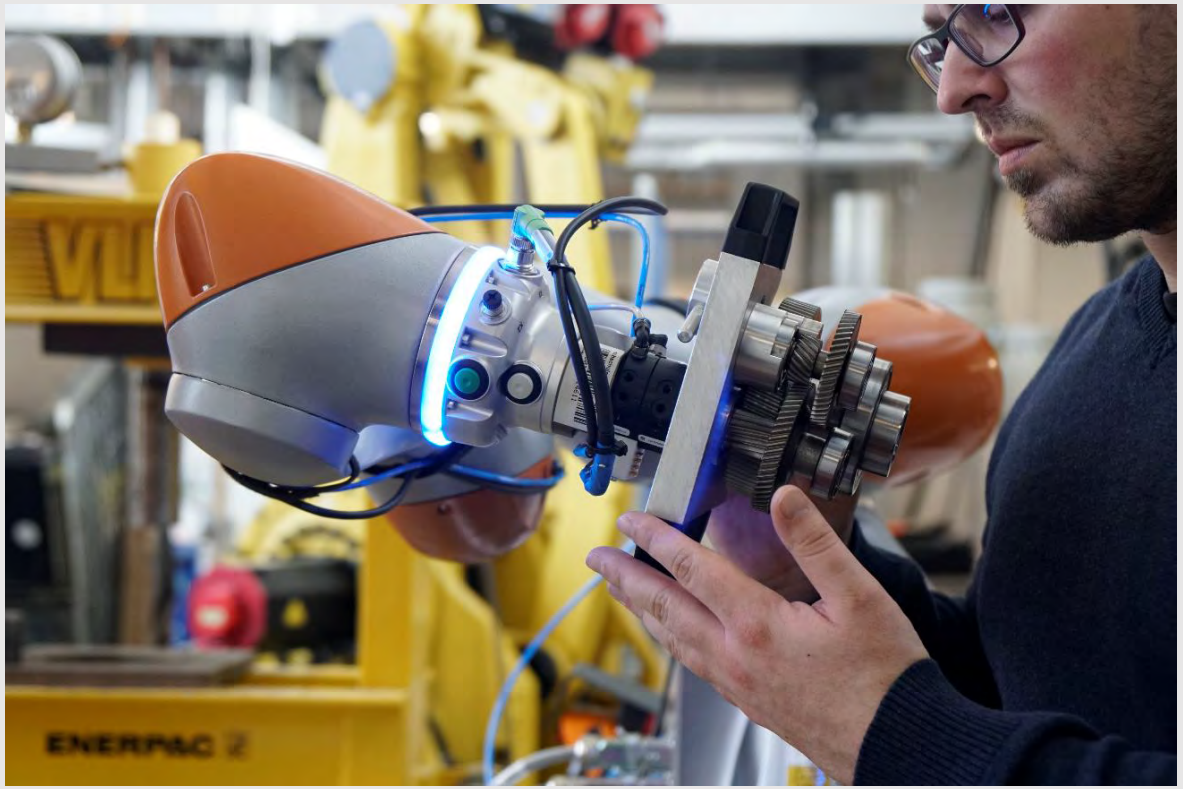
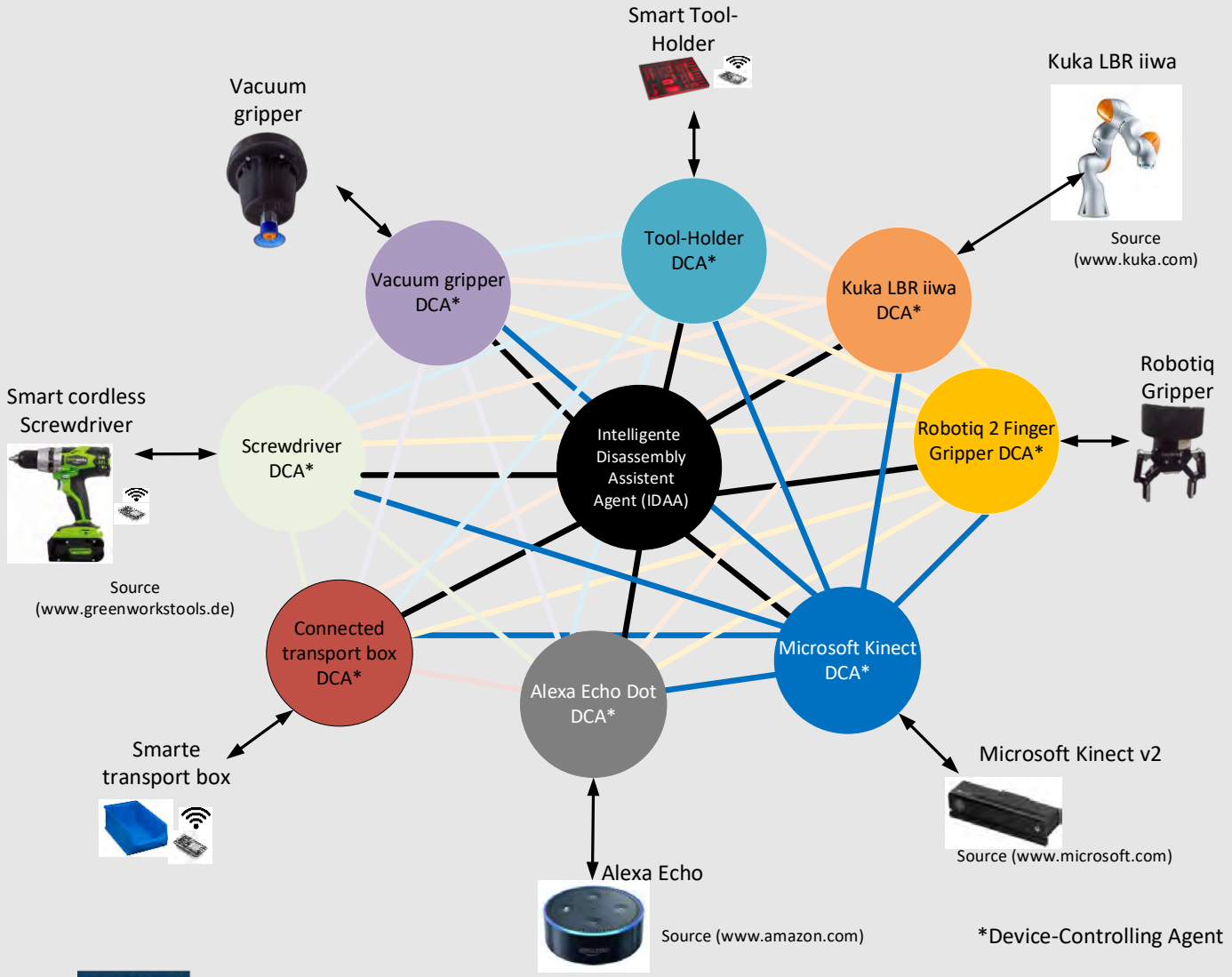
# Project 1: HRC-disassembly of a gear mtor



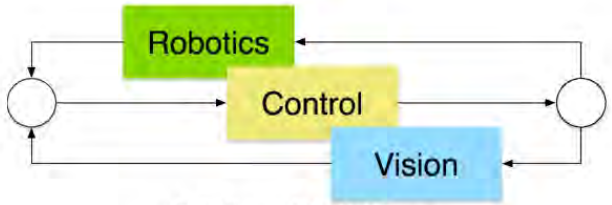
# Robotic assistance system (RAS)
# Intelligent disassembly assistance agent (IDAA)



# Video: HRC in disassembly

**Roboter-Werker-Kollaboration:**

Ausbau einer Getriebebaugruppe aus einem Elektromotor




Robotics and Control Group
Prof. Dr.-Ing. Wolfgang Gerke

**Projektleitung:** Prof. Dr.-Ing. Wolfgang Gerke
**Projektumsetzung:** Stefan Schmitt, B.Eng; Jan Jungbluth, M.Eng
**Film:** Jannik Scheer, B. Sc.

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Grande Région | Großregion
Robotix-Academy

# Projet 2:
# Decentralized disassembly and remanufacturing on an e-scooter

## Current Situation:

- E-scooters have an average lifespan of 28 days in the rental business.
- Afterwards, the e-scooters have to be collected and sent to central refurbishment stations at great expense.

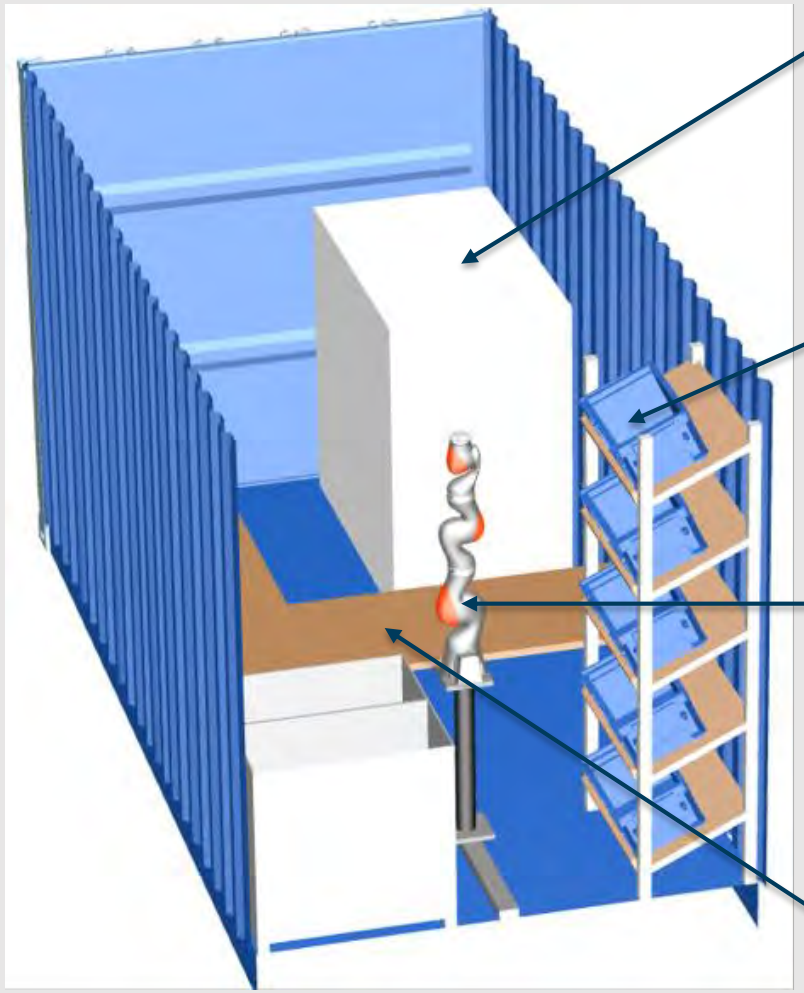
## Goal:

- In large cities, decentralized collection and inspection systems are emerging.
- The condition of the e-scooters is automatically checked and evaluated.
- Depending on its condition, the e-scooter is refurbished, repaired or dismantled in a decentralized automated process.

# Planned scenario for the model factory – decentralized disassembly Necessary technologies and business models

- Cleaning processes
- Inspection of used equipment: function test, visual inspection, safety test
  - Decision repair or disassembly
- Derivation of the disassembly steps from the product structure
- Tracking of parts through block chain technologies
- Destructive and non-destructive disassembly technologies
- Mediation platform for the distribution of parts to the users (recycling, repair, resale)
- Legal regulations (obligation to repair), subsidies for used products (tax exemption)
- Job initiative: Many assembly jobs in production are eliminated and can be used in dismantling
- Recycling management: important raw materials no longer leave the continent and have to be bought back at high cost

# Remanufacturing container for E-Scooter



Cleaning station

Storage for new parts

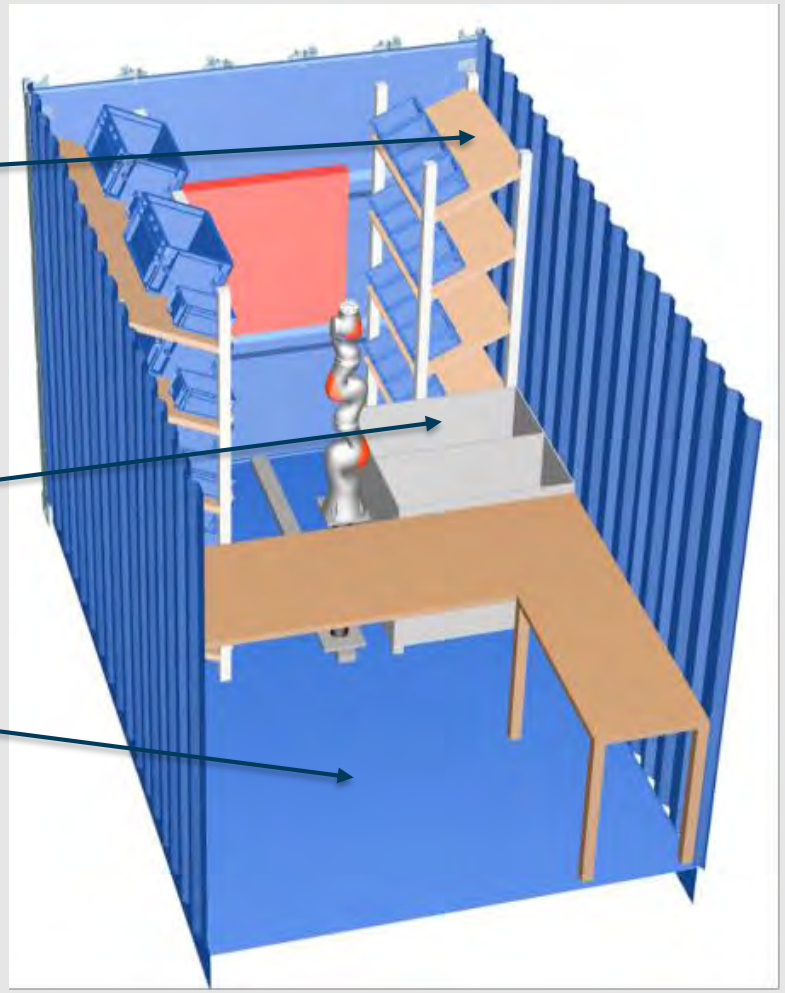
HRC-robot

Workbench for placing the E-Scooter

Storage for refurbished parts

Storage for parts to recycle

Workroom for the craftsman



# Project 3: Disassembly research of Lithium Batteries

## New Electric Cars 2020

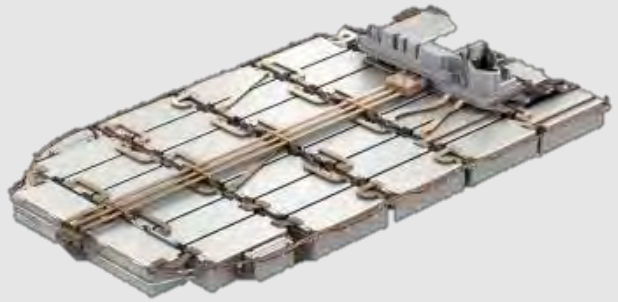
# Our theses on how the automotive market is currently changing: Conservative Forecast:

- Sales of electric vehicles will increase strongly in the next few years. Production capacities will be built up at all OEMs.
  - Tesla: 0,5Mio up to 2Mio units (Plant Berlin)[1]
  - VW: 0,3Mio units per year (Plant Zwickau)
- Currently, an extensive infrastructure is being built for the production of automotive batteries[2]
  - Microvast
  - Deutsche Accumotive
- Today's batteries have reached the end of their automotive life cycle in about eight years[3]
- Economic and useful business models for second-life batteries at low cost still need to be developed[4]

No matter if you are for or against electric cars. A new market for remanufacturing is just starting now.

1) *https://teslamag.de/news/zahlen-verwirrung-tesla-zwei-millionen-elektroautos-pro-jahr-giga-berlin-29221*
2) https://www.auto-motor-und-sport.de/tech-zukunft/alternative-antriebe/batteriezellen-fertigung-deutschland-wo-elektroauto-akkus-entstehen/
3) https://ecomento.de/ratgeber/wie-hoch-ist-die-lebensdauer-von-batterien-elektroautos/
4) Fraunhofer ISI: Batterien für Elektroautos: Faktencheck und Handlungsbedarf

# What does this mean for remanufacturing?



- Electric cars can no longer be resold, for example to Africa
- The raw materials in the batteries are important and must be recycled.
- The battery recycling law will be further stricter in the future.
- The recycling of small lithium-ion batteries has already established itself in Europe.
- E-vehicle batteries are much larger and heavier and have much more energy stored.
  - For parts with increased hazard potential like the battery of an e-vehicle is the removal and a separate handling is required.
  - The processes for disassembly are much more complex and must be designed to be safe.

Existing remanufacturing processes from the combustor engine cannot be transferred so easily.

# Jaguar I-Pace Recycled to Jaguar I-Pace


https://www.youtube.com/watch?v=W-m-J6nha8Y

# First step: What is the situation in the workshops? This will later also apply to the recyclers

## Organisation:

- The mechanics must be trained as electrical specialists. ✓
- The training courses are currently offered by the OEMs, but for the time being only for licensed workshops. ✓
- The workshops need new equipment (high-voltage equipment). ✓

Personal protective equipment

Special tools

New processes and accessories (e.g. locks)


Software

# First step: What is the situation in the workshops? This will later also apply to the recyclers

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## Problems from everyday life:

- How can I discharge the battery (90 kWh)?
  - Making 6.300 cups of coffee
  - This corresponds to burning about 10 liters of gasoline

→ We have to think about what to do with the energy!

- Are the battery systems repaired on site or completely replaced?

  (List price for battery: IPACE 40.000€)
- What do I do with the battery cells afterwards?

  Who collects the batteries?

→ We need logistics service providers.

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  (List price for battery: IPACE 40.000€)
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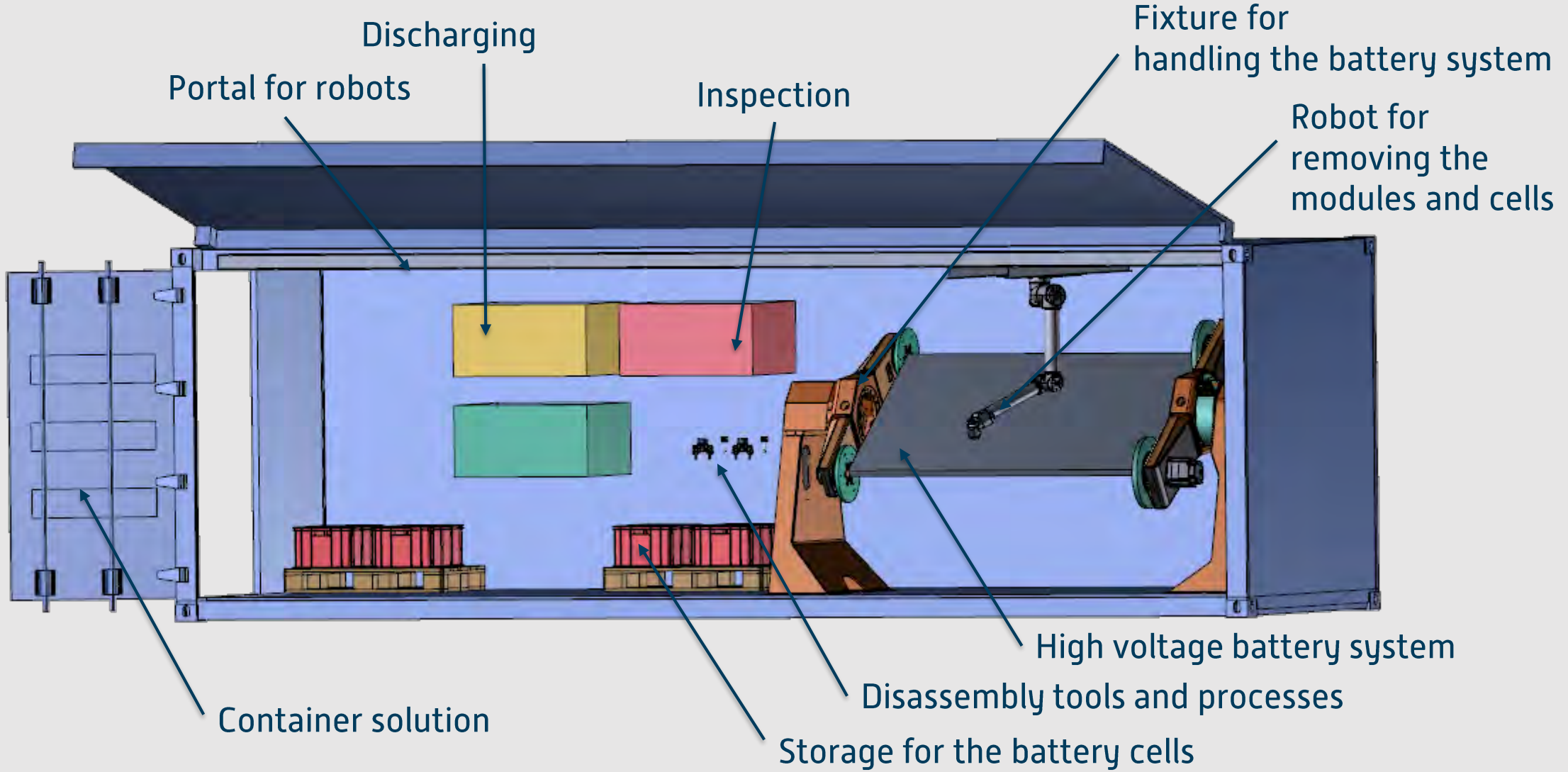
- Who collects the batteries?

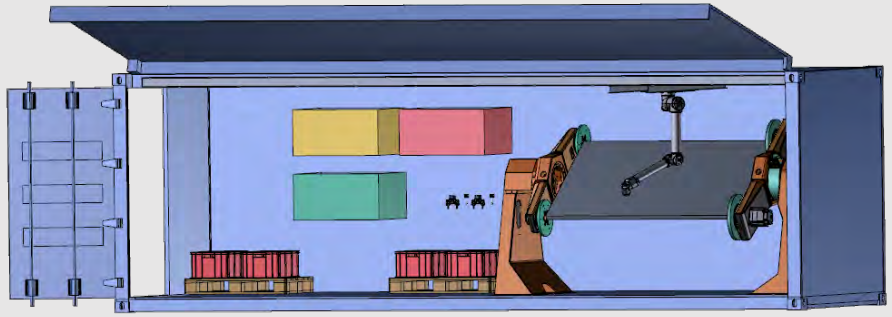
→ We need logistics service providers.


How do we deal with vehicles that had an accident?

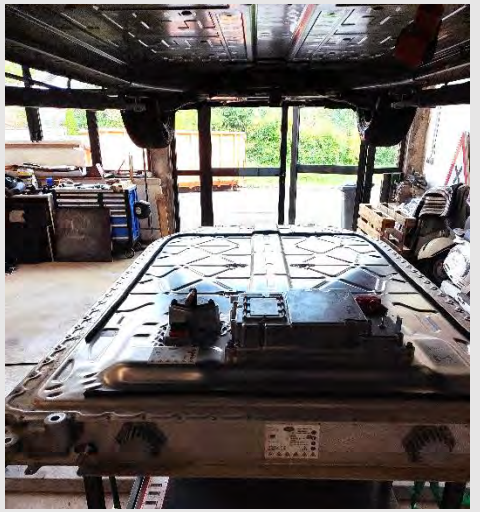
# Our solution approach is a decentralized, partially automated disassembly station



# What do we need for such decentralized disassembly systems?



- We need a business model
  - Who operates the disassembly system?
  - Where are such systems installed?
  - How expensive can the service be?
- Technical functions
  - It must be possible to disassemble different products, variants and generations. Critical quantity, so that such a system is profitable.
  - We need a high cycle time (approx. 36 modules à 12 cells per battery)
  - The whole system must be safe and ergonomic for the user.
  - It must also be possible for workshops with little or no automation experience to use the system.



There are already first approaches. However, these are more likely to be laboratory tests and experiments and not suitable for high volumes.

# We would like to develop a system with the following functions:

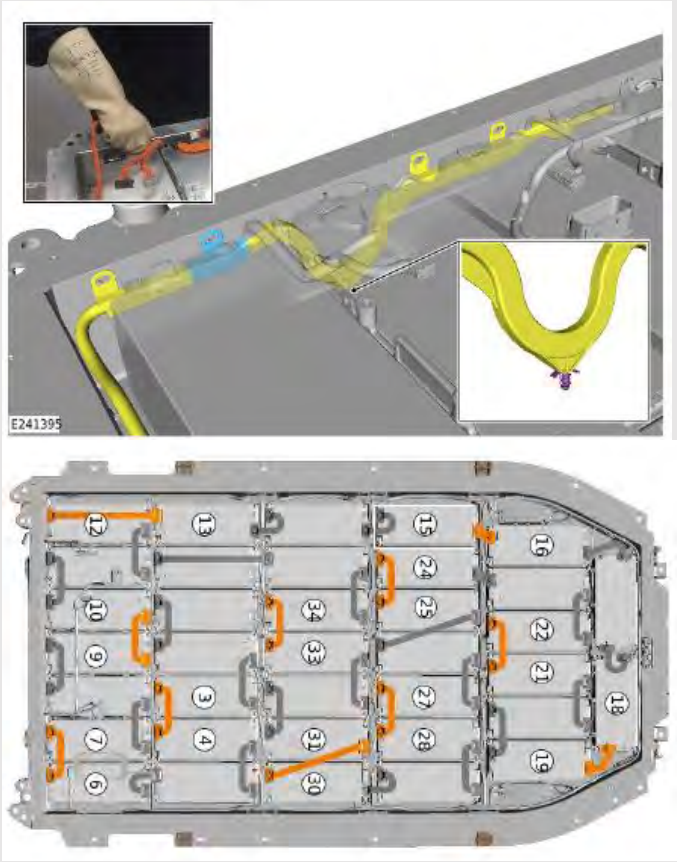
- Development of the robot functions and tools for disassembly the battery system:
  - Open the system
  - Separate, remove, inspect, discharge and store the modules / cells
- Development of autonomous functions that the system execute the right operations according to the product:
  - Digital Twin for programming, control and operation of the system
- Human-machine-interaction
  - processes that cannot be economically automated
  - for malfunctions caused by used parts

  → e.g. telepresence robotics
  - machine malfunctions
  - Loading and unloading, configuration and commissioning of the system

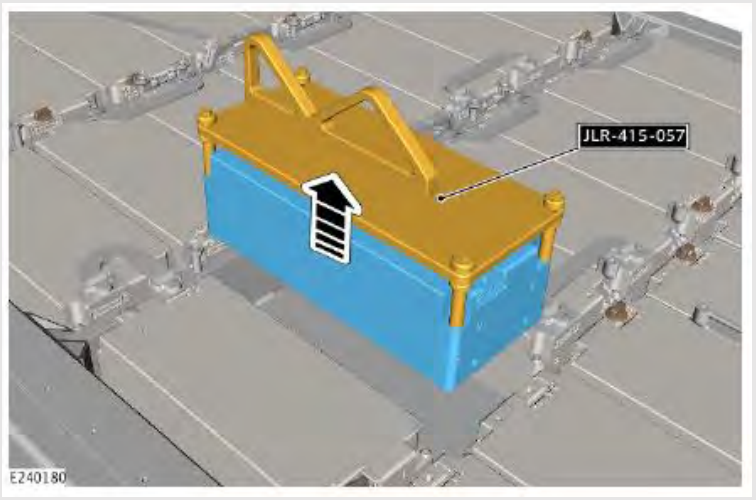
  → Expert systems and guide systems

# Steps for Disassembly


Open cover




Reduce voltage and remove cable


Lock connection points and remove module

Quelle: Jaguar Land Rover Ltd.

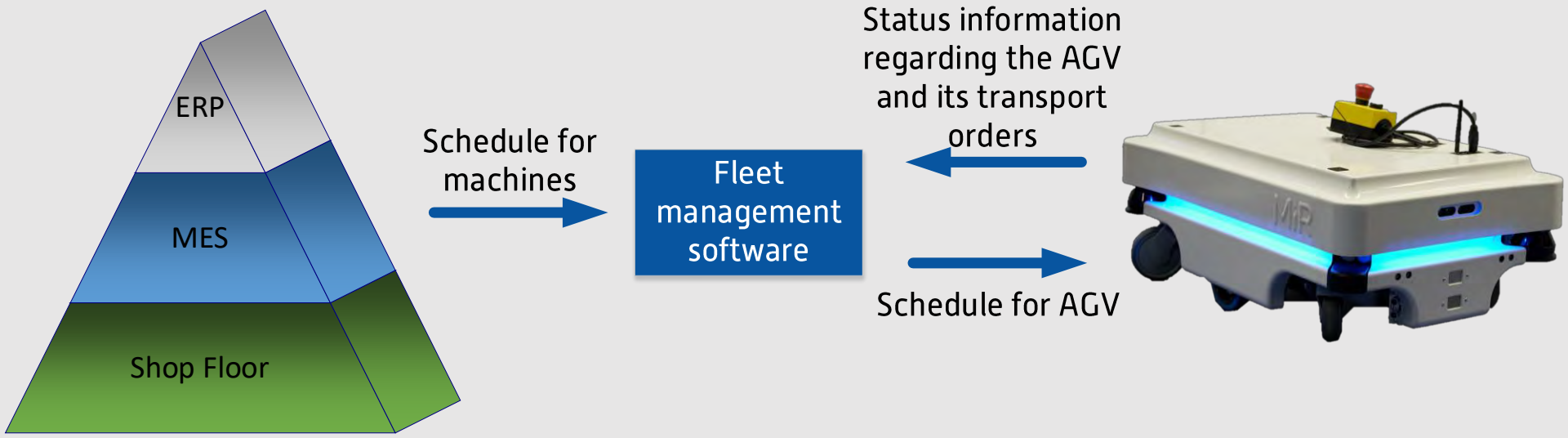
# Roadmap:

- Step 1:Feasibility Study
  - Automatic opening of battery
  - Extraction of the coolant
  - Disconnecting the modules
  - Remove the Modules and then the cells
- Step 2: Increase degree of automation
- Step 3: Industrialize processes
- Step 4: Market launch

Demonstrator: Jaguar I-Pace

# Project 4: Agile Production Control for (Re-)manufacturing Systems

# State-of-the-Art: Integration of the FTS into PPC




**Current**

- Machine and transport-scheduling sequentially considered
- Material Transport considered as secondary priority

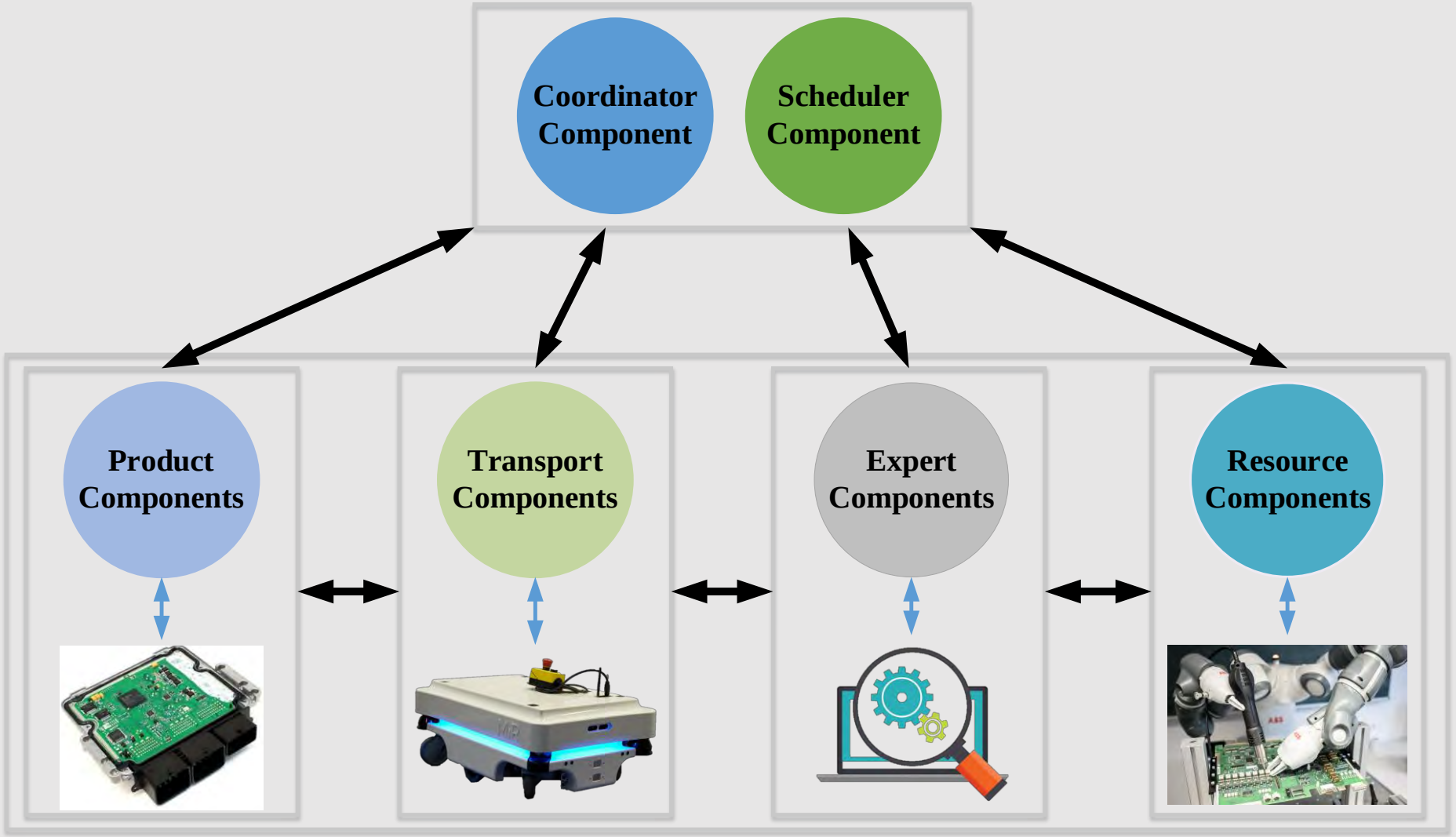
**Aim**

- Material transport planning as elementary part of scheduling
- KPI-optimisation through simultaneous scheduling

# Problem / research gaps

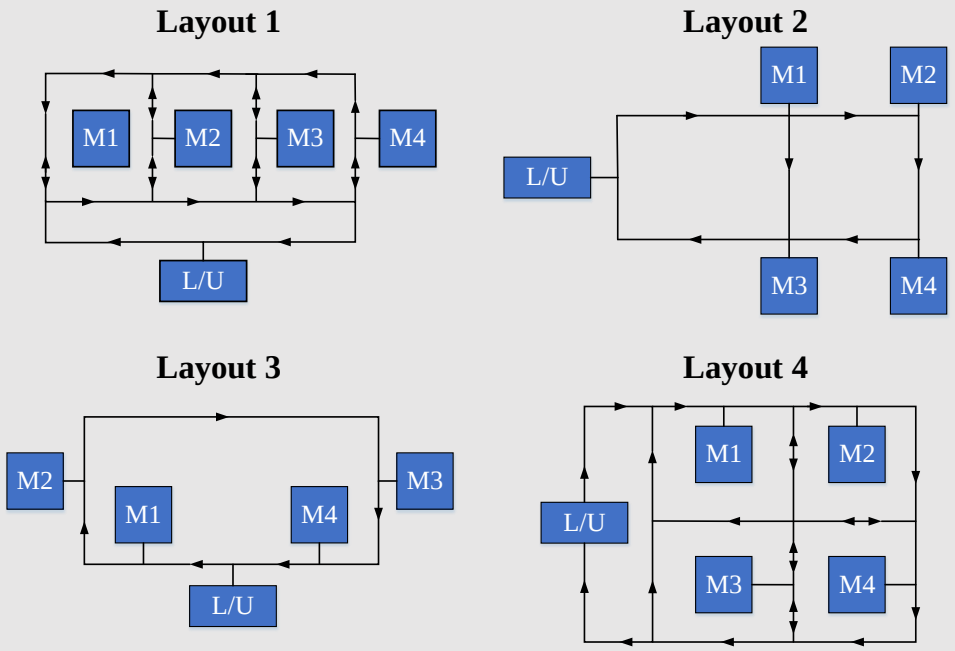
| Number | Gaps |
|---|---|
| 1 | Hybrid approaches to production control are barely investigated, only centralised or decentralised approaches with their respective cons. |
| 2 | One such approach to production control in remanufacturing, including the consideration of a flexible material transport system could not be found. |
| 3 | There exists little research to simultaneous scheduling of machines and FTSes, and this research is mainly in deterministic environments. |
| 4 | Published approaches to SAMF, despite high practical relevance, insufficiently investigate responsiveness to unexpected results. |
| 5 | Published appoaches to SAMF achieve either good optimisation results or a low computational time. |

# Decentralised Hierarchical Control Architecture



# Verification

## Four Layout Variants of the Benchmark [1, 2]



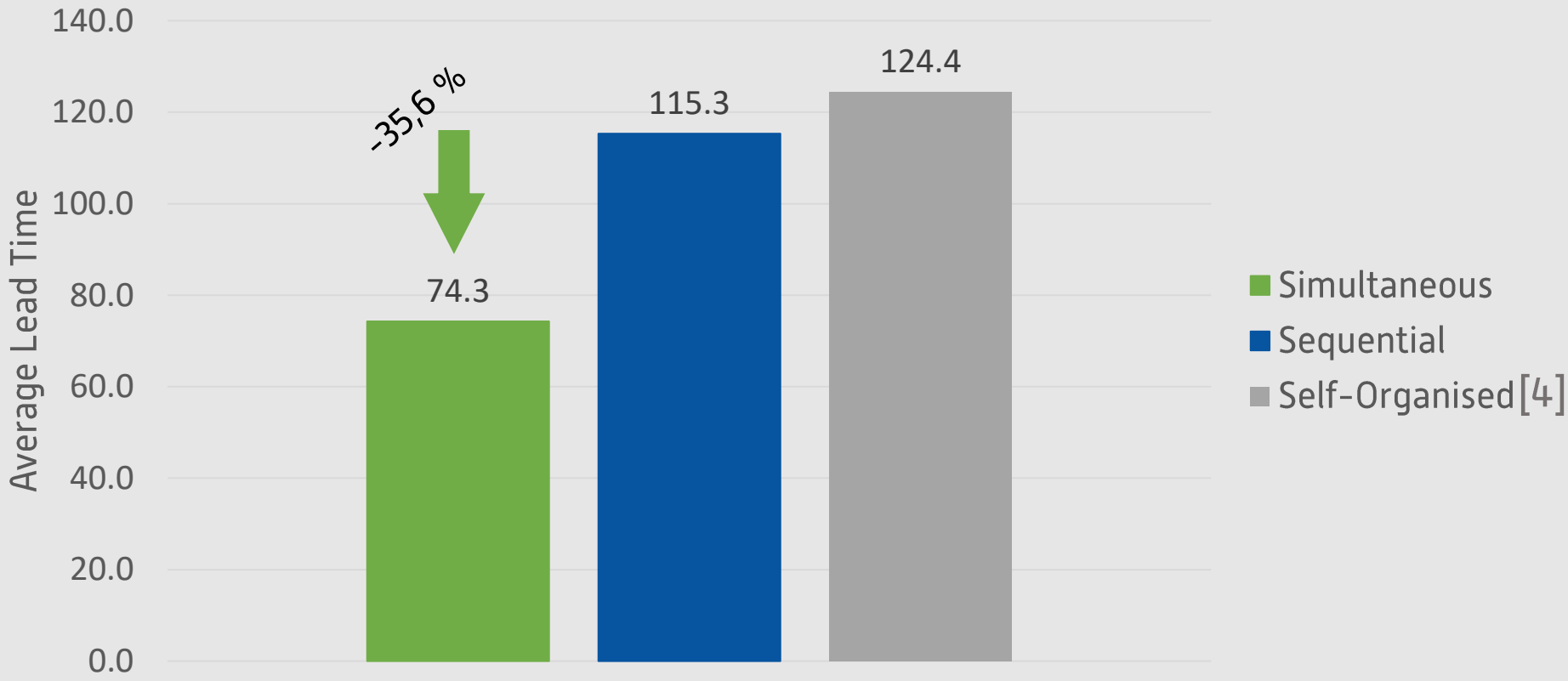

## Without Alternative Machines *[1]*

**Job Set 1**
Job 1: M1(8); M2(16); M4(12)
Job 2: M1(20); M3(10); M2(18)
Job 3: M3(12); M4(8); M1(15)
Job 4: M4(14); M2(18)
Job 5: M3(10); M1(15)

## With Alternative Machines [2]

**Job Set 1**
**Job 1:** M1(8); M2(16); M4(12)
Alt 1: M2(9); M3(14); M1(13)
Alt 2: M3(9); M4(17); M2(10)
**Job 2:** M1(20); M3(10); M2(18)
Alt 1: M3(18); M1(13); M4(17)
Alt 2: M2(21); M4(8); M3(19)
**Job 3:** M3(12); M4(8); M1(15)

# Comparison of different scheduling methods



# Rescheduling for Real-Time Optimisation

**Unforeseen events** create disturbances in scheduling
(New jobs, additional necessary Operations, machine downtime)

| Factors to consider | Data and Information |
| --- | --- |
| Status / Availability of Relevant Production Resources | ▪ Status: Defects / Idle / In-process<br>▪ In-process / Product-in-transit<br>▪ End-time of current in-process/in-transit operation |
| Status of Products | ▪ Current location<br>▪ Status of the current operation,<br>▪ Operations yet to be executed,<br>▪ Planned and real start and end-times of all operations |

# Video: Smart Model Factory for Remanufacturing

# Lab, Events and Collaboration possibilities at the Environmental-Campus Birkenfeld

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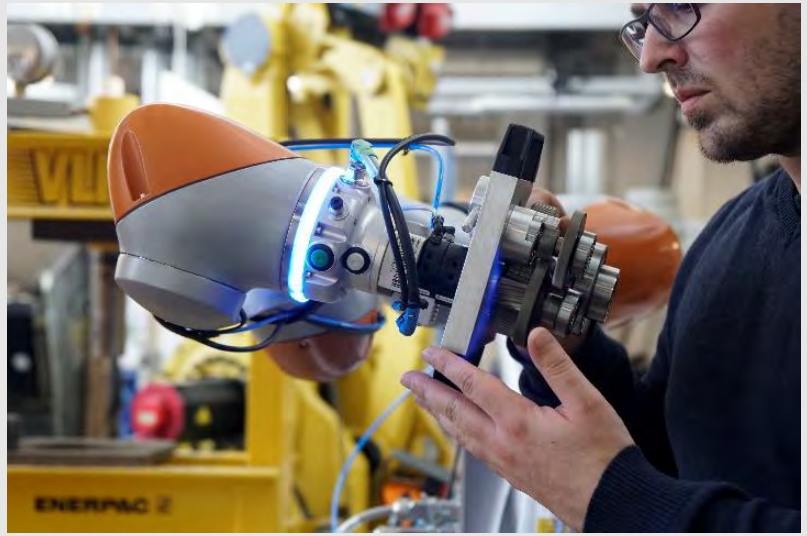
# Showroom and Coworking Space

- **Showroom**
  - Active research operation
  - Demonstration of new technologies and research results
  - Seminar and further education offers for companies and students
  - Hands-on-Technologies

- **Coworking Space**:
  - Cooperation of interdisciplinary and international research teams
  - Development of industry-related and industrial applications
  - Technology transfer



# Online symposium on innovation and automation in remanufacturing


Every **two months** the Environmental-Campus Birkenfeld organizes an online conference series on innovation and automation in remanufacturing.
(**Next event: 05. Mai 2021**, Topic: Sensor- and AI-supported identification and evaluation of used parts in remanufacturing)

https://www.umwelt-campus.de/en/online-symposium-on-remanufacturing

# Cooperation opportunities with the Environmental-Campus Birkenfeld

## Contract Research

- Direct commissioning of the university by a company

## Sovereign research

- Cooperation within the framework of publicly funded projects
- Both promotion of only one partner and promotion of both partners is possible

# Thank you for your attention!

Do you have any questions

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