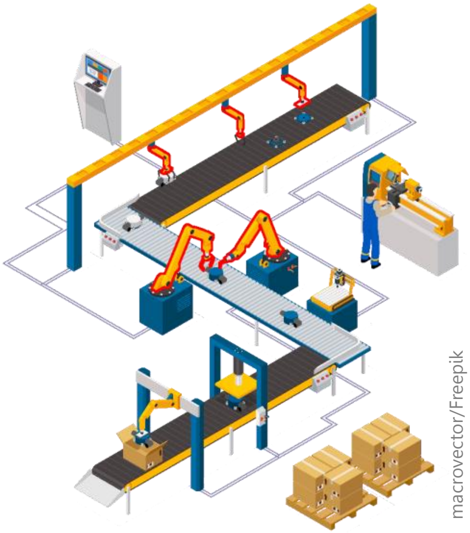
A Reusable Set of Real-World Product Line Case Studies for Comparing Variability Models in Research and Practice

Kristof Meixner[2,3] Kevin Feichtinger[1]
Rick Rabiser[1] Stefan Biffl[3]

[1] LIT CPS JKU Linz / [2] CDL SQI TU Wien / [3] ISE TU Wien

Context – Cyber-Physical Production Systems

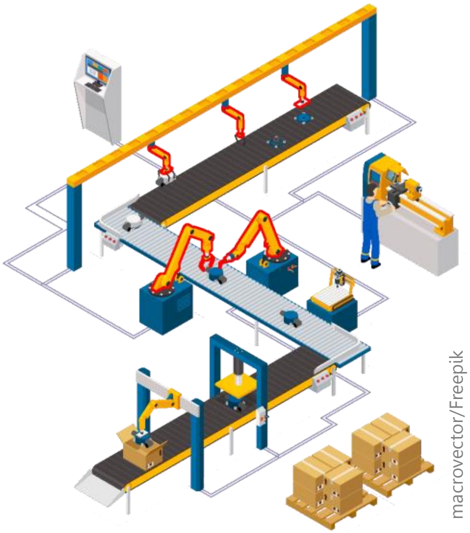
- Cyber-Physical Production Systems (CPPSs) **interact** with the environment to **self-adapt** to the conditions
- CPPSs enable **flexible production** of **customized products**, i.e., product families
- Engineering **artifacts** (e.g. CAD drawings) **contain variant** information but are **unstructured**
- Requires analyses to **model and extract the CPPS variability**



macrovector/Freepik

Problem – Cyber-Physical Production Systems

- **Amount** of structured **variability modeling approaches** is **overwhelming**
- **Industrial practitioners** are **often unaware** of available approaches and their application
- **Case studies help** researchers and practitioners **gaining insights** into variability modeling
- **CPPS real-world cases** for variability are **rare, often not accessible**, and **hard to reproduce** [1].
- Researchers **often use toy examples** or develop **fictitious case studies**.



macrovector/Freepik

Research Question 1

RQ1. Which real-world case studies satisfy requirements to investigate product variability in CPPSs?

- Proposal of **minimal requirements**
- Elicitation of **real-world case studies**

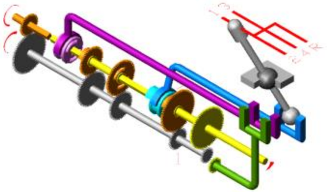
Requirements for Production System Case Studies

- **Req1. Product variability** in production systems.
  - Case must cover the **variability of products** that can be **manufactured on a production system.**
- **Req2. Structured product variants.**
  - **Products need to be sufficiently similar** to build a product line. (50% - 80% commonalities) [2]
- **Req3.** Availability of **domain experts** or **documentation.**
  - **Experts** who **understand the product line** and CPPS to discuss variability. **Documentation to** properly **describe the case study.**

Elicitation of real-world case studies

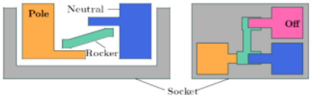
1. **Identify** accessible real-world **case studies**
   - Two methodologies, **case study guideline [3]** and **design science methodology [4]**
   - Interviews with practitioners and researchers from three collaborations
   - Identification of four cases that fulfill the requirements with documentation material

©Vaclav Jirkovsky



©World Arm Lamp, CC0 on Wikipedia

©Askwar Hilonga



Research Question 2

RQ2. How can we obtain comparable variability models from the real-world cases?

- **Translation** of the case studies to a **unified industrial CPPS domain-specific language**
- **Transformation** of the case studies **to a feature models** and back

Extraction of Variability

1. **Identify** accessible real-world **case studies**

2. **Extract variability** information to Product-Process-Resource DSL (PPR DSL).
   - Data Analysis - Modeling of the product lines in the PPR DSL [5]
   - Support of collaborations in modeling

```
Attribute "length": { type: "Number", unit: "mm" }

Product "Chassis": { name: "Chassis" }
Product "Cabin": { name: "Cabin" }

Product "Body": { name: "Body",
  isAbstract: true }

Product "Tank": { name: "Tank",
  isAbstract: false ,
  implements: [ "Body" ] }

Product "OpenTop": { name: "OpenTop",
  isAbstract: false ,
  implements: [ "Body" ], length: 30 }

Product "Legotruck": { name: "Legotruck",
  isAbstract: true ,
  children: [ "Chassis", "Cabin", "Body"],
  requires: [ "Chassis", "Cabin", "Body"] }

Product "Legotruck1": { name: "Legotruck1",
  isAbstract: false ,
  implements: [ "Legotruck" ],
  requires: [ "Tank" ], excludes: [ "OpenTop" ] }
```

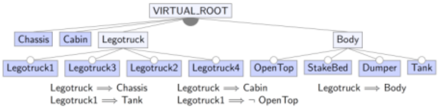
Transformation to structured Variability Models

1. **Identify** accessible real-world **case studies**

2. **Extract variability information to PPR DSL.**

3. **Transformation of PPR DSL artifacts to feature models.**
   - **VERT process [6] enables users to transform engineering artifacts containing variability information, such as the PPR DSL**
   - Definition of **TraVarT mappings [7]** between the PPR DSL and FeatureIDE [8] feature models

	PPR DSL	Feature Model
custom attribute	attribute	property
	type	property
	unit	property
	defaultValue	property
	description	property
product	id	name
	name	property
	isAbstract	defines if the feature is abstract
	implements	property/feature tree
	requires	implies constraint
	excludes	excludes constraint



Case Study – Water Filter

- **Water filter** for safe water usage in Tanzania
  - Filters impurities and remove contaminants
  - Low-cost but customizable working without electricity
- **Data**
  - Semi-structured online interview and email communication
  - Manual, project documents, company website
- **Product line**

©Askwar Hilonga

Parts/Types	Complexity	#Product Variants	#DSL Elements	#Dependencies	#Features	#Constraints	#Configurations
3D-printed truck	low	4	12	31	13	31	23
Shift fork	low	4	22	36	25	38	67
Water filter	medium	8	54	165	55	165	217
Rocker switch	medium	12	54	184	55	216	183

Discussion

- The four case studies **advance currently available industrial studies** for production systems
- Using the **PPR DSL and TraVarT** can make variability models **better comparable**
- Our approach is a good **starting point to evaluate variability modeling** approaches for CPPS
- Using the **real-world case studies** can help **educating product line engineering** to CPPS engineers [9]

Conclusion & Future Work

- Identified **selection criteria** for real-world case **studies of product lines in CPPS**
- Elicited **four case studies on product variability** from the **production domain** satisfying the requirements
  - Cases and artifacts are available online: https://github.com/tuw-qse/cpps-var-case-studies
  - Addressed **reusable and reproducible** product lines **in CPPSs**
- Introduced **transform operations** from Product-Process-Resource DSL to feature models
- **Automatically transformed** the DSL instances to feature models
- **Future Work**
  - Incorporation of process variability in the case studies
  - Usage of other variability models like decision modeling, e.g., for process variability modeling

TU WIEN TECHNISCHE UNIVERSITÄT WIEN Vienna | Austria

JKU LINZ INSTITUTE OF TECHNOLOGY | CYBER-PHYSICAL SYSTEMS LAB

Christian Doppler Forschungsgesellschaft

Kristof Meixner[2] Kevin Feichtinger[1]
Rick Rabiser[1] Stefan Biffl[2]

[1] *<first.last>*@jku.at
[2] *<first.last>*@tuwien.ac.at

Future Work

[1] https://but4reuse.github.io/espla_catalog/

[2] Paul Clements and Linda Northrop. 2002. Software product lines. Addison-Wesley Boston.

[3] Per Runeson and Martin Höst. 2008. Guidelines for conducting and reporting case study research in software engineering. Empirical Software Engineering 14 (2008), 131–164.

[4] Roel J. Wieringa. 2014. Design science methodology for information systems and software engineering. Springer.

[5] Kristof Meixner, Felix Rinker, Hannes Marcher, Jakob Decker, and Stefan Biffl. 2021. A Domain-Specific Language for Product-Process-Resource Modeling. In IEEE Int. Conf. on Emerging Technologies and Factory Automation (ETFA). IEEE.

[6] Kevin Feichtinger, Kristof Meixner, Rick Rabiser, and Stefan Biffl. 2020. Variability Transformation from Industrial Engineering Artifacts: An Example in the Cyber- Physical Production Systems Domain. In 24th ACM Int. Systems and Software Product Line Conf. - Volume B (SPLC ’20). ACM, New York, NY, USA, 65–73.

[7] Jens Meinicke, Thomas Thüm, Reimar Schröter, Fabian Benduhn, Thomas Leich, and Gunter Saake. 2017. Mastering Software Variability with FeatureIDE. Springer.

[8] Jens Meinicke, Thomas Thüm, Reimar Schröter, Fabian Benduhn, Thomas Leich, and Gunter Saake. 2017. Mastering Software Variability with FeatureIDE. Springer.

[9] Kristof Meixner, Rick Rabiser, and Stefan Biffl. 2019. Towards Modeling Variability of Products, Processes and Resources in Cyber-Physical Production Systems Engineering. In 23rd Int. Systems and Software Product Line Conf. - Volume B. ACM, 68:1–68:8.