Maturity variations of PLC-based control software within a company and among companies from the same industrial sector

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Introduction and Motivation

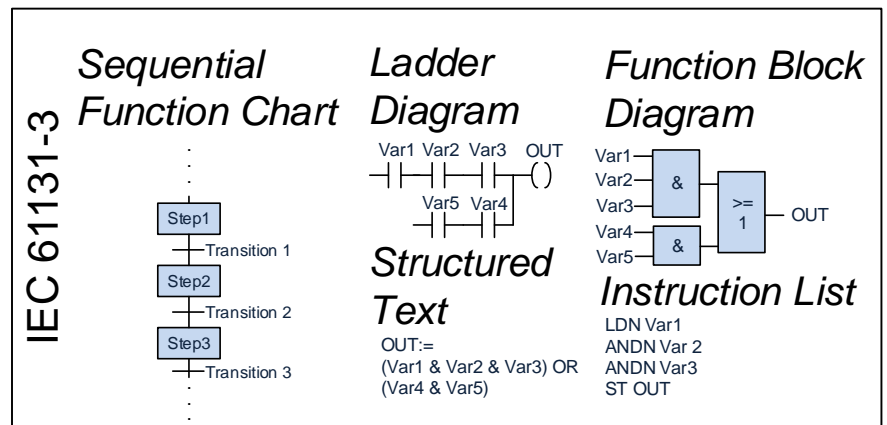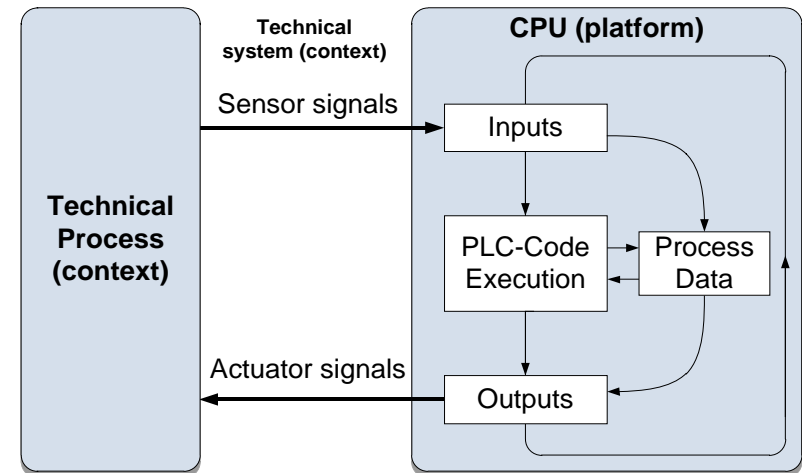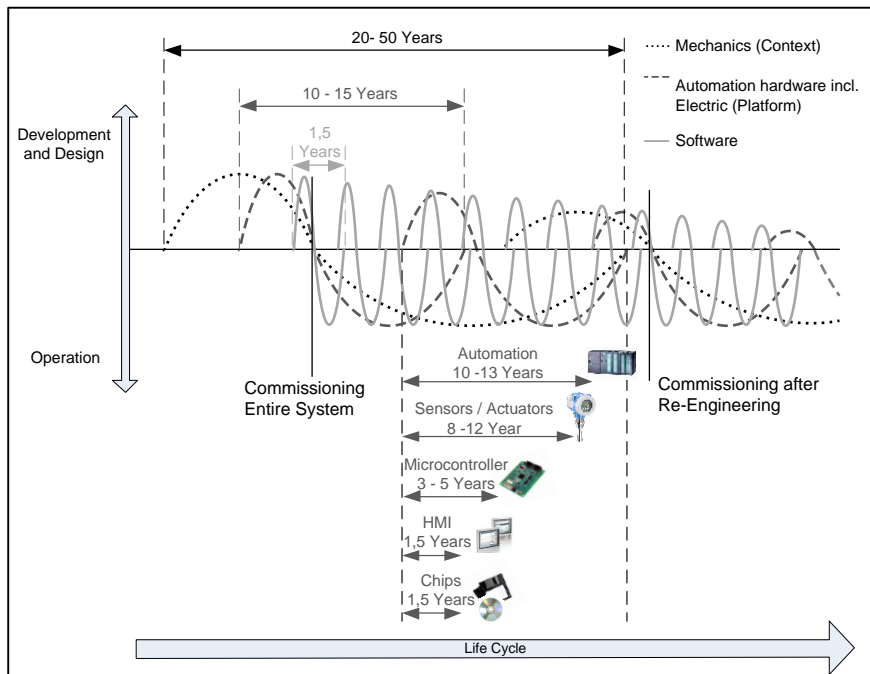Technical constraints on automated Production Systems (aPS):

− Lifecycles last up to 50 years [1]

− Hard real-time requirements, cyclic behavior (1µs – 1s), and proprietary hardware (PLC)

− Online changes are mandatory

− Domain specific programming language (IEC 61131-3)

Source: Siemens AG

Source: Bayer AG, Leverkusen

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MDE in aPS: UML and SysML for code generation

Variant and version management: especially relevant for plant and machine manufacturing due to parallel operation with different machines for different customers on different sites; approaches form academia include product lines and feature models [3, 4]
Vogel-Heuser et al. [2] showed extensive use of "copy, paste and modify" in industry
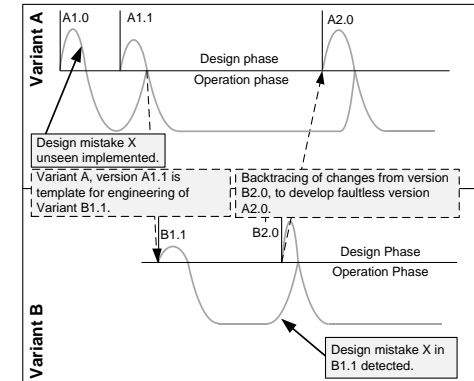
Standard functions and standards in implementation:
ISA-88 for hierarchy of modules [5]
modules implement typical standard functions for diagnosis, i.e. fault detection, and fault handling [6]
beverages: PackML including OMAC state machines [7]

https://store.codesys.com/omac-packml-state-machine.html
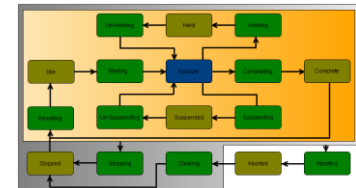
Benchmarking and measure for SW quality in aPS: Comparison of machine manufacturing (MM), special purpose machinery (SPM) and plant manufacturing (PM) failed in [2]

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Research Method
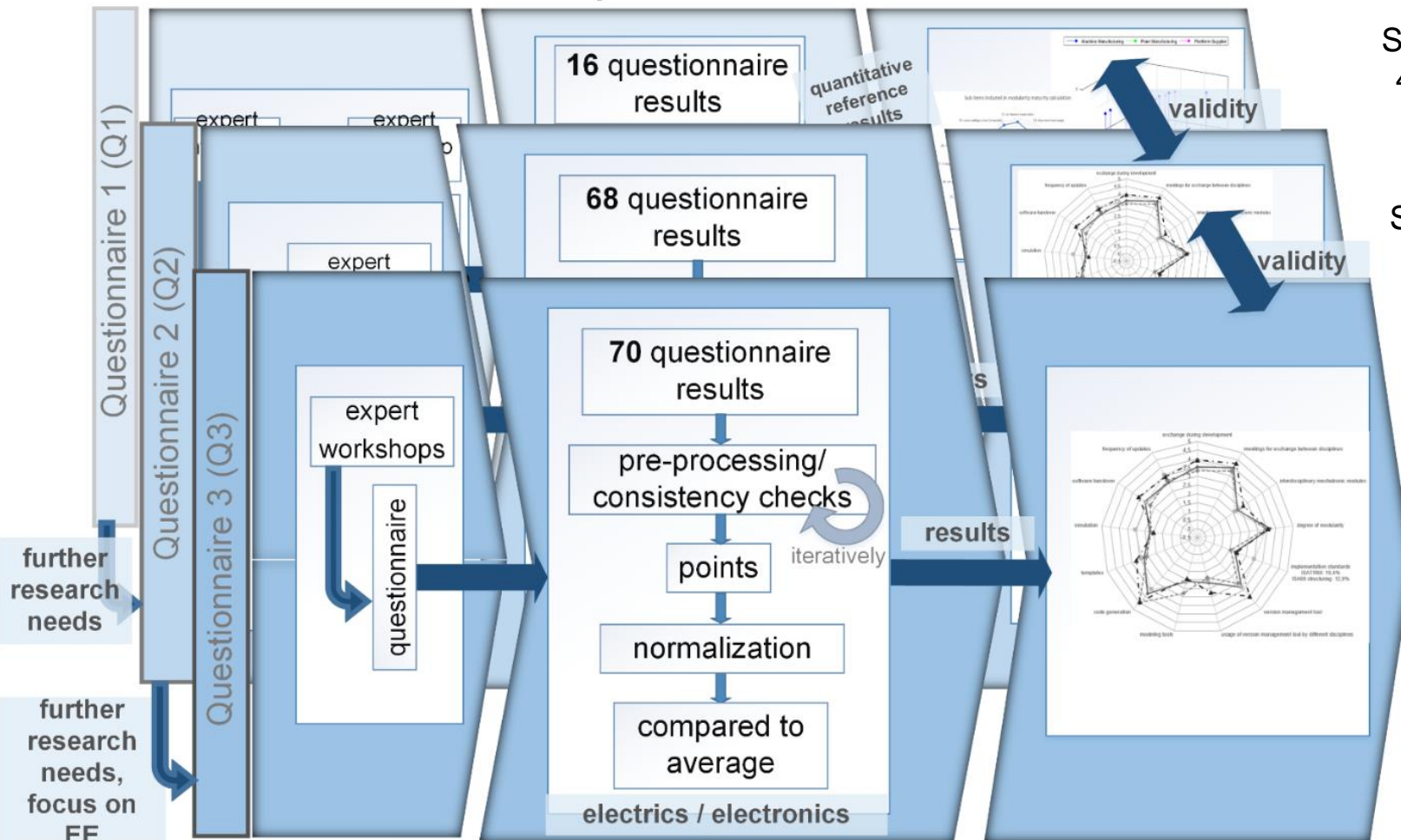

SWMAT4aPS
45 questions

SWMAT4aPS+
52 questions

$SWMAT4aPS_{i/m}$
42 questions

3 questionnaires → characteristic maturities and maturity variations

Companies participating in the survey

Group	Company	Industrial sector	Business type	Complexity and size	PLC supplier*/OO	Programming Languages**	Customer has access to code	MDE***
P1-x (Q2)	1-1	Steel industry	large scale PM	6, 1k-2k#	S/n.a.	HPL, FBD, ST, M/S, CFC	Partially	EA, M/S, Eclipse
	1-2			5, <5k#	S, R/n.a., B, SE/OOp	HPL, M/S		EA, M/S
	1-3			4, >5k#	S, R/n.a.	HPL, all IEC		EA, M/S
	1-4			5, >5k#	S, R/n.a. SE, OOp	HPL, FBD, IL, CFC		EA, M/S
P2-x	2-0 (Q1)	Food, Pharma	SPM and PM	n.a., <1k#	R/n.a., SE/OOp	ST, SFC, FBD, LD	Never	M/S
	2-1 (Q2)	Pharma		5, <200#	B, SE, B&R/OOp	HPI, ST, SFC, FBD	Partially	EA, M/S
	2-2 (Q2)	Pharma		3, <200#	S, R/n.a. F/-OOp	HPL, IL, LD, SFC	Never	
	2-3 (Q2)	Pharma, Med, Consumer		6, 200-500#	R/n.a., B/OOp	HPL, FBD, IL, ST	Partially	-
P3-x (Q1)	3-1	Food & Bev.	SPM and PM	n.a., 200-500#	S, R/n.a. B&R	M/S, ST, IL, LD	Partially	M/S
	3-2	Food, Pharma, Logistics		n.a., >1k#, 10k LOC	S, R/n.a. B&R, F	M/S, all IEC, other		M/S
	3-3	Food, Logistics		n.a., 0.5k-1k#, some 10k LOC	S, R/n.a. B&R, F	all IEC, other		-
P4-x (Q1)	4-1	Food, Beverage	SPM and PM	n.a., 40k LOC	S, R/n.a.	All IEC	Partially	-
	4-2			n.a., 40k LOC	S, R/n.a.	M/S, ST, FBD, LD		M/S
	4-3			n.a., 5k LOC	S, R/n.a.	ST, FBD, IL, LD		-

PY-x (QZ): company group Y, company x, questionnaire Z
*PLC supplier: B = Beckhoff; BR = Bosch Rexroth; B&R = Bernecker + Rainer; F = Fanuc, R = Rockwell Automation, S = Siemens, SE = Schneider Electric, OOp = OOpartially
**Programming lan... ...s; M/S –
Matlab/Simulink; C...
Complexity: numbers – subjective complexity measure ranging from 1 to 6, w/ 6 being the most complex, cp. [1]; # – number of Program Organization Units;
LOC – Lines of Code

Extreme positive, negative and variation according to Runeson et al. [8]

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Research Questions

| Research Questions (RQ)	Detailed Research Questions		
Are there **typical maturity values and variations** for the proposed metrics within the same company or within a specific industrial sector? (RQ1)	Are the proposed **metrics applicable** independently from software complexity and size? (RQ1.1)		
	Can companies from within the **same industrial sectors** be compared using only the proposed metrics? (RQ1.2a)		
	Do industrial sectors have **characteristic values**? (RQ1.2aF)		
	Can companies from **different industrial sectors** be compared using only the proposed metrics? (RQ1.2b)		
	Are **maturity variations** among groups within one company or companies from one network detectable by metrics in one main market? (RQ1.3)		
		How large is the **variation among a company's groups / network**? (RQ1.3a)	
		Does **analysis of clusters** deliver additional insights compared to analysis of all criteria? Are there clusters of criteria that correspond to **implemented strategies**? (RQ1.3b)	
		What are **thresholds for acceptable variations**, related to the company's strategy? (RQ1.3c)	
How large is the **gap between** approaches from **research and** the **industrial** state of the art in aPS design? (RQ2)	Do companies use **MDE**? (RQ2.1)		
	Do companies apply **variant design and management**? (RQ2.2)		
		What are typical **reasons** for a lack of variant design? (RQ2.2a)	
		Are **universal modules** used as an approach of variant design in industry? (RQ2.2b)	
		Is **variant management** a major **driver for reusability** of mechatronic modules? (RQ2.2c)	
		Are **product line approaches** applied to cope with variability? (RQ2.2d)	
	Do companies make use of the **IEC 61131-3 OO extension**? (RQ2.3)? What are company's **reasons** to apply OO IEC? (RQ2.3F)		

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Typical maturity values and variations within the same company or within a specific industrial sector? (RQ1)

Are the proposed **metrics applicable** independently from software complexity and size? (RQ1.1)

Yes

Can companies from **different industrial sectors** be compared using only the proposed metrics? (RQ1.2b)

Yes
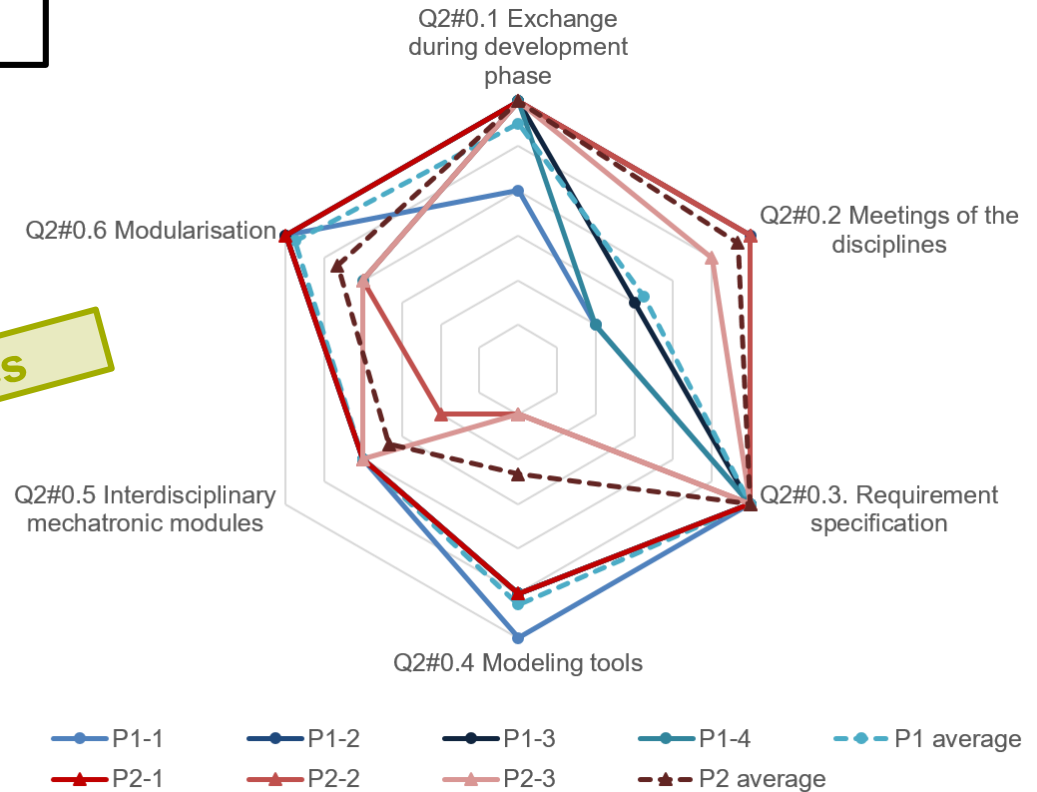
different industrial sector and scale (Q2)

Typical maturity values and variations within the same company or within a specific industrial sector? (RQ1)

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Are **maturity variations** among groups within one company or companies from one network detectable by metrics in one main market? (RQ1.3)

Partially

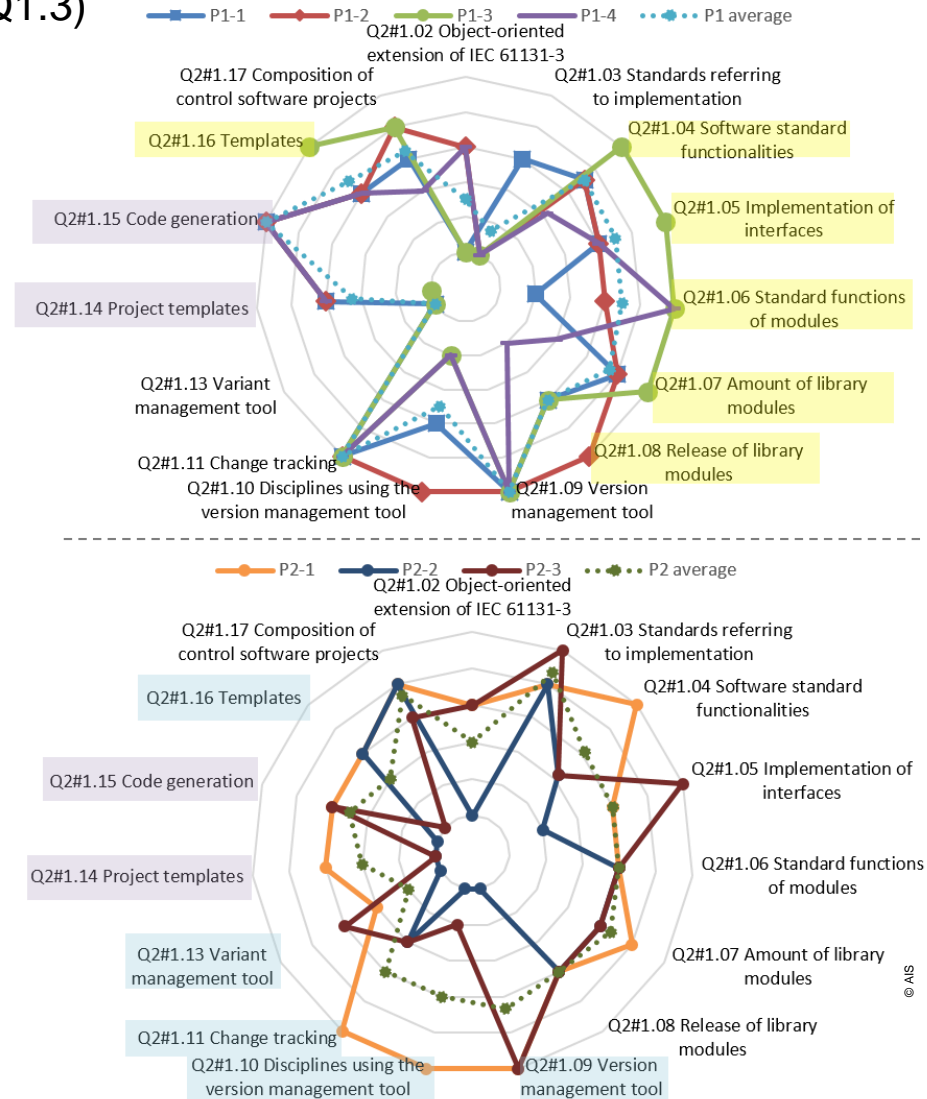How large is the **variation among a company's groups / network**? (RQ1.3a)

Does **analysis of clusters** deliver additional insights compared to analysis of all criteria? Are there clusters of criteria that correspond to **implemented strategies**? (RQ1.3b)

Yes

What are **thresholds for acceptable variations**, related to the company's strategy? (RQ1.3c)

33%

Typical maturity values and variations within the same company or within a specific industrial sector? (RQ1)
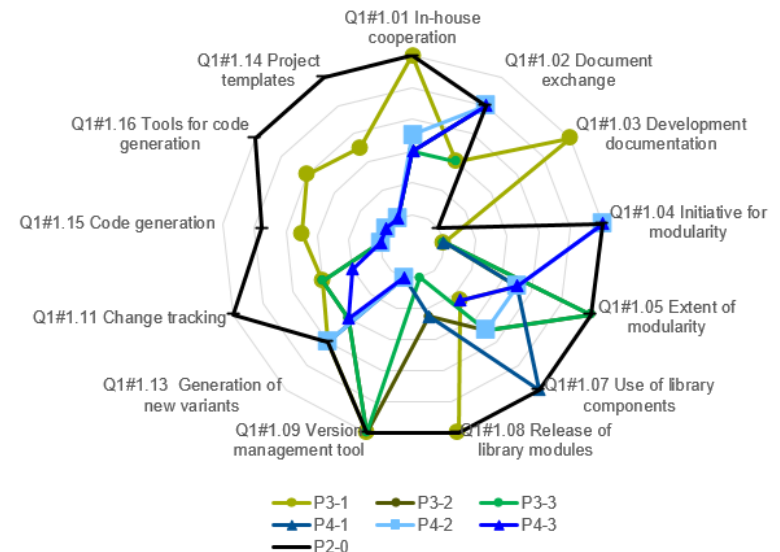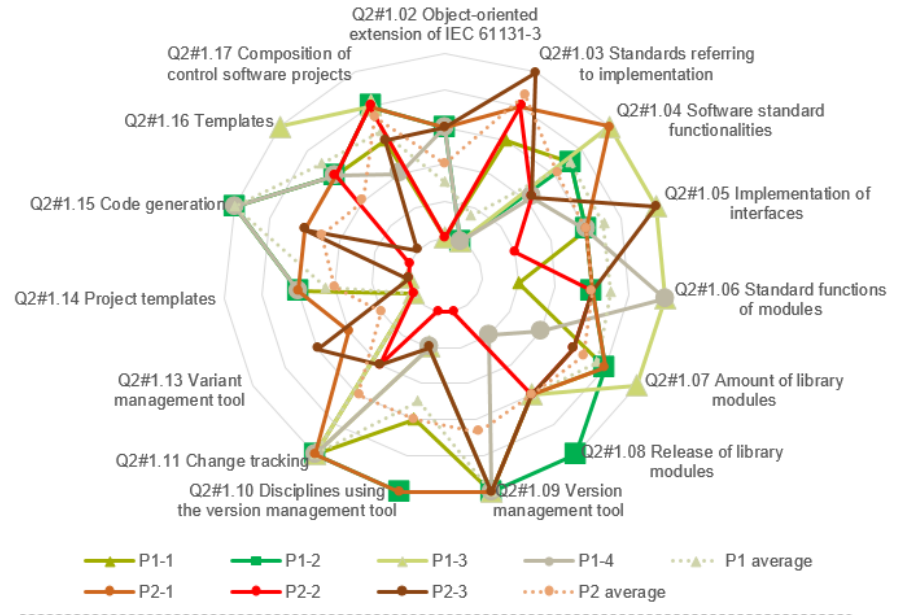
Yes

Can companies from within the **same industrial sectors** be compared using only the proposed metrics? (RQ1.2a)

P3 and P4 operate in the same industrial sector

No

Do industrial sectors have **characteristic values**? (RQ1.2aF)

Typical maturity values and variations within the same company or within a specific industrial sector? (RQ1)
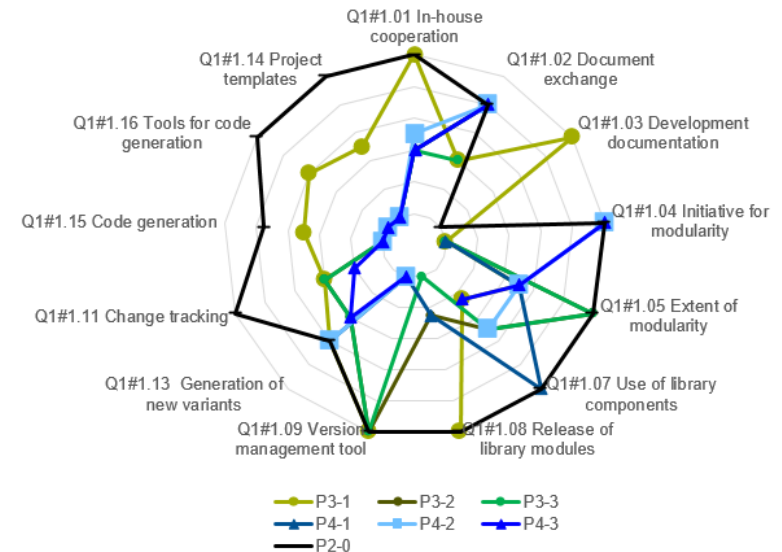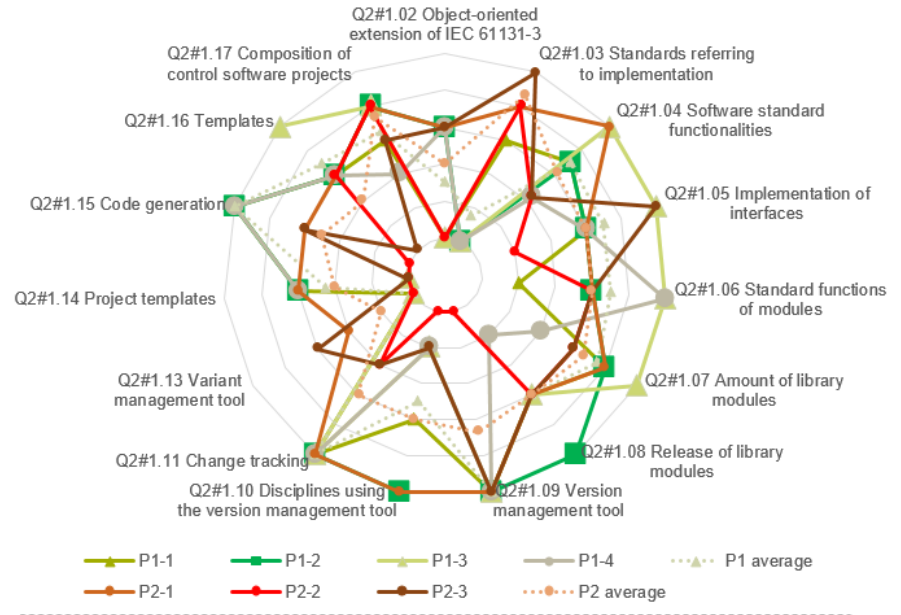
Yes

Can companies from within the **same industrial sectors** be compared using only the proposed metrics? (RQ1.2a)

P3 and P4 operate in the same industrial sector

No

Do industrial sectors have **characteristic values**? (RQ1.2aF)

Gap between academia and industry in aPS design (RQ2)

Do companies use **MDE**?
(RQ2.1)

Yes

12% of PLC and 8% of HMI code
is generated from models like UML
and Matlab/Simulink

Do companies make use of
the **IEC 61131-3 OO
extension**? (RQ2.3)?
What are company's
reasons to apply OO IEC?
(RQ2.3F)

Partially

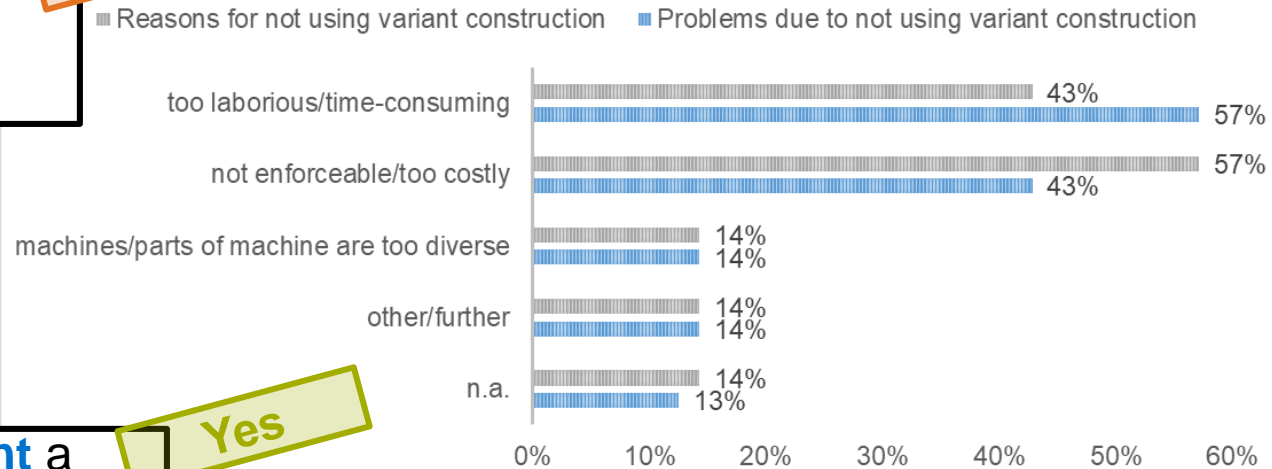Yes, Q2: 42%; Q3: 33%
Reasons: code comprehensible,
quality, time/cost savings, tools

Do companies apply **variant
design and management**?
(RQ2.2)

Yes

Q2: 42% no usage
Q3: 25% usage, 52% partial usage, 10% no usage

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Gap between academia and industry in aPS design (RQ2)

What are typical **reasons** for a lack of variant design? (RQ2.2a)

No

Is **variant management** a major **driver for reusability** of mechatronic modules? (RQ2.2c)

Yes

Are **universal modules** used as an approach of variant design in industry? (RQ2.2b)

Yes

Are **product line approaches** applied to cope with variability? (RQ2.2d)

No

	Reasons for not using variant construction	Problems due to not using variant construction
too laborious/time-consuming	43%	57%
not enforceable/too costly	57%	43%
machines/parts of machine are too diverse	14%	14%
other/further	14%	14%
n.a.	14%	13%

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Overview of Findings

Research Questions (RQ)	Detailed Research Questions	Evaluation	Validity
Are there **typical maturity values and variations** for the proposed metrics within the same company or within a specific industrial sector? (RQ1)	Are the proposed **metrics applicable** independently from software complexity and size? (RQ1.1)	🟢	🟢
	Can companies from within the **same industrial sectors** be compared using only the proposed metrics? (RQ1.2a)	🟢	🟢
	Do industrial sectors have **characteristic values**? (RQ1.2aF)	🔴	🟡
	Can companies from **different industrial sectors** be compared using only the proposed metrics? (RQ1.2b)	🟢	🟢
	Are **maturity variations** among groups within one company or companies from one network detectable by metrics in one main market? (RQ1.3)	🟢	🟢
	How large is the **variation among a company's groups / network**? (RQ1.3a)	🟡	🟢
	Does **analysis of clusters** deliver additional insights compared to analysis of all criteria? Are there clusters of criteria that correspond to **implemented strategies**? (RQ1.3b)	🟢	🟢
	What are **thresholds for acceptable variations**, related to the company's strategy? (RQ1.3c)	🟢	🟢
How large is the **gap between** approaches from **research and** the **industrial** state of the art in aPS design? (RQ2)	Do companies use **MDE**? (RQ2.1)	🟢	🟢
	Do companies apply **variant design and management**? (RQ2.2)	🟢	🟢
	What are typical **reasons** for a lack of variant design? (RQ2.2a)	🔴	🟢
	Are **universal modules** used as an approach of variant design in industry? (RQ2.2b)	🟢	🟢
	Is **variant management** a major **driver for reusability** of mechatronic modules? (RQ2.2c)	🟢	🟢
	Are **product line approaches** applied to cope with variability? (RQ2.2d)	🔴	🟡
	Do companies make use of the **IEC 61131-3 OO extension**? (RQ2.3)? What are company's **reasons** to apply OO IEC? (RQ2.3F)	🟡	🟢

Evaluation / validity is 🟢 = high 🟡 = medium 🔴 = low

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Conclusion

SWMAT4aPS$_{i/m}$ showed

- typical maturity values and variations for the proposed metrics within the same company or within specific industrial sectors for some selected companies (RQ1)
- a huge gap between research results and state of the art in industry regarding Model Driven Engineering, Variant Design as well as Object Oriented PLC programming (RQ2)
- → Get industry to the level academia already is at!

Outlook

Our group is continuing this kind of comparison between academia and industry

→ Currently working on fourth questionnaire

- Refine unclear results
- Internationality
- More companies
- Focus on MDE as well as reusability, especially variant and version management

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Thank you for your attention!

[1] B. Vogel-Heuser, S. Feldmann, J. Folmer, J. Ladiges, A. Fay, S. Lity, M. Tichy, M. Kowal, I. Schaefer, C. Haubeck, W. Lamersdorf, T. Kehrer, S. Getir, M. Ulbrich, V. Klebanov and B. Beckert, "Selected challenges of software evolution for automated production systems", *IEEE Int. Conf. on Industrial Informatics*, Cambridge, UK, July 2015, pp. 314-321.

[2] B. Vogel-Heuser, J. Fischer, S. Feldmann, S. Ulewicz, S. Rösch, "Modularity and Architecture of PLC-based Software for Automated Production Systems: An analysis in industrial companies", *Journal of Systems and Software*, vol. 131, pp. 35-62, 2017.

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[4] M. Kowal, S. Ananieva and T. Thüm, "Explaining Anomalies in Feature Models", Pro*ceedings of the 2016 ACM SIGPLAN Int. Conf. on Generative Programming: Concepts and Experiences*, Amsterdam, Netherlands, October 2016, pp. 132-143.

[5] B. Vogel-Heuser, J. Fischer, S. Rösch, S. Feldmann and S., Ulewicz, "Challenges for Maintenance of PLC-Software and Its Related Hardware for Automated Production Systems: Selected Industrial Case Studies", IEEE Int. Conf. on Software Maintenance and Evolution, Bremen, Germany, September 2015, pp. 362-371.

[6] B. Vogel-Heuser and E.-M. Neumann, "Adapting the concept of technical debt to software of automated Production Systems focusing on fault handling, modes of operation, and safety aspects", IFAC World Congress, Toulouse, France, 2017.

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[8] Runeson, P., Höst, M., Rainer, A. and Regnell, B., Case Study Research in Software Engineering: Guidelines and Examples. Wiley, 2012.

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