Modularity and architecture of PLC-based software for automated production Systems: An analysis in industrial companies

1. Introduction and Motivation
2. SWAT4aPS concept
3. SWAT4aPS hypothesis
4. Selected results
5. Overall maturities
6. SWAT4aPS+ and Outlook

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Technical Constraints of aPS and Motivation

Technical constraints of automated Production Systems (aPS):
- Hard real-time requirements, cyclic behavior (1µs – 1s), and proprietary hardware (PLC).
- Online change is mandatory
- Domain specific programming language (IEC 61131-3)

Source: Siemens AG
Source: Bayer AG, Leverkusen

Sequential Function Chart
Ladder Diagram
Function Block Diagram
Structured Text
Instruction List

Development and Design
Commissioning Entire System
Automation 10 -13 Years
Sensors / Actuators 8 -12 Year
Microcontroller 3 - 5 Years
HMI 1.5 Years
Chips 1.5 Years

Operation
Commissioning after Re-Engineering
Automation 10 -13 Years

Life Cycle
20- 50 Years
10 - 15 Years
1.5 Years

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Maschinenwesen
Prof. Dr.-Ing. Birgit Vogel-Heuser | SE 2018 | 09. March 2018
Software Maturity for aPS (SWMAT4aPS)-Benchmark process to identify strengths and weaknesses in software modularity

16 world-leading companies in machine and plant manufacturing including four case studies

Categorization of companies
- library and platform providers (1 and 2)
- machine suppliers (3–14)
- plant suppliers (15–16)
### Research questions and hypotheses

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Related Hypotheses</th>
<th>Proof</th>
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Validation of SWMAT4aPS (RQ1)

H1.1: The questionnaire delivers valid results in accordance with the detailed expert analysis of four selected companies.

H1.2: Platform suppliers reach higher maturity values than machine suppliers than plant manufacturers.

Interdependencies of maturity levels (* mean value)

<table>
<thead>
<tr>
<th>Maturity level</th>
<th>Case study A (8)</th>
<th>Case study B (14)</th>
<th>Case study C1 (5)</th>
<th>Case study C2 (6)</th>
<th>Machine manufacturing companies, mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modularity</td>
<td>0.86</td>
<td>0.75</td>
<td>0.32</td>
<td>0.36</td>
<td>0.50</td>
</tr>
<tr>
<td>Test/Quality assurance</td>
<td>0.63</td>
<td>0.85</td>
<td>0.36</td>
<td>0.28</td>
<td>0.51</td>
</tr>
<tr>
<td>Start-up/Operation Maintenance</td>
<td>0.58</td>
<td>0.95</td>
<td>0.55</td>
<td>0.54</td>
<td>0.58</td>
</tr>
<tr>
<td>Overall</td>
<td>0.77</td>
<td>0.80</td>
<td>0.36</td>
<td>0.37</td>
<td>0.52</td>
</tr>
</tbody>
</table>

Maturity levels of case studies compared to the machine manufacturing companies mean

<Overview of maturity levels of companies>
Most significant weaknesses in software maturity phase do they occur, possible causes / reasons / prerequisites?

H3.3: Due to necessity of on-site changes in plant manufacturing, machine and plant manufacturers follow different release procedures for software libraries.

Release procedure (workflow) of library element in machine (a) vs. plant manufacturing industry (b)
Most significant weaknesses in software maturity phase do they occur, possible causes / reasons / prerequisites?

H3.4: Weaknesses in the tool chain support (mean value machine manufacturing companies) can be identified for selected aspects, e.g. continuous integration, code generation or version management.
Prerequisites of Reuse

H3.5: Appropriate module libraries, release procedure of library components, version management and change tracking are prerequisites for all ways of reuse.

- Correlation analysis of an interaction variable’s impact on two reuse indicators
- Additive interaction variable includes four questions from the questionnaire
  - use of library components
  - release procedure of these library components
  - used version management tool
  - change tracking of versions
- Considered ways of reuse: code generation and configuration

Table I. Correlations with Interaction Variable for Questionnaire Items # 23, # 24, # 26, # 27
Influencing Items # 28 and # 30

<table>
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<tr>
<th>Interaction Variable</th>
<th>(# 28)</th>
<th>(# 30)</th>
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<tr>
<td>interaction variable</td>
<td>1.000</td>
<td>.739**</td>
</tr>
<tr>
<td>(question # 28) code generation from tools</td>
<td>.739**</td>
<td>1.000</td>
</tr>
<tr>
<td>(question # 30) code configuration (templates)</td>
<td>.520*</td>
<td>.846**</td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
Results of Expert Analysis

H4.2: Different approaches for code configuration exist in industry, that can be assigned to different governance levels.

Template-based configuration procedure in case study

Parameter-based configuration procedure in case study D
Prerequisites of Modularity Maturity $M_{MOD}$

H4.4: The better the criteria decomposability, composability, understandability and protection are fulfilled, the higher the governance level the more mature the software architecture level as well as the code graph, and the higher the modularity maturity ($M_{MOD}$).

**Partially true**

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<td><strong>Q</strong> $M_{MOD}$</td>
<td>0.86</td>
<td>0.75</td>
<td>0.32</td>
<td>0.36</td>
<td>-</td>
</tr>
<tr>
<td>Governance level</td>
<td>+ (L1 *)</td>
<td>+ (L3)</td>
<td>- (L0)</td>
<td>- (L0)</td>
<td>+ (L2)</td>
</tr>
<tr>
<td>Decomposability</td>
<td>++</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Composability</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>++</td>
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<tr>
<td>Understandability</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Protection</td>
<td>++</td>
<td>++</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Overall Scores from expert analysis (sum)</td>
<td>8</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>6</td>
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Call graphs generated for the analysis of case study A, B and C

**Frequent cross connecting calls**

**Strict tree structure**
Research questions and hypotheses results

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Current status of software development in industrial practice

SWMAT4aPS+

Evaluation of participants who answered the question „How are your control software projects on average made up?” with > 50% machine-specific code:

<table>
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<th>Description</th>
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<tr>
<td>Usage of IEC 61131-3 IL</td>
<td></td>
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<tr>
<td>Interfaces implemented as data exchange across global variables</td>
<td></td>
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<tr>
<td>Team Foundation Server as Version Management Tool</td>
<td></td>
</tr>
<tr>
<td>Source code hand-over to the customer</td>
<td></td>
</tr>
<tr>
<td>n-axis-positioning rated as critical application</td>
<td></td>
</tr>
<tr>
<td>Degree of modularization</td>
<td></td>
</tr>
<tr>
<td>Standards for the implementation of software projects</td>
<td></td>
</tr>
<tr>
<td>Amount of library blocks</td>
<td></td>
</tr>
<tr>
<td>Release process of library blocks</td>
<td></td>
</tr>
<tr>
<td>Disciplines using version management tool</td>
<td></td>
</tr>
<tr>
<td>Usage of a variant mgm. tool</td>
<td></td>
</tr>
<tr>
<td>Usage of automated configuration based on templates</td>
<td></td>
</tr>
<tr>
<td>Usage of templates</td>
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Diagram showing various software development aspects such as in-house cooperation, document exchange, development documentation, and initiative for modularity. The diagram also highlights metrics like code generation from tools, change tracking of versions, and version management tool usage.
SWMAT4aPS-Benchmark process to identify strengths and weaknesses in software modularity

- SWMAT4aPSi/m includes Technical Debt and more details on electrical engineering
- SWMAT4aPSi/m with 79 participants is currently being evaluated
- Outlook: International questionnaire
Thank you for your attention!

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Questions of the first questionnaire

General descriptive information (not included in maturity calculation) besides #14 for complexity

- How many engineers and technicians are involved in the development projects?
- How many engineers and technicians work on-site?
- How many programmers are employed in the IT department?
- What number of start-up personnel is employed in the department?
- How many programmers are on-site (at customer’s premises)?
- How many employees are involved in on-site start-up (at customer’s premises)?
- How many programmers are there per application/machine?
- How many start-up employees are there per application/machine?
- Number of CPUs per machine/plant?
- Are these CPUs PC-based?
- What is the scale of the main applications created in your company?
- What is the scope of an application: lines of code?
- What is the scope of an application: number of components?
- Measure for complexity calculated as 0.5 (CPUs + programmer)
Questions of the first questionnaire

Sub items included in modularity maturity calculation ($M_{MOD}$)

- How is the in-house cooperation arranged?
- Which documents are exchanged during a development project?
- How is the development project documented?
- Who started the initiative to use modularization?
- What is modularized?
- Is continuous integration used?
- If yes, what is the tool chain you use?
- What programming languages are used in your company?
- How often are library components used?
- Please briefly describe the release procedure of library components.
- How is the decision to form new variants made?
- Is your company using a tool for version management?
- How are changes for versions in your company tracked?
- How often is code generation from EPLAN or other engineering tools applied?
- Which tools/models are used for code generation in your company?
- Are projects configured automatically from libraries based on templates?
Questions of the first questionnaire

Sub items included in quality and testing maturity calculation ($M_{\text{TEST}}$)
- Are there any quality gates before adding a new library component?
- What quality assurance measures are used in your company?
- What scenarios are tested or what requirements have to be met by the created tests?
- How is the software tested?
- Are simulations used for testing?

Sub items included in start-up, operation and maintenance maturity calculation ($M_{\text{OP}}$)
- Is the start-up of the machine/plant done on-site by the designer/programmer?
- How is the delivery to the customer conducted?
- How are updates installed?
Does the service department know the current customer’s software status on-site?

Manually evaluated questions from the questionnaire (not included in company profile lines because of insufficient answers)
- How long does a typical start-up process take?
- How are new elements added to libraries? – related additional text to #24
- Please describe the release procedure of a library element (from implementation/programming of the element to its library integration) – related additional text to #24
- By whom is the start-up of the machine/plant done on-site otherwise?
- On which level of the software do you use which programming language?
- Which are the most critical technical tasks to be automatically controlled in your applications?
Towards Industrie 4.0

- Software engineering for automated production systems (aPS) seems to be lagging behind classical software engineering
- The changes towards Industrie 4.0 require the software to be more maintainable over decades for thousands of machine and plant variants
- Reusability and variants & version manageability are key factors for efficient development for multi and frequent customization
- Manage and identify the view on software modularity
  - Industrial companies from automated production systems (machine and plant manufacturing)
- A **diagnosis tool** or **process** is needed for detecting **weaknesses** in **software engineering** or workflow characteristics