Chapter 15
Workflow Validation Framework in Collaborative Engineering Environments

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ABSTRACT
Automation systems like power plants or industrial production plants usually involve heterogeneous engineering domains, e.g., mechanical, electrical, and software engineering, which are required to work together to deliver good products and/or services to the customers. However, the heterogeneity of workflows used in different engineering domains makes it hard for project managers to integrate and validate such workflows. A workflow modification language can be used to define the workflows and their modifications; however, further formalization is needed to integrate the workflows. The authors of this chapter propose to extend the Engineering Service Bus (EngSB) framework with a mechanism to integrate and validate heterogeneous workflows from different engineering fields and to link connections between different types of signals in broader sense, including process interfaces, electrical signals, and software I/O variables. For evaluation, they perform a feasibility study on a signal change management use case of an industry partner in the hydro power plant engineering domain. Major results show that the framework can support workflow validation and improve the observability of heterogeneous workflows in collaborative engineering environments.

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INTRODUCTION

Complex automation systems, like power plants or industrial production plants, involve different kinds of engineering fields, e.g., mechanical, electrical, and software engineering, which are required to work together to produce high quality products and/or services. However in collaborative systems, each stakeholder typically works separately in his/her workplace, defining and using his/her own workflow to solve specific tasks. The interactions between different stakeholders are coordinated and monitored by project managers, who have the responsibility to monitor the project progress and take actions or decisions based on the current project status, e.g., adding more personnel or change/improve the overall engineering process.

To be able to monitor the project progress, project managers require an integrated overview of the different workflows used by heterogeneous project stakeholders, such as that project managers can monitor interactions between engineers and that they can validate the designed workflows compared to the actual engineering processes.

The major challenges here are: (a) how to oversee heterogeneous workflows from different stakeholders to support an overview of the project progress and, (b) how to validate the designed workflow model with the actual engineering processes.

Several workflow validation approaches have been introduced, for example by Raedts et al. (Raedts, I. et al., 2007), who propose a workflow validation approach for homogeneous and centralized systems. However, heterogeneous notations usually used to represent the workflows (e.g., flowchart, petri net, BPMN notation) make the validation across different workflows in the collaborative systems hard.

For managing workflow validation in collaborative systems, we propose to extend the Engineering Service Bus (EngSB) framework (Biffl, S., Schatten, A., & Zoitl, A., 2009a) with a process analysis approach. The EngSB is an approach to bridge technical and semantic gaps between engineering models and tools for quality and process improvements of Software Engineering (SE) and other engineering disciplines that interact with SE. The EngSB is based on proven concepts of the Enterprise Service Bus (ESB) (Chappell, D., 2004) approach situated in the business IT context which are adapted to address the needs of software & systems engineering (Biffl, S. & Schatten, A., 2009). By extending the EngSB with a process analysis approach, we aim at advantages as (a) heterogeneous and collaborative systems as the nature of an EngSB context, (b) semantic and technical integration approaches to overcome heterogeneity of collaborative systems, and (c) a process analysis approach to support project monitoring and quality assurance of collaborative systems.

We use the Process Mining1 (ProM) tool for validating the integrated workflow model with heterogeneous event logs from different engineering fields. We evaluate our proposed approach by implementing the workflow integration and validation method to an industrial use case in the hydro power plant engineering domain, to show the feasibility of the approach for distributed information systems. We compare the efforts required by project managers to integrate and validate the heterogeneous workflows between using a primarily manual approach and using our approach. Major results show that our workflow integration and validation approach can support the work of project managers in monitoring and comparing the designed workflow model and running processes in heterogeneous engineering environments.

The remainder of this chapter is structured as follows. Section 2 presents related work on heterogeneous engineering environments and workflow integration and validation approaches. Section 3 identifies the research questions. Section 4 describes the use case and the solution approach. Section 5 presents a snapshot of a hydro
power plant engineering project as a prototypic implementation for workflows integration and validation. Finally, section 6 concludes and identifies future work.

RELATED WORK

This section summarizes background information on automation systems engineering, heterogeneous engineering environments, and the basic concepts of the proposed workflow validation approach.

Automation Systems Engineering

Current automation systems, e.g., complex industrial plants for manufacturing (Biffl, S., Sunindyo, W. D., & Moser, T., 2009b) or power plants (Schindele, A., 2009) involve distributed software to control systems behavior. Software engineering depends on specification data and plans from a wide range of engineering aspects in the whole engineering process, e.g., process planning, mechanical, and electrical engineering artifacts, or physical plan design. This expert knowledge is represented in domain specific terminologies, standards, methods, process, models, tools, and people. Weak semantic integration of expert knowledge across domain boundaries of engineering aspects and weak technical integration of tools within an engineering environment make late changes in the engineering process inefficient, risky, and error-prone.

Other risks originate from the size and complexity of plants and type of projects (Schindele, A., 2009), e.g., customized and large power plants designed according to modernization projects of existing power plants (i.e., extension and maintenance) and individual customer needs (i.e., individual customer-specific solutions). The technical plan documentation often differs from the real solution at the plan site because of last-minute on-site modifications (e.g., during commissioning and/or construction) with limited documentation of changes. Consequently, there is a shortage of feedback of the “as-built” documentation at the plant site to the engineering documentation at the engineering site. Thus, changes are risky (testing of changes), time consuming (research of as-built documentation), and error-prone because of a highly manual activity, e.g., synchronizing engineering documents across disciplines.

Assuming that semantic and technical gaps between different engineering teams can lead to a shortcoming of quality-assured artifacts and inefficient change management approaches across engineering domains (Schäfer, W. & Wehrheim, H., 2007), a major challenge is to address the gap between heterogeneous disciplines on a semantic and technical level to enable data collection and efficient change management for project control and monitoring during development, commissioning, and maintenance. In this chapter, automation systems engineering is the main context of the workflow integration and validation approach.

Heterogeneous Engineering Environments

Research on heterogeneous engineering environments is quite new, while demands on the usage of software as a part of complex systems together with other engineering domains are inevitable (Biffl, S. & Schatten, A., 2009). There are several approaches for technical integration of component-based industrial automation systems. However only little work is available regarding the effective and efficient integration of engineering tools and systems along heterogeneous engineering processes.

Biffl et al. (Biffl, S. & Schatten, A., 2009) propose the “Engineering Service Bus” (EngSB) to bridge technical and semantic gaps between engineering processes, models, and tools for quality and process improvements in software and systems engineering. The EngSB applies proven concepts of the “Enterprise Service Bus”
from a business IT context to automation systems engineering. The major benefits of the EngSB (see the Open Source prototype implementation OpenEngSB) for heterogeneous engineering environments are as follows. (a) simple aggregation of components and services according to the project needs based on a common abstract infrastructure for communication between tools and systems, (b) improved coordination between tools that were not designed to cooperate by access to data and relevant changes in other tools, (c) legal recording and systematic closing of open loops in engineering team processes. However, further configuration and administration like validation and verification of process models need to be investigated, since the EngSB is only a middleware layer concept and does not provide additional advanced applications out of the box. In this paper, we propose to extend the EngSB approach to include a workflow integration and validation approach.

Workflow Validation

Several works on workflow validation were performed, e.g. by Cook and Wolf (Cook, J. E. & Wolf, A. L., 1999). They suggest for a process validation method based on techniques for detecting and characterizing between a formal model of a process and the actual execution of the process. These techniques are neutral with respect to the correctness of the model and the correctness of the execution. However, this work is more focused on single engineering systems. We need to expand this approach, so that it can handle different processes in heterogeneous engineering environments.

Sadiq et al. (Sadiq, S., Orlowska, M., Sadiq, W., & Foulger, C., 2004) propose a data flow and validation approach to address important issues in workflow modeling and specification. They identify and justify the importance of data modeling in workflow specification and verification methods. Their contribution includes an illustration and definition of several potential data flow problems that, if not detected prior to workflow deployment, may prevent the process from context execution, may execute the process using inconsistent data or even lead to process suspension. However, the focus of their validation approach is more based on data validation, rather than on process validation of the workflow model. But in the context of this chapter, the workflow also consists of processes that are required to be analyzed and validated.

Rozinat et al. (Rozinat, A., de Medeiros, A., Günther, C., Weijters, A., & van der Aalst, W., 2008) motivate the need for such a workflow validation mechanism and elements of an evaluation framework that is intended to enable end users to evaluate the validity of their process mining results; and process mining researchers to compare the performance of their algorithms. They focus on providing the means for a comparison of algorithms that discover the control-flow perspective of a process and on validation techniques for these process discovery algorithms. This work supports our work with the vision of validating workflow models in distributed engineering environments. However, more details on applying the common evaluation framework are still needed to be generalized in our context. Our study on several workflow validation approaches leads us to propose our workflow validation approach.

RESEARCH QUESTIONS

Heterogeneous workflow management in distributed engineering environments requires several elements to be considered, namely (a) the ability to deal with heterogeneous workflow notations, e.g., flowchart, petri nets or BPMN, (b) the ability to deal with different goals, purposes and understanding of the workflow design from different types of stakeholders, and (c) the ability to evaluate and validate workflow models with the real process steps running on the systems. Based on these requirements, we identify the following two major research questions.
**RQ.1: How to integrate heterogeneous workflows.** Heterogeneous engineers from different engineering fields, e.g., mechanical, electrical and software engineering, may have different workflows to manage their work process in a specific field, while project managers need to know the big picture of the whole workflows under their supervision to be able to monitor and control the status of running projects of the systems. Hence, the integration of heterogeneous workflows is an important step to be able to manage heterogeneous workflows in distributed engineering environments. However, this integration is hard due to the complexity of workflow elements that need to be integrated. Current approaches use direct mapping from one workflow to other workflow to create a new workflow that contains information from both workflows. The limitation of this approach is that we have to replicate the efforts each time we want to integrate a new workflow to the old one. We propose a Virtual Common Data Model (VCDM) (Moser, T., Biffl, S., Sunindyo, W. D., & Winkler, D., 2010a) which does not store the information of the workflows physically, but virtually, making the integration of new workflow with old ones more flexible. We discuss further about the VCDM in the use case and solution approach section.

**RQ.2: How to validate the integrated workflows with the engineering processes.** Validation of workflow models with running engineering processes is a key issue to assess the quality of systems. Project managers want to be able to validate the integrated workflows with engineering processes from different engineering fields, which are usually kept in event logs. An event contains information from a process event that is useful for further analysis, for example the event id, the event type, the event timestamp, the event originator, and other data. Event logs consist of sequences of events from the start to the end of the workflows. The patterns of how the events following the workflow can be analyzed to know the behaviour of the systems comparing to the designed workflow. The results of the validation can be a justification for project managers to improve the engineering processes of systems.

**USE CASE AND SOLUTION APPROACH**

This section presents: (a) the heterogeneous workflows in hydro power plant engineering as our use case for distributed engineering environments, (b) the framework for integrating and validating heterogeneous workflows from different engineering fields as our proposition of the solution approach to the research questions. The integration process of heterogeneous workflows (RQ.1) and the validation process of the integrated workflows (RQ.2) are parts of the framework.

**A Power Plant Workflow Management System**

A power plant system, as a case of distributed engineering environments, consists of heterogeneous workflows that are controlled by different stakeholders. One type of such workflows could be a signal change management process, as described by Winkler et al. (Winkler, D., Moser, T., Mordinyi, R., Sunindyo, W. D., & Biffl, S., 2011).

In power plant engineering systems integration, signals (Sunindyo, W. D., Moser, T., Winkler, D., & Biffl, S., 2010b) are considered as common concepts in this domain to link information across different engineering fields. Signals include process interfaces (e.g., wiring and piping), electrical signals (e.g., voltage levels), and software I/O variables. We use signals as a vehicle to link domain-specific data between different engineering disciplines and introduce the application field “signal engineering”.

Important challenges that should be faced in managing signals change across disciplines are
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including (a) make signal handling consistent, (b) integrate signals from heterogeneous data models/tools, and (c) manage versions of signal changes across engineering disciplines (Winkler, D. et al., 2011).

For managing these signal changes, several workflows can be used by different stakeholders according to their perspectives on how to accept/reject the signal change requests from other engineering fields.

Figure 1 shows the common workflow for signal change management in the power plan system which is used by the project manager to illustrate how the signal change should be managed. This figure is drawn using the Business Process Model and Notation (BPMN) and consists of three swim lanes, namely check-in, signal comparison and termination. The proposed signal is checked-in to the system, and then compared to the other signals which are already in the system. If the signal is similar, then no change is needed, while if the signal different from the other signals, then there are several options whether to update the signal, add the signal as a new signal or do not change the signal. All the actions will be notified and reported to the system. This workflow model is one of models that is used by project managers for monitoring signal changes. Other models can be designed by other stakeholders for different purposes, e.g. the engineer could make the workflow model that represents his/her focus on managing the signals by using other notations.

Figure 1. Signal change management workflow

![Workflow Diagram](image-url)
Framework for Integrating and Validating Heterogeneous Workflows

To guide the process of integrating and validating heterogeneous workflows in distributed engineering environments, we propose a framework illustrated in Figure 2. The heterogeneity of the workflows used in distributed engineering environments could come from different stakeholders who participate in the systems (e.g., project managers, mechanical engineers, electrical engineers, software engineers, end users), different notations used (e.g., flowcharts, Petri Nets, BPMN), different formats, different goals and purposes. The framework shows two stakeholders and one project manager as users of the system. We can include more stakeholders to show that our approach can be applied for more stakeholders.

We divide the period of the system into two times, design time and runtime. At design time, the stakeholders can create their own workflow models by using their favorite tools and notations, e.g., BPMN or Petri Net. Those heterogeneous workflows (e.g., from mechanical engineer, electrical engineer, and software engineer) are then integrated using the EngSB approach (Biffl, S. et al., 2009a). The EngSB approach integrates different workflows by using the concept of the so-called Virtual Common Data Model (VCDM) (Moser, T., Biffl, S., Sunindyo, W. D., & Winkler, D., 2010a) that does not store data from each workflow physically but virtually. It becomes a foundation for mapping proprietary tool-specific engineering knowledge and more generic domain-specific engineering knowledge to support transformation between related engineering tools (Sunindyo, W. D. et al., 2010b).

It is called “virtual” since actually there is no need to provide a separate repository to store the common data model. The common data model is a data model that can accommodate all data structures which are used by different stakeholders from multidisciplinary engineering fields. The management of the common data model with respect to different engineering fields is done via a specified mapping mechanism. The mechanism of
the VCDM approach includes 5 steps (Moser, T., Biffl, S., Sunindyo, W. D., & Winkler, D., 2010b).

a. **Extraction of workflow data from each engineering field:** The data elements which are contained in a particular tool need to be extracted in order to be available to the framework. By now, only a few engineering tools provide APIs for accessing the contained data directly; hence we use the export functionality of the tools. Then the exported data is parsed and transformed into an internal format consisting of key-value pairs for each data attribute.

b. **Storage of extracted workflow data into its own model:** The extracted and transformed key-value pairs of workflow data are stored using a Java Content Repository (JCR) implementation. For data storage, a tree structure is used, and additional functionality like roll-back or versioning is provided.

c. **Description of the knowledge for each engineering field’s workflow:** The ontologies of the workflow tool define the engineering-tool-specific, proprietary view on the information exchange (e.g., a list of signals) in an integration scenario. This includes the view on the format of the information and also describes the meaning or the use of the specific view on the existing information.

d. **Description of common domain knowledge:** The domain ontology contains the relevant shared knowledge between stakeholders in distributed engineering environments. The domain ontology is the place to model standardized domain-specific information. The proprietary information of the engineering tools which is defined in the tool ontologies is mapped to the more general information of the domain ontology in order to allow the interoperability with other engineering tools. In contrast to a common data schema, the knowledge stored in the domain ontology is defined on a more general domain level compared to the knowledge stored in the tool ontologies.

e. **Mapping of workflow knowledge to the common domain knowledge:** Each data structure segment in the tool ontology is mapped to one particular corresponding domain concept or domain concept attribute described in the domain ontology. Besides, the granularity of the mapped elements does not need to be the same. This defines the semantic context of the information contained in the segment and allows the detection of semantically similar information produced and consumed by other workflow tools. Furthermore, the format of the information is described, enabling an automated transformation from source to target format. The mapping process can be supported by applying Ontology Alignment methods to provide hints regarding possible mappings (Moser, T. et al., 2010a).

These steps support the information systems interoperability by enabling the stakeholders from different engineering fields to work together in providing engineering process data for workflows integration and validation. During runtime, operators control the running system and capture each event generated by each component of the system. The events later are stored and integrated in event logs. The event logs are the foundation for workflow validation (Sunindyo, W. D., Moser, T., Winkler, D., & Biffl, S., 2010a). Project managers can use the information stored in the event log to validate the workflows that are already integrated in previous steps.

We use ProM, a process mining workbench for model discovery and conformance checking that supports workflow validation based on captured events (van der Aalst, W. M. P., 2005). Workflow validation is useful as justification for project managers in improving the engineering process quality.
PROTOTYPE IMPLEMENTATION

This section presents the scenario and the prototypic implementation of the change management workflow based on real world-data from a project at our industry partner, a hydro power plant system integrator.

Manual Signal Change Management

To show the improvement, that we have done at our industry partner in the hydro power plant systems integration domain, first we show the manual scenario of signal change management that is usually performed between different engineering fields. In this scenario, there are three different engineering fields, namely mechanical engineering (ME), electrical engineering (EE), and software engineering (SE). The aim of this scenario is to have a consistent signal connection between different engineering fields. Usually, prior to the signal change, each engineering field, for example from the mechanical engineering, defines its connections to other engineering fields, for example to electrical engineering and software engineering. These connections are useful for cooperation between different engineering fields, for example some mechanical/physical switches are connected to electrical signals that can be controlled or monitored via software variables.

If one signal in the mechanical engineering is changed, other signals in other engineering fields also should be changed as well, to ensure consistent connections. Figure 3 shows two scenarios on how to deal with and disseminate signal changes from one engineering field (ME) to other engineering fields (EE and SE), the first scenario (a) is when the signal is successfully updated, and the second scenario (b) is when the signal updates are not propagated to other engineering fields.

First, the mechanical engineer (ME) checks in the signal changes in his work place. Then the
ME will compare the signal to EE and SE. If related signals are found, the EE and SE will return the old related signals to the ME, such that the ME can update the relationships from old signals to EE and SE. If the update succeeds, the EE and SE will send acknowledgments to the ME. After the completion of updates, the ME will check out the scenario. If the update failed, the EE and SE reject the update and this also will be sent to the ME. In this case, the update will be rolled-back from the EE and SE before check out.

**Automated Signal Change Management**

Automated signal change management, as illustrated in Figure 4, improves the situation described in the manual scenario, by adding the EngSB as a component to integrate and facilitate signal change management. In this case, the EngSB has a mechanism called VCDM to accommodate the signal matching from one engineering field to other engineering fields.

For example, the signal comparison is done only between the ME and EngSB, since all information from the EE and SE are already kept in the EngSB. So the ME only deals with the EngSB for signal comparison and gets feedback from the EngSB that the old signal has been found. The update process is also simpler, since the ME only has to send the update request to the EngSB and gets a notification whether the update is succeed or failed, so the ME should rollback its signal change. The EngSB has the responsibility to propagate the signal change to the other engineering fields, and sends a notification whether the update succeed or failed.

**Implementation of Workflows into Petri Net Diagram**

In order to validate the heterogeneous workflows of signal change management in hydro power plant engineering, we implement an automated signal change scenario using a Petri Net Diagram, as illustrated in Figure 5. The classical Petri Net is a directed bipartite graph with two node types called places and transitions. The nodes are connected via directed arcs. Connections between two nodes of the same type are not allowed. Places are represented by circles and transitions by rectangles (Murata, T., 1989).

The signal update is started by the ME. He checks in the signal update and sends a signal comparison request to the EngSB. The EngSB receives the signal comparison request, identifies the signal in its VCDM and sends back the old signal to the ME. The ME will send the update request to the EngSB that will be propagated to the EE and SE. After getting replies from the EE and SE via the EngSB, the EE will send his acknowledgement that the signal has been updated or the signal update requests are rejected, in which case he should roll back the signal change in his engineering field.

The workflows implementation using Petri Net diagram well shows the scenario of signal change
management from mechanical engineer to other engineering fields. This could help project managers to control/overview/manage the big picture of signal change management and the interaction between the engineering fields during the signal change processes.

CONCLUSION AND FUTURE WORK

Integration and validation of heterogeneous workflows from different engineering fields are critical issues in collaborative engineering environments, since individual disciplines apply different tools and workflow notations to represent their activities. This heterogeneity hinders efficient collaboration and interaction between various stakeholders, such as mechanical, electrical, and software engineers. In this chapter, we presented a framework to enable different workflows integration and validation.

The EngSB framework is the core of technical and semantic integration to collect engineering process data from different engineering fields. This framework is important to provide means for validating workflows used in collaborative engineering environments. A virtual common data model (VCDM) can support the workflow integration in the EngSB, while process mining tools such as ProM can be used to analyze and validate the results of the workflow integration. However, we still need to perform more empirical studies to justify the benefit of this approach over related approaches.

Future work will include (a) improvement of process quality based on the workflow validation results, (b) applications of other approaches to validate the workflows, (c) an organizational analysis approach to check the sources of change in the workflows.
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REFERENCES


**ADDITIONAL READING**


**KEY TERMS AND DEFINITIONS**

**Automation Systems Engineering:** The development of industrial automated systems like power plants or production plants which involve heterogeneous engineering domains, e.g., mechanical, electrical, and software engineering.

**Collaborative Engineering Environments:** Environments which consist of heterogeneous engineering fields, that enable collaboration among engineering groups, supported by workflows, tools.
and methodologies that allow knowledge sharing and engineering activities in real time, regardless of their locations.

**Engineering Service Bus (EngSB):** A platform that integrates different tools, systems and steps in the software development lifecycle similar to enterprise service bus (ESB) platform but more in the engineering context.

**Process Improvement:** A series of actions taken by a process owner to identify, analyze and improve existing processes within an organization to meet new goals and objectives.

**Process Mining:** A process management technique that allows mine and analyze process data based on collected event logs.

**Process Observation:** An activity to collect information about running process in the systems.

**Signal Change Management:** A process to manage signal changes between different engineering domains.

**Workflow Integration:** A process or activity to integrate some workflows into one workflow.

**Workflow Validation:** A process of determining the degree to which a workflow model and their associated data are accurate representations of the real world from the perspective of the intended use(s).

**ENDNOTES**

1. [http://www.processmining.org](http://www.processmining.org)
2. [http://www.openengsb.org](http://www.openengsb.org)