

Simulation of Multi-Stage Industrial Business Processes Using Metamodelling Building Blocks with ADOxx

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Abstract. This paper introduces Industrial Business Process Management (IBPM) as a novel research direction for information science (IS) based on the European Commission's project GOOD MAN. The project's aim is to establish a knowledge-based, ICT-supported approach for IBPM using system's engineering and optimization techniques realized by hybrid conceptual modelling methods. The contribution of this paper is a novel procedural framework that guides the design and development of such hybrid modelling methods. The framework comprises three abstraction levels: a) abstract metamodel building blocks – to define the abstract modelling language constructs and model processing capabilities required for domain aspects (e.g., in manufacturing: multi-stage, material, information and control flows); b) model & functional building blocks - as concrete modelling structures and analytical functionalities processing the models; and c) execution building blocks - a corresponding modelling and model processing environment implementation to support the modeller during the application. Composition and injection mechanisms on abstract building blocks enable efficient realization of concrete modelling and model processing capabilities by re-using and/or extending existing artefacts. Evaluation is performed by using the metamodelling platform ADOxx for a proof-of-concept implementation of a multi-stage manufacturing process simulation environment.

Keywords. Business Process Management • Simulation • Analysis • Industrial Case • Metamodelling • Method Engineering

1 Introduction

Management of industrial manufacturing environment systems has seen a continuous adaptation and change in the past years as a result of the ongoing evolution in the context of the 4th industrial revolution coined Industry 4.0. Advanced

manufacturing processes, flexible information and communication technologies, and involvement of knowledge workers require for modelling, simulation and forecasting techniques as enablers to contribute to the challenges of the manufacturing industry in the future (European Commission 2013). This paper presents an integrated, tool-supported, knowledge management system that enables the modelling, simulation and analysis of manufacturing systems by utilizing a conceptual modelling method, as defined in (Karagiannis et al. 2016b), enriched with a multi-stage simulation capability. The herewith created conceptual models convert tacit to explicit knowledge and enable knowledge processing (cf. (Cairó Battistutti and Bork 2017)).

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The starting point relates to the observation that Business Process Management (BPM) is perceived as a commodity today. After an evolution from re-engineering and optimization considerations in the 1980s and standardization initiatives thereafter, BPM has now reached the level of an established, industry-independent management standard (Karagiannis and Woitsch 2015). As discussed in Utz and Lee (2017), development efforts along this evolution resulted in a plethora of different process management methods and notations, with BPMN 2.0 (Object Management Group 2011) as the most prominent and widely accepted notation. The standard claims to be an industry-domain independent notation that is understandable by business and technical users alike, therefore bridging the gap of understanding between these two worlds. Looking at past research work and application in the domain, two observations are applicable to the above statement.

Firstly, BPMN 2.0, as the name suggests, is a *notation*, hence neither provides or prescribes analytical processing techniques nor application procedures. The value of the notation in its standard representation lies within the functional capability; models can be transformed from a graphical representation to an executable format in workflow engines. The value of the model is limited to execution and implementation support; verification and validation mechanisms as well as governance and management capabilities are limited and only available through appropriate interpretation and/or mappings during implementation. Rausch et al. (2011) showcase the required transformation on tool level to provide model-value functionality and governance/management structures.

Secondly, the expressiveness of BPMN 2.0 is limited and does not cover all aspects of the manufacturing domain. Work presented by Zor et al. (2011) provides evidence for this observation: either additional elements need to be specified or mappings/interpretations are required to capture the specifics of a production process.

The following chapters aim to overcome these limitations by introducing a hybrid composition of modelling techniques derived from specific

sub-domains in the manufacturing field while using a common meta-modelling platform as an invariant. Modelling languages and algorithms for simulation and analysis, summarized as model processing techniques, are realized on abstract level. This enables their application and usage on concrete syntax level of the model structure. The concrete level elements are custom and relate to the type of the manufacturing system and organization-specific requirements. The simulations do not only show how the manufacturing systems should work, but also serve as a means to elicit system requirements (Kaschek et al. 2008). Consequently, the contribution of this research is a procedural framework that guides the design and development of hybrid composed modelling methods. The framework establishes abstract building blocks as the primary artefact steering the design and development.

The remainder of this paper is structured as follows: Section 2 provides details on the idea of Industrial Business Process Management and a review of related work in the area of metamodelling and model processing techniques. Requirements derived from the Agent Oriented Zero Defect Multi-Stage Manufacturing (GOOD MAN) project are presented in Section 3. The core contribution of this paper follows in Section 4, where a procedural framework based on metamodelling building blocks is introduced, comprising a proof-of-concept implementation using the ADOxx metamodelling platform (ADOxx.org 2018). Finally, concluding remarks point to further research directions in Section 5.

2 Industrial Business Process Management

The framework presented in this paper is introduced in the context of, and evaluated against the requirements from Industrial Business Process Management (IBPM). Looking at literature from research, the term as such has not been defined yet concretely. Therefore, we propose to position it based on a review of past work and on observations of running research and innovation projects

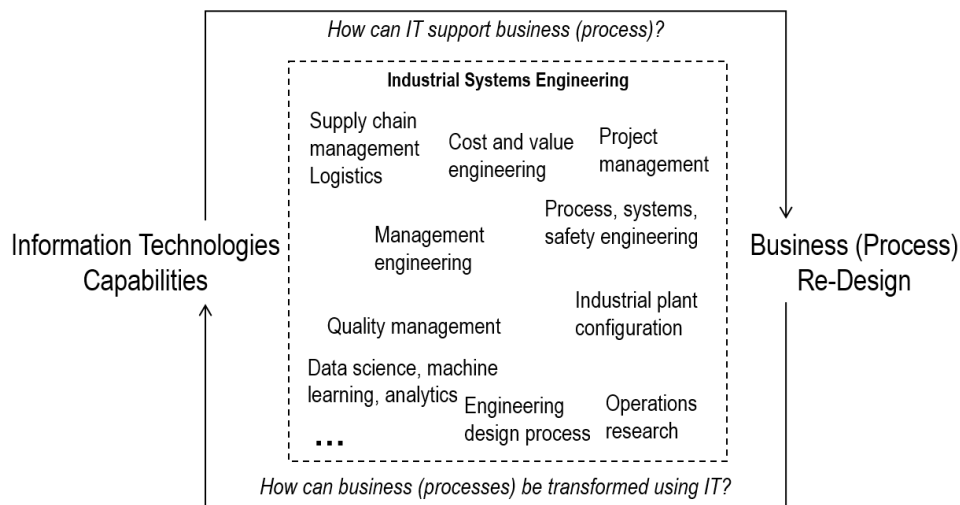


Figure 1: Industrial Engineering Domains (based on (Davenport, Short et al. 1990) and (Maynard and Zandin 2001))

in the domain. These projects are focused on the management of industrial manufacturing systems.

A prominent definition from the past contributes to the argumentation in this paper. Davenport, Short et al. (1990) characterize industrial engineering as a combination of “business process re-design with information technologies capabilities”. The finding in their publication is that “industrial engineers have never fully exploited” the relationships and capabilities of IT. This statement is regarded as being still valid - even stronger nowadays as the evolution in IT is progressing at a rapid pace. Publications related to bridging the well-known business and IT-alignment gap (Hinkelmann et al. 2016; Hrgovcic et al. 2011; Woitsch et al. 2009) underpin the importance of research in this field.

Figure 1 combines the interactions between business and IT with the disciplines in the domain of industrial engineering. The idea of Industrial Business Process Management builds on the findings that no single, general purpose approach is applicable in such a complex domain. Rather, a hybrid composition of different techniques is required. In the following, first steps towards solving this deficit are proposed by focussing on the support for the design and analysis of complex industrial systems. Industrial engineers shall use

an appropriate model-based approach, by utilizing a supporting modelling and model processing environment (Sandkuhl et al. 2018).

3 Multi-Stage Zero-Defect Manufacturing in GOOD MAN

The work performed in the context of the Agent Oriented Zero Defect Multi-Stage Manufacturing (GOOD MAN) project¹ defines an application case for Industrial Business Process Management. As an innovation action funded by the European Commission’s Horizon 2020 Factories of the Future program, the core idea of GOOD MAN is to integrate and combine process and quality control for a multi-stage manufacturing production (Kimura and Terada 1981).

The collaborative project consists of nine partners from four European countries with different competences and experiences: Industrial end-users from the automotive and white ware production industry provide the industrial requirements for the project and perform the demonstration and evaluation in multi-stage production lines with different levels of automation and production rate. Industrial technology experts in the field of advanced IT solutions (big-data and analytics,

¹ GOOD MAN project page [online]: <http://www.goodman-project.eu/>, accessed on January 10, 2018

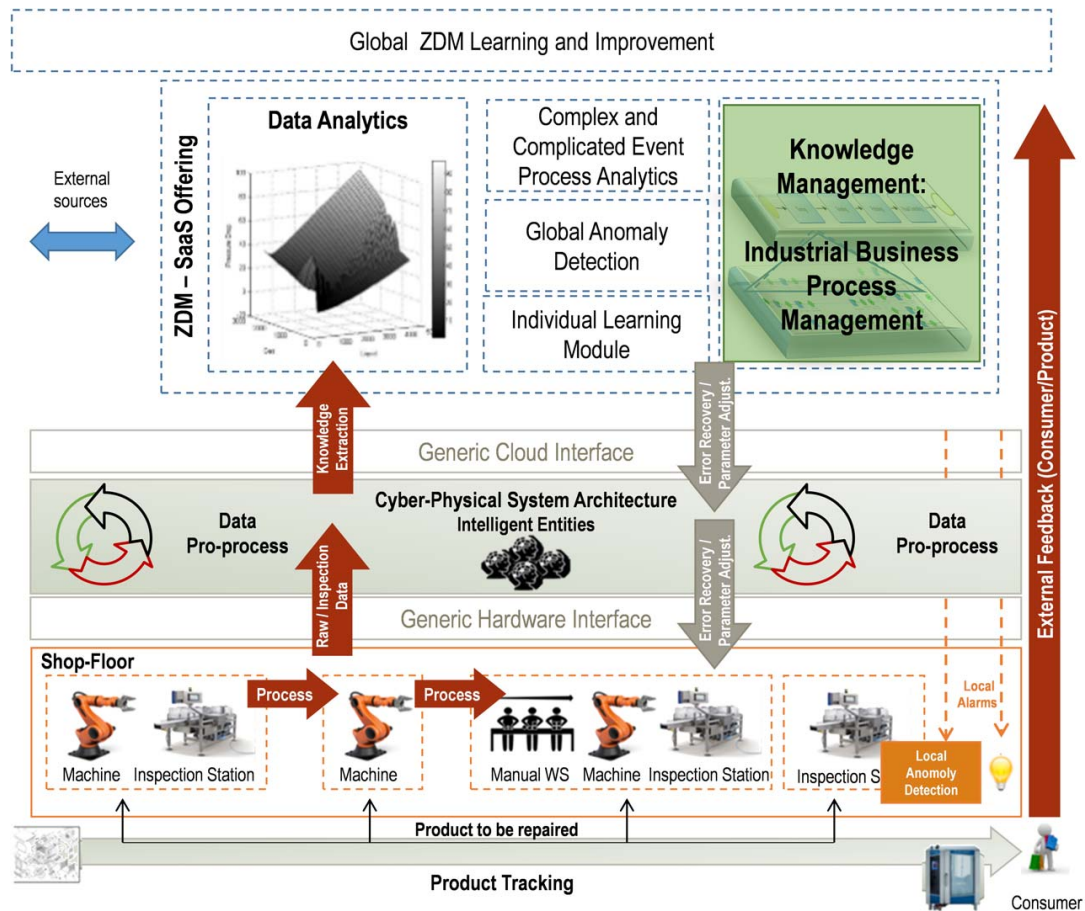


Figure 2: GOOD MAN Conceptual Architecture (adapted from (GOOD MAN Project 2017c))

metamodelling and modelling, and automatic systems on quality control) define and develop the software system as depicted in the conceptual architecture described in Section 3.1 and visualized in Figure 2. The project started on October 2016 and will run for 36 months with a budget of 5 million euro.

3.1 Conceptual Architecture

The core idea of GOOD MAN is to integrate and combine process and quality control for multi-stage manufacturing production processes into a distributed system architecture built as an agent-based Cyber-Physical Systems (CPS), utilizing smart inspection tools and cloud computing (see

Figure 2). Agent technologies, associated to each production stage and product, provide real-time data and defect diagnosis on stage level, inter-stage level, and on global level. All data is stored locally to enable anomaly detection on the edge, and globally to provide complex data processing. The data processing extracts the knowledge and provides it to the Zero Defect Manufacturing Knowledge Management layer.

The Zero Defect Manufacturing (ZDM) strategies as knowledge rules operate on local - directly at the stage - as well as on global system level. Here is where e.g., complex and complicated event process analytics and global anomaly detection is performed. The conceptual models

act as a formalized knowledge base that also contributes, intertwined with the sensor data from the shop floor, toward the identification of defects prior to their occurrence. The utilization of formalized conceptual modelling methods acts as a facilitator by enabling machine processing of the knowledge (Bork and Fill 2014). The ZDM-KM is moreover comprised by an individual learning module that enables an evolutionary learning of past events and the calculation of future events (i.e., defects) at certain stages of the production by inferring live sensor and process data with the existing knowledge base. The specification of the system as a whole is available in (GOOD MAN Project 2017a), further refined as decision rules and strategies in (GOOD MAN Project 2017b).

3.2 Simulation of Multi-Stage Production Processes

From a knowledge management and continuous improvement perspective, one objective of the project is to provide an environment for industrial business process management as defined above that enables the analysis and evaluation of hybrid production designs. Hybrid production processes in this case are understood as flexible, loose-coupled combinations of models with domain-specific views and concepts. These views include elements such as a distinction of material flows, information flows, quality data streams, and monitoring techniques, production stages and stations. As detailed in (Utz and Lee 2017), using BPMN 2.0 in such cases has several limitations and drawbacks: the notation lacks domain-specific elements to express different types of flows (i.e., information, material, machine, quality) and quantify them; and, staging logic is missing including specific attributes (e.g., distance, layout, buffer sizes) to emulate the effectiveness of the scheduling.

To overcome these limitations and provide simulation support on the multiple levels of design, the following requirements have been identified:

Business Process Modelling & Simulation:

The environment should enable the industrial

engineer to model and analyse business processes using the BPMN 2.0 notation. BPMN 2.0 should be applicable for any high-level process design and analysis e.g., interaction with suppliers and consumers, sourcing processes, and management system design.

Block Diagrams Modelling & Simulation:

The detailed production processes should be modelled and analysed using a Block Diagram notation. This notation supports the definition of stages, different flow types, and composition of stations into stages. Thus, employing a higher level of detail and granularity compared to the BPMN 2.0 notation.

Multi-Stage Path Analysis Simulation: Based on discrete event simulation algorithms that enable the analysis of the dynamic behaviour of a system, a path analysis algorithm should be selected that can operate on different concrete implementations of the metamodel and provide results for quantitative facets (times, costs), and paths through multi-stage processes as traces.

4 Applying Metamodelling Building Blocks in GOOD MAN

In the paper at hand, the framework to realize these requirements is presented, that centres on building blocks. These building blocks are established on three abstraction levels: *Approach*, *Concept*, and *Implementation* (see Figure 3). The three abstraction levels comprise a procedural framework towards the design and development of hybrid modelling and model processing environments. The building blocks enable re-use for an arbitrary number of hybrid methods. Application of the framework is discussed in the context of the GOOD MAN project with the requirements as specified in Section 3.

4.1 Approach

On the *approach level*, **abstract metamodel building blocks** are introduced. Each building block on this level couples model constructs with model processing and a description in accordance with the Generic Metamodelling Framework

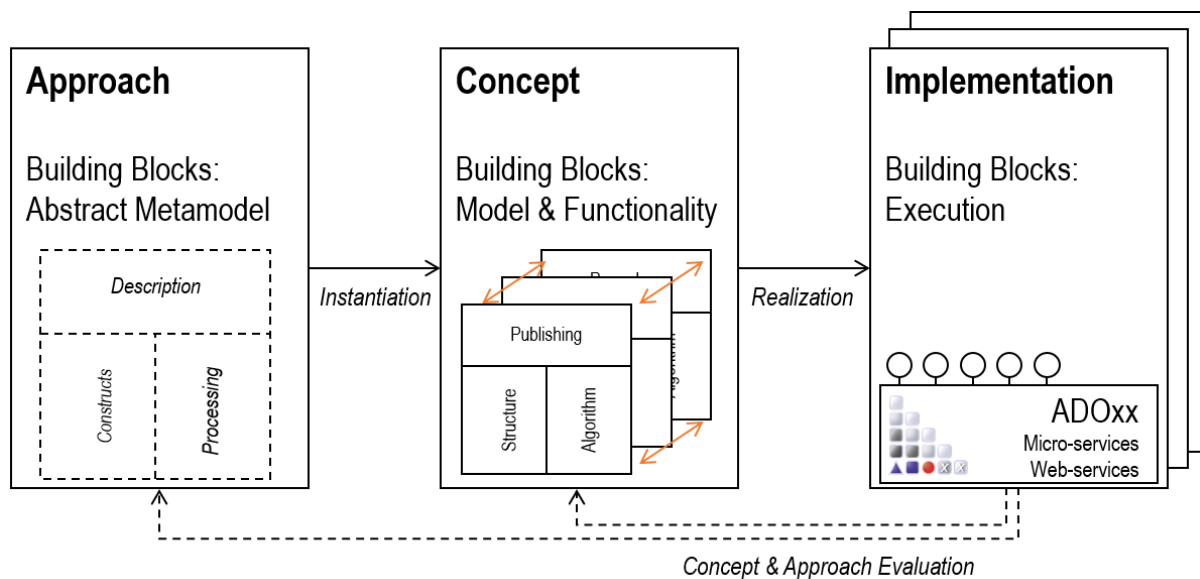


Figure 3: Metamodelling-based Building Block Framework (Utz 2018)

defined by Karagiannis and Kühn (2002). Each abstract metamodel building block consists of model **constructs** as the notation/syntax and semantics of the modelling language; the **description** that utilizes the identification and integration of multiple building blocks by means of establishing a modelling procedure; and processing capabilities supporting the modelling procedure and increasing the value of models. This enables the configuration of building blocks for analysis, simulation, and validation/verification algorithms by instantiation of the behaviour on concrete models (being instances of the building blocks on abstract level). Abstract metamodel building blocks comprise the following aspects:

- a Constructs: the hierarchy, attributes and properties required for processing are defined on an abstract level. The selection of an abstract block defines the operational semantics of the modelling techniques to be realized.
- b Processing: the specification of model processing capabilities, e.g., analysis, simulation and evaluation. The specification stays on an abstract level, utilizing the abstract constructs.

- c Description: the description of the abstract metamodel building block that enables the identification and integration of it in more complex scenarios that span multiple building blocks.

An example for abstract metamodel building blocks is discussed in the following. Figure 4 shows the conceptual architecture and how modelling and model processing functionality is provided to the end-user on a role-based level. The common level to derive functionality from is the metamodelling platform and its generic capabilities. It is assumed that these functionalities are common for any kind of implementation and can be used out-of-the-box for implementation.

On top of this layer, the abstract metamodel building blocks are realized. These blocks consist of the model processing techniques and the corresponding metamodel constructs. An example for such an abstract block in Industrial Business Process Management at GOOD MAN relates to discrete event simulation techniques, used to assess process designs using quantitative facets dynamically, such as cycle times, determining bottle-necks in the design, and resource consumption. The related algorithms operate on model constructs that define abstract flow elements (such as activities

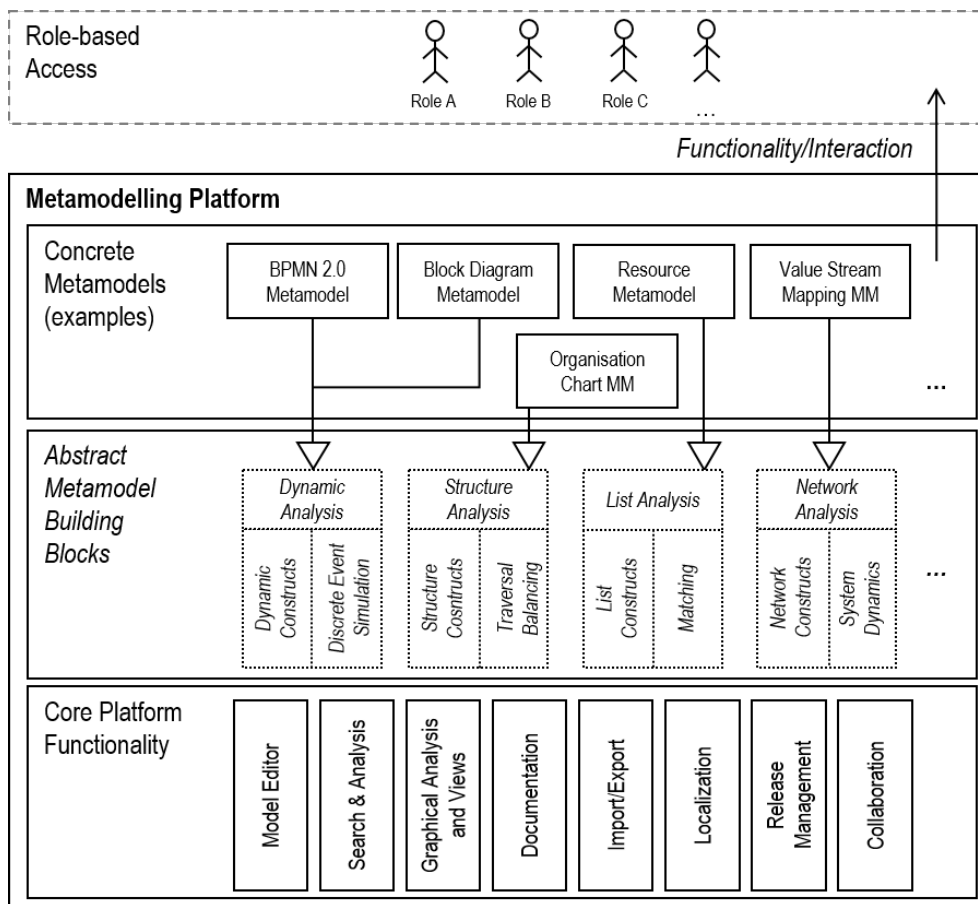


Figure 4: Using Abstract Metamodel Building Blocks to Design Modelling and Model Processing Environments

and tasks), logical control elements (such as start events, end events, exclusive/non-exclusive gateways), substantiated with quantitative information such as times and costs. The model constructs can be connected using an abstract logic flow relation including cardinality rules for verification (e.g., number of incoming and outgoing relations for the abstract elements).

4.2 Concept

The abstract metamodel building blocks introduced in Section 4.1 are instantiated in the second step of the procedural framework, the *Concept* abstraction level, into **model & functional building blocks**. It is here, where multiple building blocks are combined to realize hybrid modelling and model processing environments, addressing specific requirements of the domain. 'Model & functional building blocks' comprise:

- a Structure: the concrete constructs necessary to build an adequate model structure, necessary to create appropriate abstractions of the domain (i. e., models). Existing abstract constructs of multiple metamodel building blocks can be instantiated to realize the necessary concrete structure.
- b Algorithm: the modelling procedure by means of orchestrating the model processing functionality provided by multiple metamodel building blocks. Here is, where the abstract processing capability of metamodel building blocks is applied on concrete constructs.
- c Publishing: making the model & functional building blocks available for their later utilization in the implementation step.

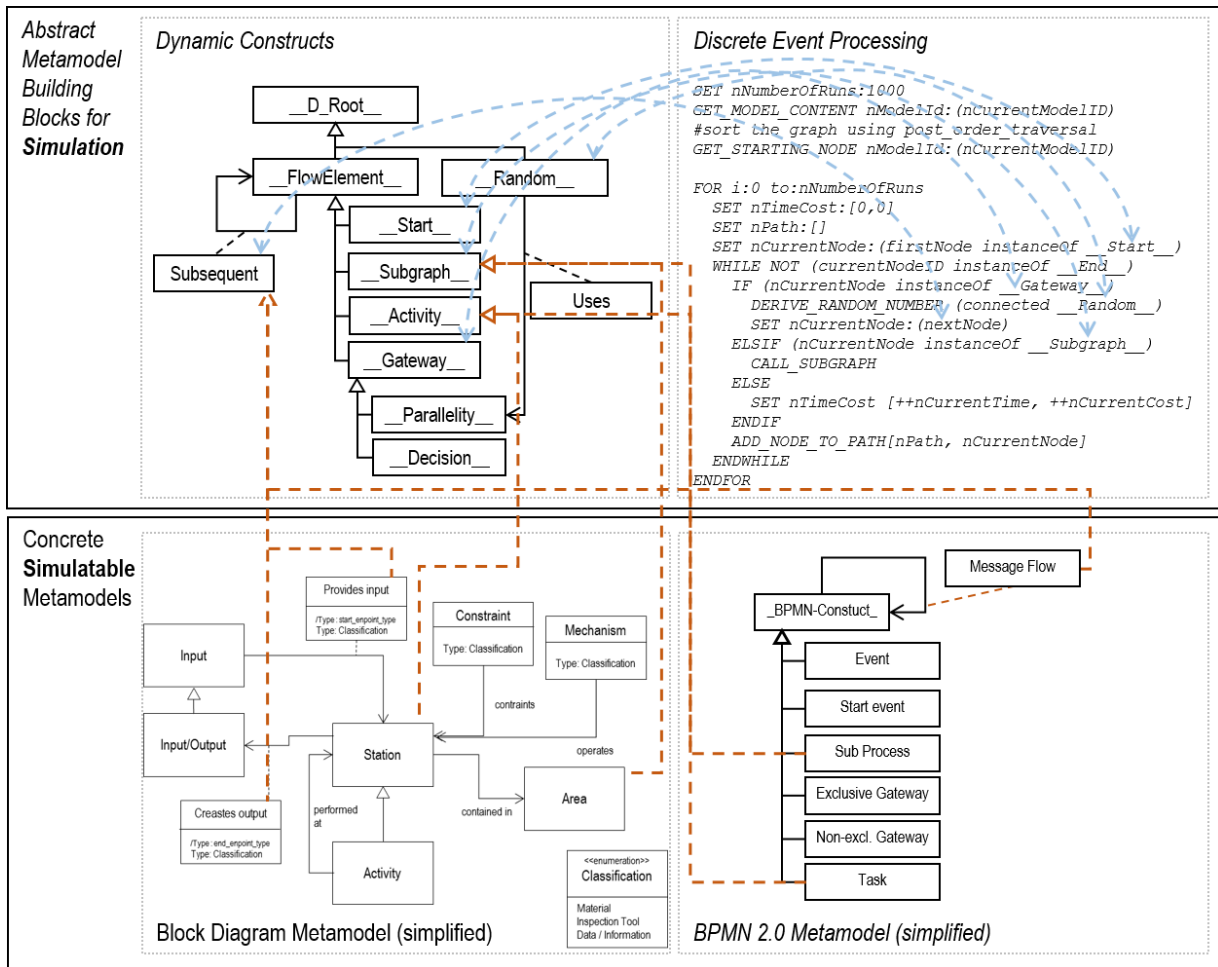


Figure 5: Building Blocks for Graph-based Simulation of Multi-Stage Production Processes

On concept level, the abstract metamodel building blocks are instantiated, hereby providing concrete, domain-specific modelling constructs to be used by the designer. In contrast to starting from scratch, the method engineer and modelling tool developer decide on the abstract structure to derive a concrete implementation from, and identify and implement the concrete model constructs. Model processing capabilities are inherited from the abstract implementation and are directly available. It is assumed that such an approach will allow for an efficient implementation, supporting the personalization and customization of platform capabilities and functionality for specific domains. This enables an agile evolution of modelling methods according to (Karagiannis 2015, 2016) without

re-implementing functionalities for each update cycle from scratch.

The proposed metamodels and mechanisms/algorithms to support the multi-stage simulation of production processes are graphically visualized in Figure 5 as class diagrams linked to a pseudo code specification of the simulation algorithm. Figure 5 shows how the structure provided in the abstract building block is used by the algorithm.

As the selected path analysis algorithm is generic, it can be applied to any kind of directed graph structure, represented with enriched semantics. The generic realization of the simulation algorithm is visualized by the blue horizontal dashed arrows from the discrete event processing specification to the dynamic constructs in Figure 5. Consequently,

all concrete metamodels derived from this abstract structure are also capable of being simulated. This is visualized in Figure 5 by the orange vertical dashed relationships between the block diagram metamodel, the BPMN 2.0 metamodel and the dynamic structure of the abstract building block.

4.3 Proof-Of-Concept Implementation

The 'model & functional building blocks' introduced in Section 4.2 are realized in the third step of the procedural framework, the *Implementation* abstraction level, into **microservice and/or webservice building blocks** that constitute the modelling and model processing environment.

The ADOxx metamodelling platform (ADOxx.org 2018; Efendioglu et al. 2016; Fill and Karagiannis 2013) has been used for the realization of the proof-of-concept. ADOxx uses metamodelling concepts and technologies. It enables the abstract metamodel definition and simulation algorithm and provides a set of platform features out-of-the box without any further implementation need. As an implementation technique, the available extension framework for micro-services has been used.

ADOxx realizes a technical implementation of the metamodel building blocks and fragments that can be dynamically injected into the platform, using a declarative JSON syntax for the structural elements, JavaScript for UI elements, and JavaScript/Java for server side functionality implementation. In this regard, ADOxx acts as an extension and deployment platform. ADOxx supports the efficient composition of hybrid modelling methods by re-using/extending existing implementations. More details on how to combine metamodel fragments can be found in (Živković and Karagiannis 2015). The 'model & functional building blocks' specified in Section 4.2 have been implemented on ADOxx and are provided by means of three micro-services:

1. an abstract metamodel building block consisting of the model structure and the analysis algorithm including result visualisation and mapping;
2. a concrete metamodel building block for Block Diagrams, defining the concrete syntax and notation of the elements used, the diagram container and the user interface elements to trigger the algorithm, and
3. a concrete metamodel building block for BPMN 2.0 in a simplified version, focussing on the core elements, their notation and similar as for 2) the user interaction elements to trigger the simulation algorithm.

The ADOxx micro-services 2) and 3) depend on the abstract implementation in 1). After injection and publishing, the industrial engineer can use the constructs to design the models and trigger the algorithms to evaluate and analyse the models.

Figure 6 shows the user interface of the resulting modelling and model processing environment for multi-stage simulation of industrial business processes. Both concrete metamodels can be used in parallel to define the models, e.g., of a multi-stage oven manufacturing process, and run path analysis algorithms. The figure shows a sample BPMN 2.0 model (top left corner), a sample Block Diagram model (bottom left corner), both for the oven case, and a results window shown after execution of the multi-stage path analysis simulation algorithm (on the right). The generic structure of the building blocks in general, and the simulation algorithm in particular, allow for adaptations and reuse in heterogeneous domains by different modelling languages.

5 Conclusion

Based on related works and requirements from industrial research projects, this paper proposed a procedural framework that specifically addresses the requirements of the industrial domain - a hybrid modelling and model processing method. The article showed how this framework can be used to design and develop a modelling and model processing environment based on abstract metamodelling building blocks. Using a multi-stage oven manufacturing example, the utility of the framework has been shown for Industrial Business Process Management (IBPM).

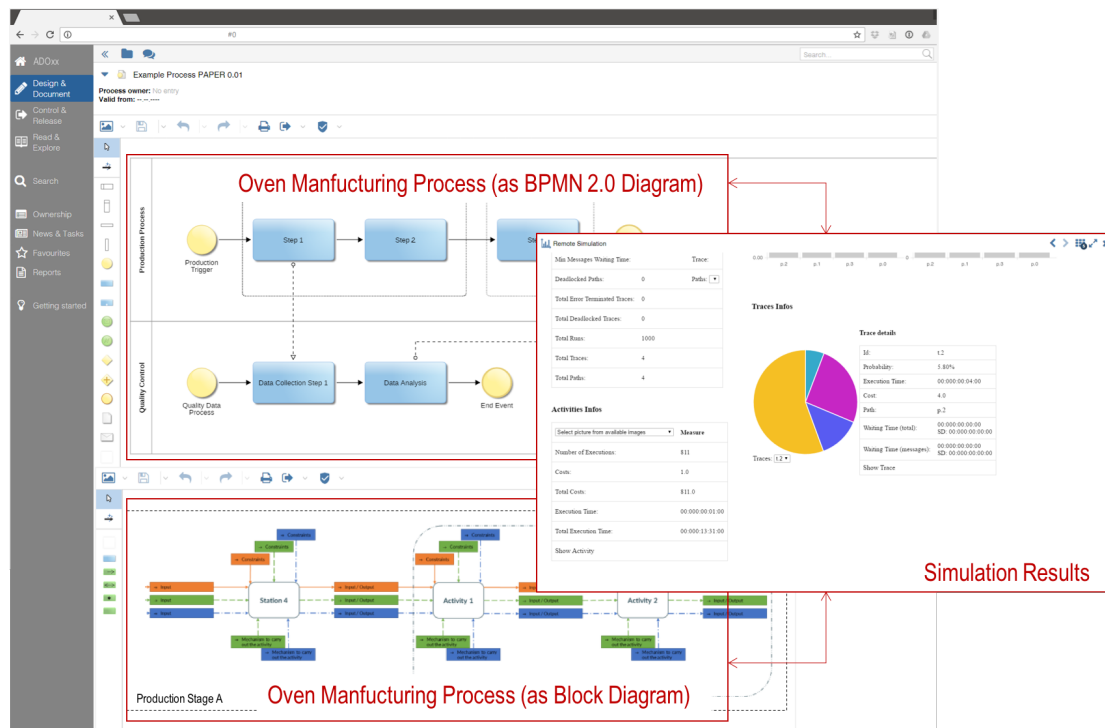


Figure 6: Graph-based Simulation of Multi-Stage Production Processes with the ADOxx-based Prototype

As a proof of concept, the metamodelling building blocks have been implemented on the ADOxx platform. Besides the model editor, the tool comes also with a generic implementation of a multi-stage business process path simulation algorithm that can be applied to any concrete graph-based modelling language. The whole implementation relies on abstract metamodelling building blocks that enable efficient adaptation and injection in other hybrid methods. A consideration for abstract metamodelling building blocks framework relates to their composition according to the requirements of the modelling procedure through cross-referencing concrete level implementations and aligning input/output relations along the line.

The article at hand aims to stress the importance of conducting further research in order to empower the industry to overcome the challenges raised by e. g., the digital transformation, enterprise ecosystems, and Industry 4.0. One modelling language and standard modelling languages are not suitable of capturing all upcoming requirements (cf. Pittl and Bork (2017)). It is therefore

necessary to think about efficient ways of re-using existing functionality and constructs, and ways of combining them, that copes with the increasing complexity of today's industrial world. This paper proposes abstract metamodelling building blocks as one possible solution for the design and development of hybrid modelling methods and supporting environments.

In our future research, we intend to apply the presented proof-of-concept implementation in the context of the project in order to gain feedback on the maturity of our domain-specific elevation of the industry-independent standard BPMN 2.0 towards a hybrid modelling method that covers the requirements of industrial manufacturing processes management. This combination of multiple modelling languages also comes with risks, e.g., with respect to consistency (Awadid and Nurcan 2017; Bork et al. 2015; Karagiannis et al. 2016a), usability (Sabegh and Recker 2017), and intuitive understanding (Michael and Mayr 2017). We will therefore investigate how industrial engineers can apply our approach in practice in order to

revise the requirements and refine the implementation. The gained feedback will likely also trigger changes to the proposed procedural framework, which will contribute to acceptance and adoption in the future.

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