Towards Viewpoint-Oriented Engineering for Industry 4.0

A Standards-Based Approach

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***Abstract*—Digitalised production based on networked, cyber-physical systems is the basis of the fourth industrial revolution ("Industry 4.0"). Yet, the adoption of this technology in practice remains a challenge for many companies. One of the main obstacles is the high complexity of Industry 4.0 applications, whose engineering requires multidisciplinary expertise that is usually fragmented among different stakeholders. This paper proposes a viewpoint-oriented approach for engineering Industry 4.0 applications, aiming to better adapt system models to the various stakeholders and concerns. The approach uses a combination of existing or emerging standards in the areas of systems and software engineering (ISO/IEC/IEEE 42010:2011) and Industry 4.0 (RAMI 4.0, IEC 61131-3). On this basis, the paper elaborates the notion of viewpoints with respect to their modelling and implementation including an industrial use case.**

Keywords—Viewpoints; Systems Engineering; Industry 4.0; RAMI 4.0; ISO/IEC/IEEE 42010:2011

I. Introduction

The term "Industry 4.0" denotes the digitalisation and decentralisation of production operations, and their integration from shop floor to office floor and across company networks [1]. Industry 4.0 aims to provide greater flexibility, enabling the individualisation of products and services for different customers. These new technological possibilities can lead to entirely new business models [2].

Despite the high business potential of Industry 4.0, manufacturing companies are still reluctant in transforming their production systems. One of the major reasons is the lack of multidisciplinary experts able to engineer Industry 4.0 applications that are often very complex [3]. In this paper, an approach is presented to facilitate Industry 4.0 systems engineering, by disentangling the various disciplinary and application-specific perspectives following the general idea of reducing complexity through a separation of concerns [4]. An effect of this "viewpoint-oriented" approach is the possibility of using concurrent engineering where separate views can be created in parallel [5]. Concurrent engineering is generally recommended for developing mechatronic systems [6] including Industry 4.0 systems. The viewpoint-oriented engineering approach proposed in this paper is unique in that it is strongly based on industry standards rather than proprietary solutions. It is currently being elaborated and turned into a software tool within the ongoing research project SICHTEN 4.0. Its expected benefits include:

1. lower cost by lessening the need to involve highly-trained, multidisciplinary experts
2. reduced time to market by enabling the concurrent execution of engineering tasks
3. enhanced interoperability through the use of standards

The paper commences, in Section 2, with a brief overview of related work on viewpoint-based development in software and systems engineering, including the standard ISO/IEC/IEEE 42010:2011. Section 3 presents an overall framework for viewpoint-oriented engineering of Industry 4.0 applications, applying ISO/IEC/IEEE 42010:2011 to the "Reference Architecture Model Industrie 4.0" (RAMI 4.0). Section 4 elaborates viewpoint orientation within the Industry 4.0 domain and relates its key aspects to existing automation standards. Section 5 concludes the paper with an outlook on future research.

II. Background: Viewpoint-Oriented Modelling

A number of researchers [7, 8, 9, 10, 11, 12] have explored the idea of using viewpoints for systems engineering. Their basic assumption is that organising system models according to different viewpoints facilitates the development and understanding of the models by different stakeholders. This is shown to be useful for complex systems engineering projects where multiple stakeholders with different fields of expertise need to collaborate.

Foundational work on viewpoint-oriented modelling has been carried out by Finkelstein et al. [7]. They describe the use of different views by different stakeholders, highlighting the composition of viewpoints and a few common consistency issues between individual viewpoints. They also present the use of viewpoint templates for the design of methods for system development.

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Goldschmidt et al. [8] have described a taxonomy of views, with a focus on their use for defining domain specific modelling languages (DSML). Similarly, Fischer et al. [9] have proposed a framework describing viewpoints and related concepts such as "view", "view type", "meta-model" etc. They have also derived a set of features to be provided by viewpoint-oriented modelling tools. Among the features are support for using pre-defined viewpoints, creating ad-hoc viewpoints, and specifying transformation rules between viewpoints. A comprehensive overview of features of a number of viewpoint-oriented approaches can be found in a recent survey [10].

A viewpoint-oriented modelling method has been developed by Krumeich et al. [11] based on the conceptual framework provided in [9]. The method focuses on the identification of conflicts across different views and the resulting adaptation of models. A prototype has been implemented, using the Eclipse Modeling Framework (EMF), for the viewpoint-oriented modelling of business processes.

The ModelJoin approach [12] includes a domain-specific language (DSL) for the definition of views of a software system. The views can be created automatically based on the user-defined composition of existing views, such as architectural views and performance views. The ModelJoin DSL uses a syntax similar to SQL, and is implemented based on the Ecore meta-model of EMF.

Most of these approaches use their own definitions and meta-models. A standard framework for viewpoints and associated concepts has been provided by the ISO/IEC/IEEE 42010:2011 norm "*Systems and software engineering – Architecture description*". It explicitly distinguishes the notion of a view from the notion of a viewpoint. Specifically, a view is defined as a "work product expressing the architecture of a system from the perspective of specific system concerns". A viewpoint is defined as a "work product establishing the conventions for the construction, interpretation and use of architecture views to frame specific system concerns". The distinction between a view and a viewpoint is likened to the distinction between a map and a legend (that provides the conventions for producing and reading the map).

A viewpoint according to ISO/IEC/IEEE 42010:2011 is associated with a number of elements including:

- Concerns (i.e., the interests of one or more stakeholders of a system)
- Typical stakeholders
- Model kinds (e.g., data flow diagrams, Petri nets, state machines, etc.)
- Correspondence rules (i.e., mappings between model elements across different models/views)
- Operations on views (including methods for creating, interpreting, analysing and implementing views)

To date there has been hardly any application of this standard or other viewpoint-oriented approaches in the context of Industry 4.0 systems. An exception is the Industrial Internet of Things Reference Architecture (IIRA) that explicitly references ISO/IEC/IEEE 42010:2011 in its definition of viewpoints [13]. However, IIRA has a broader scope as it encompasses other domains than just manufacturing, and the idea of viewpoint-oriented engineering has not yet been articulated in this context.

III. A Framework for Viewpoint-Oriented Engineering

The notion of viewpoint-oriented engineering includes a distribution of modelling tasks according to the needs of the application and the available expertise. Stakeholders can create partial models describing their own views of the system. This can be done independently within the bounds of the respective viewpoints, reducing or eliminating the need for a multidisciplinary engineer with expertise spanning several viewpoints. Partial models are integrated into a coherent system model, using model-based development techniques. Interactions between stakeholders are required when different views need to be coordinated due to model conflicts or global design constraints. In this section, a framework for such an approach is presented based on the notion of viewpoints as defined in ISO/IEC/IEEE 42010:2011.

For Industry 4.0 systems, we can specify viewpoints based on the "Reference Architecture Model Industrie 4.0" (RAMI 4.0) [14] that is currently being transformed into an international ISO/IEC standard. RAMI 4.0, shown in Fig. 1, describes Industry 4.0 systems along three dimensions:

1. *Layers*: comprises various system aspects: Business (processes on shop floor and office floor), Functional (functions and services), Information (data models), Communication (interfaces for data exchange), Integration (digital signals from the physical world) and Asset (physical or virtual objects such as human operators, production machines, workpieces, documents, etc.).
2. *Life Cycle & Value Stream*: comprises the life-cycle phases of types (e.g. product models and process models) and instances (e.g. concrete products and executed processes), as well as associated value chains.
3. *Hierarchy Levels*: comprises the functional control hierarchy in a production system, as an extension of the traditional automation pyramid.

Each of the three dimensions of RAMI 4.0 can be seen as a viewpoint consistent with ISO/IEC/IEEE 42010:2011 [15]. We expand on this idea and conceptualise viewpoints as partial volumes in the three-dimensional RAMI 4.0 space. Examples are shown in Fig. 1, including viewpoints relating to "production control", "business processes" and "integration". The location of viewpoints in RAMI 4.0 can be chosen depending on the specific application. While the examples in Fig. 1 are presented as coherent volumes, viewpoints may also be defined to cover non-coherent volumes. In addition, viewpoints may be nested in other viewpoints.

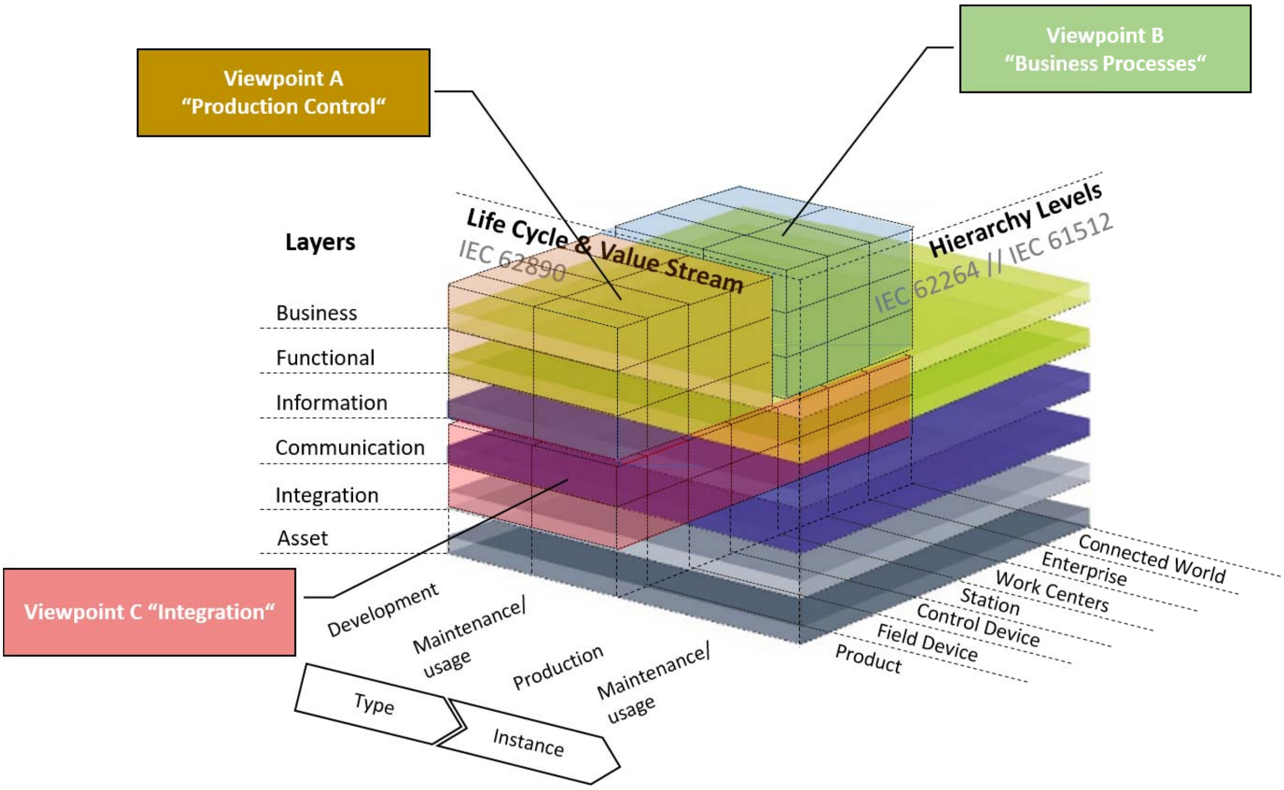

Fig. 1. Defining viewpoints based on RAMI 4.0

IV. Elaborating Viewpoint Orientation

In this section, we present an elaboration of viewpoint-oriented engineering for Industry 4.0 systems undertaken in the SICHTEN 4.0 project, concentrating on the viewpoint concept that is central to this approach. In particular, we provide details on concerns and stakeholders, model kinds and correspondence rules for the "business processes" viewpoint, implementation methods and an industrial use case.

A. Defining Concerns and Stakeholders

The Plattform Industrie 4.0 initiative that has developed RAMI 4.0 proposes a number of so-called "basic views" [16], most of which can be mapped onto the notion of concerns in ISO/IEC/IEEE 42010:2011. They include concerns related to performance, security, people, business and others.

To date there are no particular stakeholder types listed in the publications of Plattform Industrie 4.0. However, a few typical stakeholders can be drawn from the Industrial Internet of Things Reference Architecture (IIRA), such as business decision-makers, product managers, system engineers, component architects, developers and integrators. The cooperation currently taking place between Plattform Industrie 4.0 and the Industrial Internet Consortium (IIC) [17] might lead to the definition of similar stakeholder groups in a future version of RAMI 4.0.

For specific Industry 4.0 applications, users should be allowed to create their own concerns and stakeholders (or roles) in addition to using pre-defined ones. Tool support is being developed in the SICHTEN 4.0 project to provide this functionality within a knowledge portal [18].

B. Model Kinds and Correspondence Rules for the "Business Processes" Viewpoint

Established model kinds for Industry 4.0 exist mainly for the domain of real-time production control (corresponding to viewpoint A in Fig. 1). These model kinds include the five IEC 61131-3 programming languages for PLCs that have been adopted as standard modelling approaches in AutomationML (https://www.automationml.org/). Yet, for business processes (viewpoint B in Fig. 1) there is a lack of model kinds within the production domain. While a few researchers in Industry 4.0 have proposed using modelling languages from business process management and system engineering, such as BPMN (http://www.bpmn.org/) and SysML (http://www.omgsysml.org/), the usability of these approaches in practice is limited partly due to their complexity [19, 20]. In addition, there are difficulties in defining correspondence rules to allow model-based transformations into executable control software, due to ambiguities in the language specifications [21].

A model kind that has been shown to be more easily usable as well as directly executable is provided by Subject-oriented Business Process Management (S-BPM) [22, 23, 24]. S-BPM models can be created with almost no prior modelling training [25]. Process models in S-BPM are composed of three fundamental building blocks, which roughly correspond to the subject-predicate-object structure of natural language:

- Subject: is a functionality within a process (e.g. “Billing” or “Transport” within an order delivery process)
- States: are the components of a subject’s internal behaviour represented as an abstract state machine. There are three types of states:
    - “Receive” states: for receiving messages
    - “Send” states: for sending messages
    - “Function” states: for performing actions that do not involve message exchange, typically operating on data objects (termed business objects)
- Message: is the data exchanged between subjects, where the data can be a single signal or an arbitrary data structure (business object)

S-BPM process models can be directly transformed into Sequential Function Charts (SFC) (one of the five IEC 61131-3 model kinds), based on their common modelling paradigm using state machines [26]. This facilitates the definition of correspondence rules between the two model kinds, enabling a seamless integration of the business processes and production control viewpoints.

C. *Operations on Views: Implementation Methods*

Viewpoints contain methods for the creation, interpretation, analysis and implementation of views. In this section, our focus is on implementation methods.

The basis for implementing views is established by model-based and generative development. The benefits of this approach include low programming effort, high code quality and short time to market. As shown in Fig. 2, the views created by different stakeholders are integrated to form a complete and coherent model of the Industry 4.0 system. This model is used as input to a core application that generates executable code either dynamically (i.e. as directly executable, non-persistent code) or on demand (i.e. as persistent code to be executed by PLCs). A number of standard interfaces are generated including OPC UA, MQTT, AMQP and PLCopen XML. Roundtrip engineering allows feeding changes on persistent code back into the model.

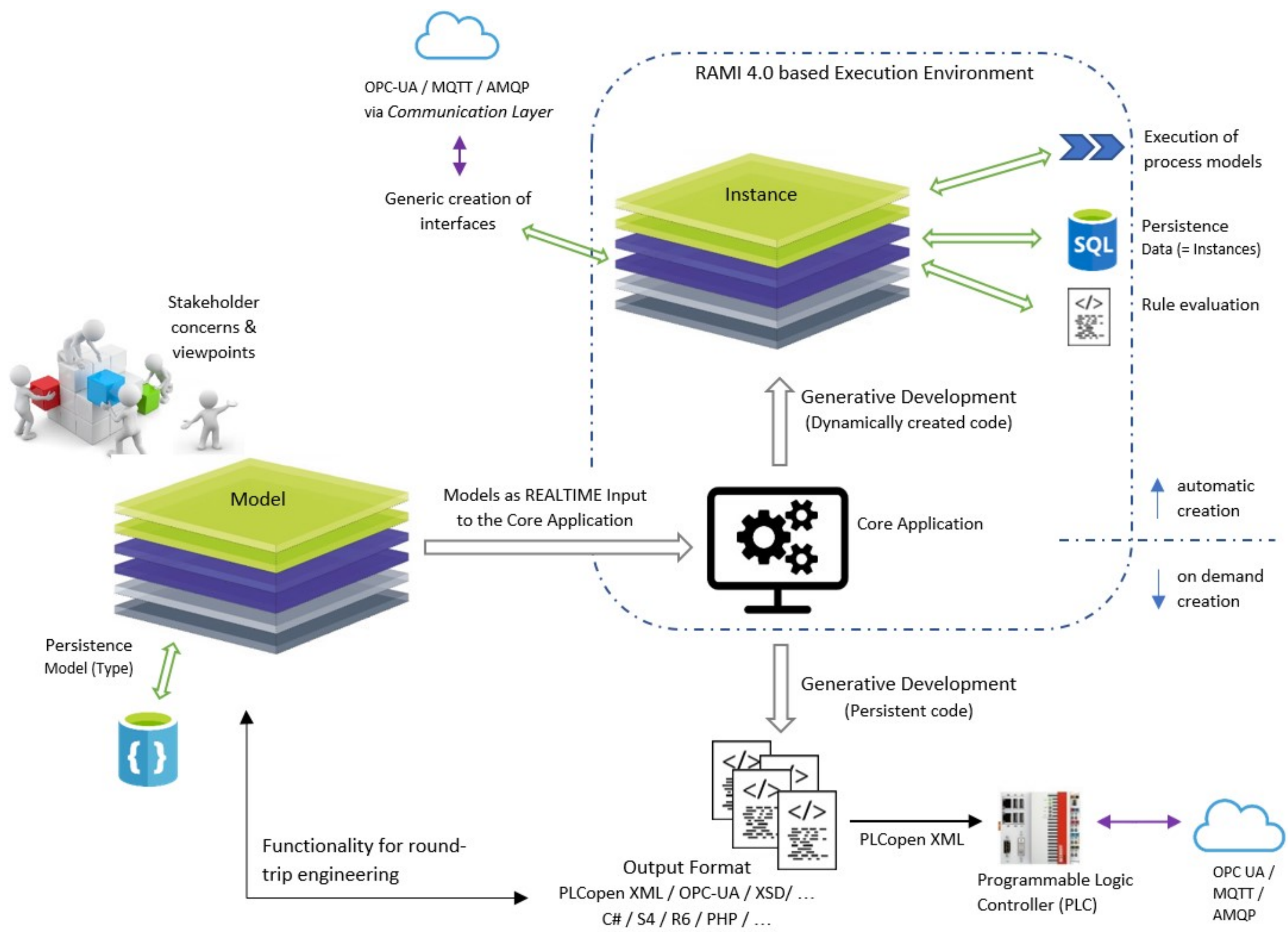

Fig. 2. Implementation of views using model-based, generative development

D. Industrial Use Case

The viewpoint-oriented approach will be implemented for engineering an Industry 4.0 system on the shopfloor of an Austrian carpenter. The system will enable predictive maintenance of a production machine based on sensor data, as shown in Fig. 3. The data captures machine usage, tool life and errors occurring. Events are detected according to predefined rules and sent to an event hub running in the cloud. The event hub analyses the events and triggers activations of physical signals, maintenance processes on the shopfloor and ordering processes on the office floor. The goal of the system is to provide maintenance services and associated materials before any damages or unplanned downtimes occur.

This use case involves various stakeholders, including shopfloor workers, office workers, maintenance engineers and IT integrators. The modelling tools being developed in the SICHTEN 4.0 project will provide them with different viewpoints to enable concurrent engineering of the Industry 4.0 application. There will be an assessment whether these viewpoints can sufficiently address all the concerns and areas of expertise of the different stakeholders and ultimately reduce time to market.

V. Discussion

This paper presents the foundations of a viewpoint-oriented engineering approach, bringing together ideas and standards from two areas: software and systems engineering on the one hand, and automation technology and Industry 4.0 on the other hand. The comprehensive use of standards is a condition for the agility and interoperability required in most Industry 4.0 applications [27]. Standards compliance is seen as an important factor contributing to long-term market success.

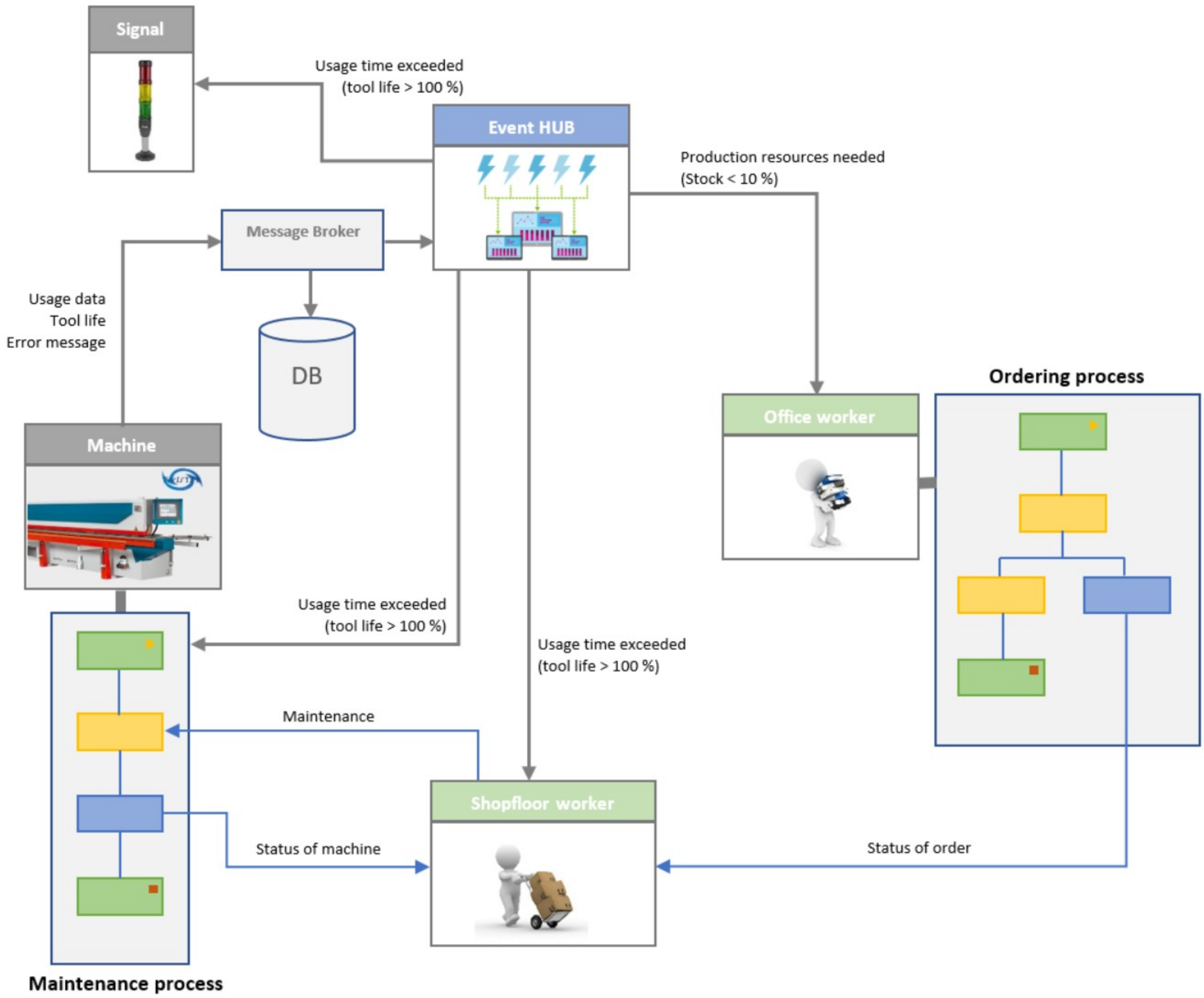

Fig. 3. Scenario of predictive maintenance serving as a use case for viewpoint-oriented engineering

Future research in the SICHTEN 4.0 project will focus on refining the "business processes" viewpoint, as it is insufficiently covered by existing industry standards. In particular, its model kinds will be defined using fundamental constructs of S-BPM, with the requirement of establishing a complete, bidirectional mapping (i.e. correspondence rules) onto SFCs. Further mappings will be investigated between S-BPM and other process modelling languages including BPMN [28] and VDI/VDE 3682 [29] to allow for high-level process visualisations.

Another research avenue – outside the scope of the SICHTEN 4.0 project – includes an extension of viewpoint-oriented engineering from solely providing a modelling environment to also include a test and execution engine. This corresponds to using viewpoints covering "instances" in the RAMI 4.0 *Life Cycle & Value Stream* dimension, in addition to "types" that modelling is concerned with. Such an extension could seamlessly embed the tool in an agile engineering methodology that iterates between modelling and testing.

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