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Simulation of Database Interactions for Early Validation of Digitized Enterprise Processes

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Abstract

Digitized enterprise processes often encompass interaction with relational databases. Describing and simulating large-scale and complex processes on different abstraction levels lead to the use of tools and methods of Model-based Systems Engineering. In practice, current entity-relationship modeling approaches solely enable modeling relational database structure without simulation of database interactions at an early development stage. However, in general, it is known that early validation improves common understanding and communication in the development team and reduces the risk of design flaws. This paper presents an approach for model-based enterprise process digitization and a previously developed and now enhanced broker-based SysML Toolbox for integrating real relational databases into SysML simulations. The approach comprises status quo documentation concerning enterprise processes, development of digitized processes and required relational database structures as well as validation of digitized processes using the SysML Toolbox.

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Keywords: Entity-Relationship Modeling; Relational Databases; Enterprise Process Digitization; Model-based Systems Engineering.

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1. Introduction

The aviation industry is characterized by extensive supply chains and demanding certification requirements. A large network of highly specialized *small and medium-sized enterprises* (SME) supplies few *original equipment manufacturers* (OEM). Worldwide competition requires more efficiency and OEM demand for better insights into their supply chain in terms of production process and stock level to reduce production risks. In addition, OEMs prepare automated procurement and invoicing processes leading to additional requirements towards supplier systems. Usually, SME use historically evolved traditional systems and enterprise software by different providers that must be enabled for cooperation within the enterprise as well as with OEM and other SME systems. Moreover, much information is captured in a paper-based manner. As already popular in other industries with less demanding certification requirements, a central database in the form of an *enterprise resource planning* (ERP) system is a promising element for digitizing SME processes.

Integrating ERP and legacy systems as well as enterprise software into digitized enterprise processes and considering all relevant aviation-specific requirements is a challenging task. Usually, SME lack the capability to modify their current system and software environment and must rely on external providers. Specifying and integrating a suitable ERP system is crucial for meeting actual enterprise needs by an ERP database and respective ERP system suppliers' solutions. This paper focuses on simulating database interactions for validating specified enterprise processes. The validated processes are the basis for further specification of the ERP system and modifications to the legacy software environment.

The approach starts with documenting current enterprise processes together with enterprise employees in workshops and modeling of these workshop results. The complexity and the extent of enterprise processes lead to the application of models in combination with the *Systems Modeling Language* (SysML). Models are defined as an abstract description of reality [1] and allow describing processes and systems in a central model repository. Modeling tools provide different views on modeled information. These views remain consistent even after changes in one view due to central model repository linkages. Model consistency and automatic creation of different views are advantages towards document-based approaches for process and relational database structure development.

Digitized processes are developed based on current traditional and physical processes and relevant stakeholder requirements, following the description of established and matured enterprise processes. Simulation and validation of novel digitized enterprise processes at an early stage in process development increases detailed process comprehension, supports communication between SME and ERP system integrators, and reduces the risk of expensive changes at later integration stages. So-called entity relationship (ER) modeling approaches [2] [3] [4] for structural aspects of relational databases already exist. However, existing ER modeling approaches do not focus on behavioral modeling of digitized enterprise processes for process validation using simulations. Therefore, a previously developed *SysML Toolbox* [5] is enhanced for simulation and validation of developed enterprise processes. This broker-based SysML Toolbox already allows validation of processes developed in SysML by means of software and hardware interactions. Hence, this paper presents further development of elements for interacting with relational databases to validate enterprise processes that are modeled using the SysML in *Cameo Systems Modeler* 19 SP 3. These elements allow interaction with real databases during process simulation. Application of database interaction elements of the SysML Toolbox is demonstrated in a digitized process by means of component inspection for quality assurance and its validation for an SME supplier in aviation industry.

2. Database Models for Digitized Enterprise Processes

Developing digitized enterprise processes requires an overview of existing processes. Growing organization size and demanding tasks such as the regulation-compliant production of aircraft parts come along with complex enterprise processes. Tools and methods of *Model-based Systems Engineering* (MBSE) are an established approach for developing complex systems and processes. Models provide tailored and consistent views on a central model repository [1] thus supporting communication in the development team, increasing system understanding, and reducing consistency errors known from document-centric approaches. The *Business Process Model and Notation* (BPMN) is developed for documenting, analyzing, and conceptualizing enterprise processes [6]. However, the BPMN is not used for process simulations on different levels of abstraction (*i.e.* top-level, high-level, system level) in order

to validate enterprise processes. The development of processes on different levels of abstraction is supported by the *Systems Modeling Language* (SysML). Simulation and validation of these processes are described in subsection 3.3.

2.1. Motivation for Digitization of Enterprise Processes

Production of aircraft parts and appliances requires certification as a production organization (*i.e.*, a *Production Organization Approval*, POA) according to EASA Part 21/G within Europe. Organizations holding POA are certified for releasing *EASA Form 1* documents that assure that a product, part, or component is manufactured in accordance with approved type design and production process parameters. Aircraft equipment production processes are often distributed over multiple, highly specialized suppliers that often do not hold POA. Instead, these suppliers must establish final inspections to declare conformity with design organization specifications in so-called *Certificates of Conformity* (CofC). An *Acceptance Test Certificate*, also known as *Quality Certificate*, is issued in final acceptance containing information about part properties, *e.g.*, part number, mass, and dimensions [7]. In this paper, the exemplary enterprise process for issuing the *Acceptance Test Certificate* in a medium size aviation supplier comprises manual certificate creation by quality managers using templates in a word processor. Digitization of *Acceptance Test Certificate* could assist quality managers by preparing documents, *e.g.*, by automatic part and order number insertion, thus providing benefits in terms of more efficiency and fewer errors. Therefore, digitized processes must be able to interact with organization databases to retrieve relevant information for *Acceptance Test Certificates*.

2.2. Relational Database Modeling

Databases represent a typical and central information source in companies and therefore play a key role in enterprise process digitization. Description and understanding of databases in the context of comprehensive and complex enterprise processes can be supported by means of modeling approaches. Entity-Relationship (ER) modeling is a standard for database modeling, especially for relational databases, and was first published by Chen [2]. An ER model describes the enterprise data scheme graphically in *Entity-Relationship Diagrams* (ERD). Each entity represents an element in the enterprise about that data or information can be stored. Entities are illustrated as boxes in ERD and the relation between entities is presented graphically via lines. To group entities and their relations, Codd introduced the term relational model in [8], where all data is represented in terms of tuples and grouped into relations. Relational databases are organized in terms of the relational model.

Some tools offer specific plugins to transform an ERD into a relation database scheme automatically, e.g., the *Cameo Data Modeler Plugin* (*https://www.nomagic.com/ product-addons/magicdraw-addons/cameo-data-modeler*). The relational model only represents the structure of entities, but not the behavior. While the structure takes entity types and relations into account, the correctness and completeness of database structures have to be evaluated in simulations of the related enterprise processes. A successful use of enterprise database structures depends on the information process design which considers ergonomic database interactions. Therefore, early simulations of interactions between digitized information processes and databases are required.

3. Methodology for Simulation of Digitized Enterprise Processes for Process Validation in a Database Context

To simulate database interactions according to the processes and the data model a previously developed broker-based SysML Toolbox [5] was extended. Subsequently, the extension of the SysML Toolbox and representative parts of the digitized process on supplier side as well as the corresponding conceptual enterprise data model are described. This extension is pursued on three levels of abstraction, *i.e.*, top-level, high-level, and system-level.

3.1. Developing Digitized Enterprise Processes

The potential of digitization of supplier processes was discussed in workshops with experts from different departments during the project „Industrie 4.0-Fähigkeit der KMU bei der Herstellung, Lieferung und der Zulassung von Flugzeugausrüstung (KMUDigital)" [engl.: "Industry 4.0 capabilities in SME in production, supply, and certification of aircraft equipment (SMEDigital)"] [9]. Paper-based processes were replaced by digitized processes

which were modeled with *Cameo Systems Modeler* using the SysML. Digitized processes encompass *Engineering*, *Production Planning*, and *Quality Management* (see top left in Fig. 1).

When a development order enters the *Engineering* department, the engineers create drawings and documentations. These documentations serve as input for *Production Planning* in that a schedule is created. Quality engineers create a quality certificate for the components according to the defined working steps in the production schedule. The high-level processes of the process *Create Quality Certificate* are carried out by *Inspector*, *Terminal*, and *Database* (see right in Fig. 1). High-level processes are described in more detail at system-level. The system-level processes are presented for the high-level process *scan the chosen product* (see bottom left in Fig. 1). The main difference to the paper-based processes is the need for a database for storing and searching data as well as allowing distribution of data at different locations at the same time.

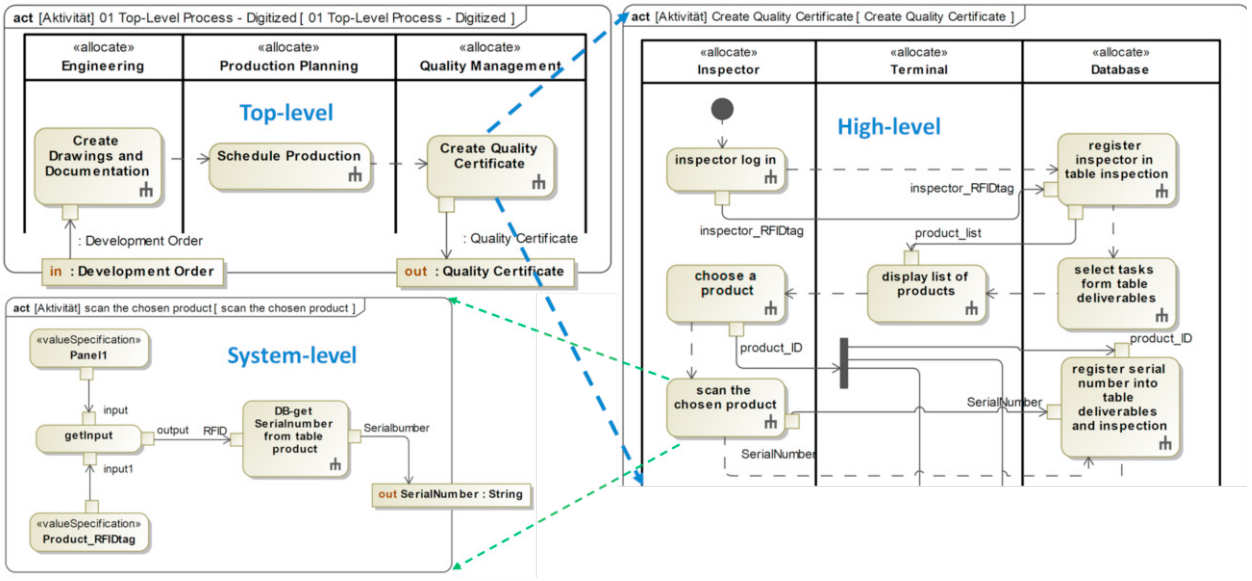


Fig. 1. Quality certificate creation process at top-, high-, and system-level.

3.2. Conceptual Data Models for Enterprises

The simulation of database interactions requires a database with available information such as the data of inspector, quality criteria, product as component, and customer order. All required attributes are defined and represented as ERD in *Cameo Systems Modeler* using the SysML. The entity types are represented as blocks and the relations as association blocks in SysML block definition diagrams. The entity types *Quality* and *Product* are presented in Fig. 2. These entity types have the relation *inspects*. Identification numbers, product properties, dates etc. of entity types and relations are modeled as attributes and are displayed in the *values* compartment of blocks.

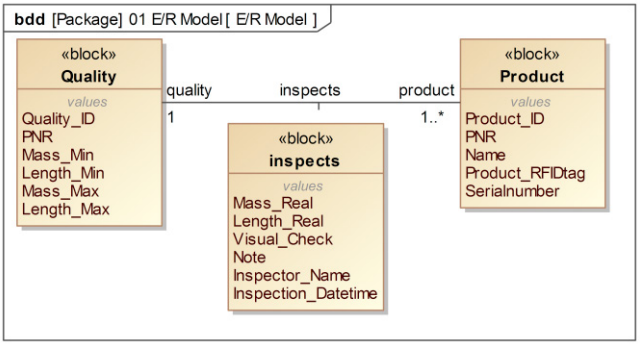


Fig. 2. Presentation of the entity types *Quality* and *Product* and the relation *inspects* in a block definition diagram (bdd).

3.3. The SysML Toolbox for Creating SQL Commands

Using methods and tools of MBSE is an established approach for the development of complex systems and related processes. The broker-based SysML Toolbox allows simulation and verification at early stages of the development process and is presented in [5]. The SysML Toolbox offers predefined model elements to simulate communication processes to support the development of new services. Simulating and validating digitized enterprise processes requires an expansion of the toolbox. Therefore, database-specific modeling elements were added to the SysML Toolbox as presented in the following.

The *Structured Query Language* (SQL) is often used to define, manipulate, and query relational databases [10]. Therefore, the SysML Toolbox is enhanced by an implementation of SQL for defining, manipulating, and querying databases in *Cameo Systems Modeler* (version 19.0), *i.e.,*

- **Data Definition Language (DDL) for defining databases:** ALTER TABLE, CREATE DATABASE, CREATE TABLE, DROP DATABASE, and DROP TABLE;
- **Data Manipulation Language (DML) for manipulating databases:** DELETE FROM tableName WHERE condition, INSERT INTO tableName VALUES value, UPDATE SET WHERE; and
- **Data Query Language (DQL) for querying databases:** ALL, AND condition, ANY, AS ASC, AVG, BETWEEN, OUNT, DESC, EXISTS, FULL OUTER JOIN, GROUP BY, HAVING, IN NOT NULL, IN, INNER JOIN, IS NULL, LEFT JOIN, LIKE, LIMIT, MAX, MIN, OR, ORDER BY, RIGHT JOIN, SELECT column FROM table, SELECT column FROM table WHERE condition, SELECT DISTINCT column FROM tableName, SUM, TOP, and UNION.

The model element *opaque behavior* is used for creating SQL commands according to the previously introduced categories DDL, DML, and DQL in SysML (see Fig. 3, left). The *opaque behavior* is an implementation specific model element for specifying executable behaviors in SysML. The following languages can be used for executable *opaque behaviors* in *Cameo Systems Modeler*: *Object Constraint Language* (OCL) 2.0, binary, *BeanShell*, *Groovy*, *JRuby*, *JavaScript*, *Jython*, or *StructuredExpression*. The java-like scripting language *BeanShell* is chosen as language for all *opaque behaviors* for defining, manipulating, and querying databases. In this way, developers can use the implementation-specific model elements via drag-and-drop in their SysML model as *opaque actions* to model and simulate database information flows for validation of developed enterprise processes.

The opaque actions *SELECT_column_FROM_tableName_WHERE_condition* and *GROUP_BY* are parts of the SysML Toolbox and presented in Fig. 3 right. The opaque action *SELECT_column_FROM_tableName_WHERE_condition* needs the columns, the table name, and the condition as input parameters, and creates a SQL statement as output parameter. The opaque action *GROUP_BY* requires the generated SQL statement and the column name as input parameters and returns a message (SQL command) as output value. The relational open source database MariaDB is chosen to simulate enterprise information flows to and from a database. To simulate modeled database information flows in *Cameo Systems Modeler*, the *MariaDB JDBC* java client *mariadb-java-client-2.5.3.jar* has to be imported into the tool. Simulation and validation of modeled enterprise processes with database interactions are supported during the design phase by the SysML Toolbox. Fig. 3 (right below) visualizes the database connection with the SysML element *opaque action* using the *opaque behavior connectMariaDb.bsh* for sending a SQL command to MariaDB and then getting an output from MariaDB.

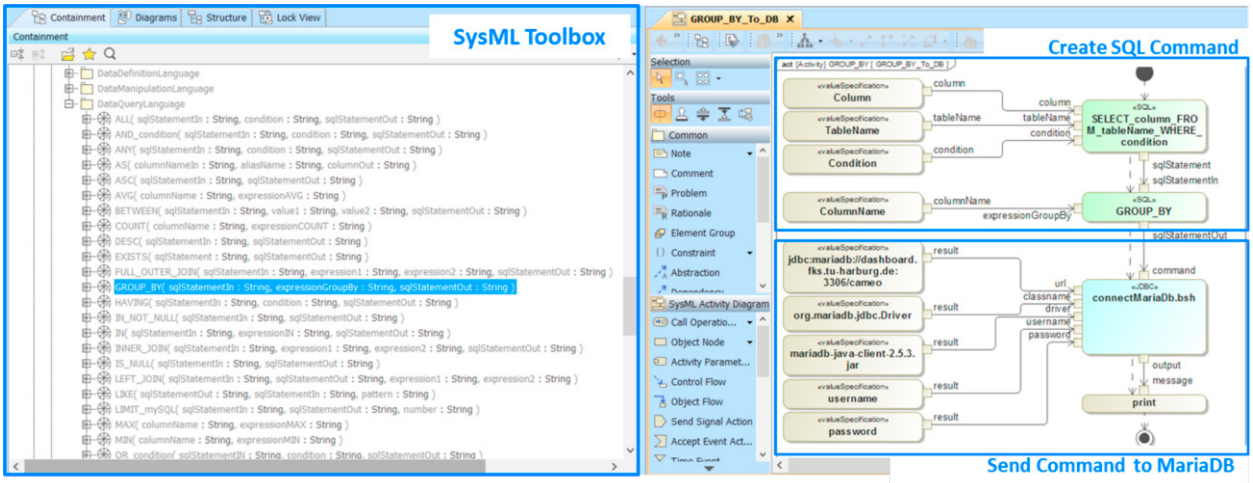


Fig. 3. SysML Toolbox with opaque actions for creating SQL commands (left). An activity diagram with a modeled SQL command GROUP_BY which is sent to the MariaDB database.

4. Application and Results

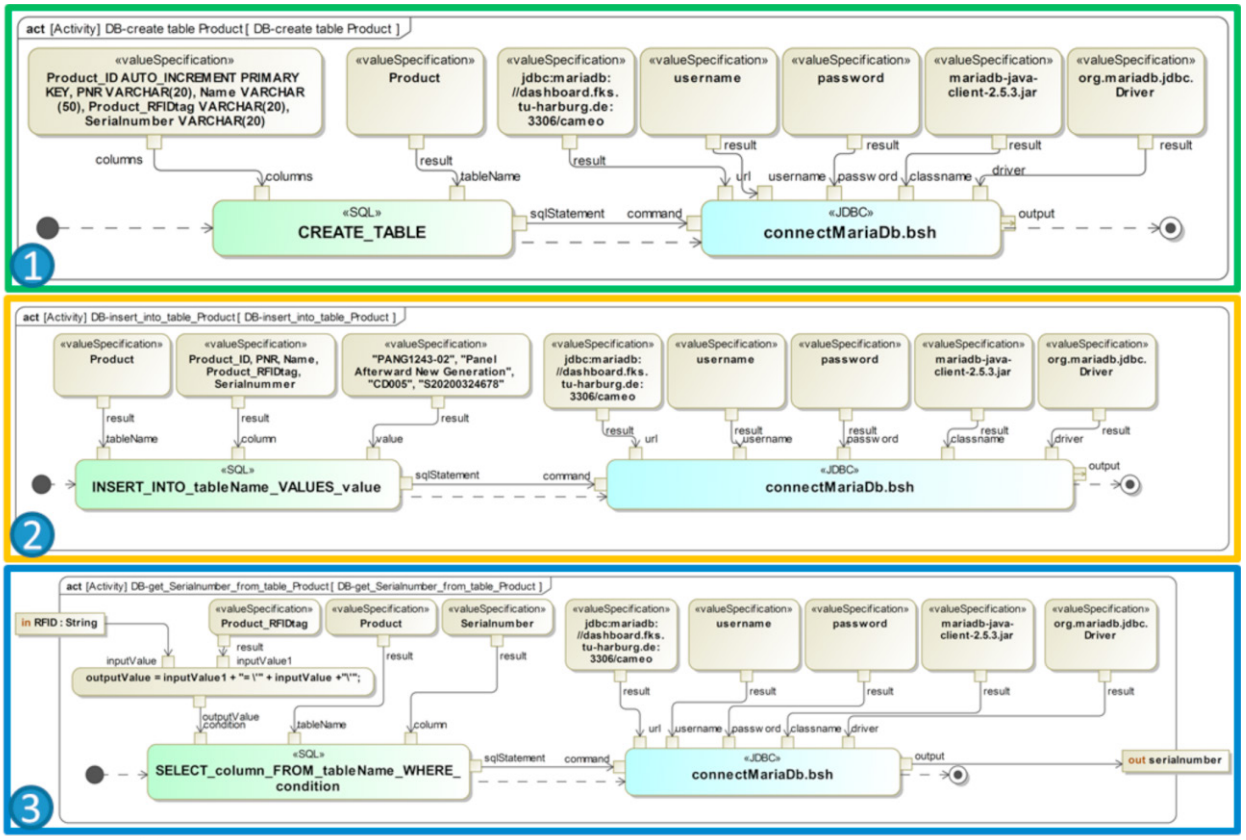
The research project „Industry 4.0 capabilities in SME in production, supply, and certification of aircraft equipment" (KMUDigital, engl.: SMEDigital) aims at developing digitized enterprise processes in SME in aviation supply chain to meet the challenges described in the introduction [9]. The quality certificate generation process is used for demonstrating the presented approach. To keep overview of all products and their properties, a table is required that is created based on an ERD. This ERD was modeled in SysML (*cf.* Fig. 2).

Based on the ERD tables were created using the SysML Toolbox. The model-based creation of the table *Product* in MariaDB is shown in Fig. 4. The opaque behavior elements *CREATE_TABLE* and *connectMariaDB.bsh* of the SysML Toolbox are used in an activity diagram (see Fig. 4, No. 1). After running the simulation for this activity diagram in *Cameo Systems Modeler*, a blank table named *Product* is created with the columns named *Product_ID*, *PNR*, *Name*, *Product_RFIDtag*, and *Serialnumber*.

The opaque behavior element *INSERT_INTO_tableName_VALUES_value* from the SysML Toolbox is used for filling the table *Product*. The data will be inserted into the table *Product* after running the simulation depicted in Fig. 4 (No. 2). Fig. 4 (below) shows that the simulation for inserting values into the table *Product* was executed eight times for eight products. In order to obtain the *Serialnumber* for an associated *RFIDtag* from MariaDB, the opaque behavior elements *SELECT_column_FROM_tableName_WHERE_condition* and *connectMariaDB.bsh* are used.

The product is identified by the serial number which is written on the task paper in the current quality certificate creation process. Hence the block product in ERD had only the serial number as the unique identifying attribute at the beginning of the modeling. The most frequently occurring disadvantage of the current process is that a component cannot be identified if the task paper gets lost or separated unintendedly from the correspondent product. Another disadvantage is that the status of inspection processing is unknown until someone finds the product and the allocated task paper. It is normally very difficult to find out the information about any requested product in a quite short time, *i.e.*, responding to the customer in which status the ordered components are. For these reasons the RFID tag is considered in the target process.

At the beginning of the modeling there was neither attribute *Product_RFIDtag* in the block product nor in the table product. The modeler noticed that he could not input the serial number directly into the database until he designed the target process. Then the modeler can correct the ERD and database structure by adding the attribute in the SysML model and the column *Product_RFIDtag* in the database. The Fig. 4 (No. 3) depicts that the inspector scans the RFID tag and the code of this tag comes into the database instead of the serial number.



1

Product_ID	PNR	Name	Product_RFIDtag	Serialnumber
2				
1	MTF32-03	Mirror Toilette Forward	CD101	S1004001
2	MTF32-03	Mirror Toilette Forward	CD103	S1004005
3	MTF32-03	Mirror Toilette Forward	CD102	S1004003
4	PANG1243-02	Panel Afterward New Generation	CD001	S20200324123
5	PANG1243-02	Panel Afterward New Generation	CD002	S20200324345
6	PANG1243-02	Panel Afterward New Generation	CD004	S20200324567
7	PANG1243-02	Panel Afterward New Generation	CD003	S20200324456
3 8	PANG1243-02	Panel Afterward New Generation	CD005	S20200324678

Fig. 4. Modeled SQL command: create table *Product* in MariaDB (No. 1), modeled SQL command: fill the table *Product* with product information (No. 2), modeled SQL command: search for the serial number (No. 3), created Table in MariaDB with product information (below).

During the KMUDigital project the digital certificates were generated as described above. All the required data for the paper certificate was printed on the terminal or the customer could find the qualification data of his ordered components by selecting the related CPO – Customer Purchase Order. The customer could also get more information directly in the database than before only getting the information on the paper-based certificate, *i.e.*, the name of inspector and the date and time of inspection. The customer could also see how many products have been qualified by checking the status in the database without asking allowance from the supplier. Lots of such possibilities can be designed and modeled easily and flexibly by using the method described in this paper.

5. Conclusion

The presented approach for simulating enterprise processes with a focus on database interactions for process validation comprises model-based process development, information model setup, and execution of process simulations. Information modeling utilizes the entity-relationship principle in SysML block definition diagrams. Process simulations are based on a collection of opaque behaviors enabling interactions between the model and a relational database. The opaque behaviors are added to the SysML Toolbox and can be assigned to call behavior actions in SysML activity diagrams. Future work can combine SysML Toolbox elements for message broker communication and relational database operations so that database operations can be performed based on commands received via messages. The availability of information stored in databases to other systems via messages is an important aspect for the development of dispersed services and system cooperation.

Approach application to an enterprise process for component inspection and quality certificate creation in aviation supply industry enabled successful process validation at an early design stage. Process simulations containing database interactions are created simply and efficiently so that even during target process development, simulations were executed for assessing process parts before validation. Finally, validation of enterprise processes and presentations to affected stakeholders were supported.

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References

[1] Alt, Oliver (2012) "Modellbasierte System-Entwicklung mit SysML", Munich, Hanser Verlag.

[2] Chen, Peter Pin-Shan (1976) "The entity-relationship model—toward a unified view of data" *ACM Transactions on Database Systems* **1 (1)**: 9–36. DOI: https://doi.org/10.1145/320434.320440.

[3] Kleuker, Stephan (2016) „Grundkurs Datenbankentwicklung", 4th edition, Springer Vieweg.

[4] Saake, Gunther, Kai-Uwe Sattler, and Andreas Heuer. (2018) "Datenbanken: Konzepte und Sprachen", 6th edition, MITP Verlags GmbH & Co. KG.

[5] Melzer, Sylvia, Jan Speichert, Oliver C. Eichmann, and Ralf God. (2019) "Simulating Cyber-physical Systems using a Broker-Based SysML Toolbox", in Otto von Estorff and Frank Thielecke (eds) *Proceedings of the 7th International Workshop on Aircraft System Technologies*, Hamburg, Shaker.

[6] Freund, Jakob, and Bernd Rücker (2014) "Praxishandbuch BPMN 2.0", 4th edition, Munich, Hanser Verlag: 4–5.

[7] Hinsch, Martin (2010) "Industrielles Luftfahrtmanagement – Technik und Organisation luftfahrttechnischer Betriebe", Berlin, Springer: 156.

[8] Codd, Edgar F. (1970) "A relational model of data for large shared data banks", *Communications of the ACM* **13** (**6**): 377–387.

[9] KMUDigital (engl.: SMEDigital), Industry 4.0 capabilities in SME in production, supply, and certification of aircraft equipment, https://kmudigital.fks.tuhh.de/en/home.html, consulted online on 16 June 2020.

[10] Beaulieu, Alan "Learning SQL", 2nd edition, O'Reilly Media, Inc.