SIMULATABLE REFERENCE MODELS TO TRANSFORM ENTERPRISES FOR THE DIGITAL AGE – A CASE STUDY –

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KEYWORDS

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ABSTRACT

The digital transformation of enterprises forces organizations to handle increasingly complex models of their technical and information systems architectures. Both the existing and the desired architecture must be defined and analyzed in advance of the transformation itself. A purely static analysis of the architecture structure is not sufficient. Also, the dynamic behavior of horizontally and vertically integrated systems in and amongst organizations must be considered.

Reference models help modelers and organizations in finding inspiration to handle this complexity and to develop their own models. Though reference models exist, it was almost never the intention to immediately apply them to actual problems. Then, however, means are needed that help modelers to deeply understand the reference models, to support a decision finding whether a specific reference model can be applied to an organization or not, and to adapt the reference model to a given situation.

This paper explains an approach to use simulatable process models on the base of high-level Petri nets that help in this challenging situation. It describes a modelling and simulation environment called Process Simulation Center (P-S.C) in which processes of reference models can be executed with respect to the information objects needed to control these processes. Also, the structural organization can be defined with the aid of organigrams and can be linked to the process view. Finally, process maps are used to give an overview of the enterprise's processes and their interactions.

INTRODUCTION

Several years ago, (Morgan, 1998) discussed the influence the view on an organization has on its management. One of these views was the functional or mechanical one of an organization as a machine. The current discussion on the digital transformation of enterprises and the possibilities to automize processes in a standardized way underline the importance of this view.

Today, more and more companies aspire after more automation. The upcoming internet of things and the ability to combine information systems and the real world in a cyber-physical system accelerate this development. But now, each enterprise that choses this transformation path has to answer the following questions: What are the consequences of the transformation in practice? And which of the many options to automate processes in administration and production is the one which fits best?

Since the answers to these questions are so hard to find for a specific organization, modeling of the existing and the intended organizational structures in advance of the actual transformation seems to be reasonable. However, the next question immediately occurs: Where and how to start with developing a model of a modern organization?

Fortunately, the search for such a model does not have to start from scratch. Many reference models have been developed in the past, sometimes called best practices if they have been developed in a consulting context. These models can be adapted to fit to the according application situation (Becker, Delfmann, Knackstedt, 2007, p. 27).

Because of the long-ranging consequences of transformations, any such model should be regarded with suspicion and it should always be kept in mind that, according to (Stachowiak, 1973, pp. 131-133), any model follows three principles: it is a mapping of the reality, it is a reduction of the reality, and it has a pragmatic purpose. Since these principles might have been weighted differently by the modelers of the reference model than its appliers, a validation is always necessary.

The use of reference models in information systems is an established approach (Thomas, 2005, pp. 484-496). Especially in the German information systems research, this topic has been widely discussed. Exemplarily for this, the work of (Fettke and Loos, 2002) or (Scheer, 2011) is mentioned here. However, the use of simulatable reference models has not been investigated so far.

On this base, the following section explains the research design. Afterwards, different views on enterprises used in information systems development are discussed. The main part of the paper explains how these concepts have been realized in a modelling and simulation environment called Process Simulation Center (P-S.C) with the aid of an example. The advantages of using simulation for the evaluation of the reference model is discussed next. Further developments planned for the future are discussed at the very end.

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RESEARCH METHOD

According to (Hevner et al., 2004), there are seven guidelines for Design Science Research. These and their implementation are briefly explained as follows:

Design as an Artifact: A web-based specification and simulation app for processes, the Process Simulation Center (P-S.C), has been developed which is extended by facilities to describe data structures, organizational structures and process maps.

Problem Relevance: In order to advance the quality of a reference model assessment, simulation can play an increasing impact. The applicability of a reference model to the concrete situation in an organization can be tested by simulation with respect to the given resources.

Design Evaluation: Companies already use the mentioned tool. Students of an integrated degree program in logistics adapt reference models of processes to a concrete problem in their company.

Research Contribution: The contribution consists of the creation of a practical application on the theoretical basis of high-level Petri nets combined with other views on organizations and an implementation example of a reference model. The tool, today, is able to map complex organizational structures such that new, simulatable reference models of organizations can be developed.

Research Rigor: The benefits of a simulation approach in opposite to pure visual methods is evaluated in bachelor and master courses and in cooperation with partner companies of integrated degree programs.

Design as a Search Process: The presented prototype is the latest in a series that starts from the initial implementation of the underlying principles and ends in a productive system. Each implementation step has been evaluated.

Communication of Research: The results achieved so far are relevant for both research and practice. They are presented on conferences but also, more illustrative, for practitioners.

VIEWS ON ORGANIZATIONS

Usually, the digital transformation of an enterprise leads to a total or partial replacement of analogue processes by digital, computer executable processes (Wolf and Strohschen, 2018). Figure 1 shows the dimensions of a digital transformation.

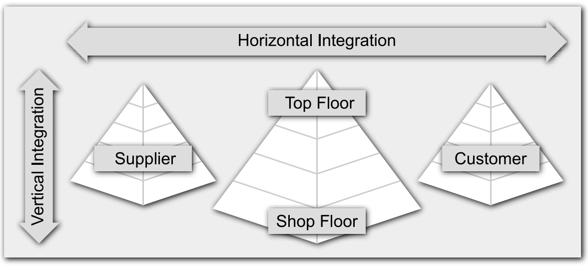


Figure 1: Integration of processes within and across companies adapted from (Simon and Haag, 2020, p. 106)

Horizontal integration occurs along the supply chain, connecting processes of both suppliers and customers with the company in focus.

Vertical integration enables seamless processes from the top floor (i.e. the business processes of the ERP system) to those of the shop floor (i.e. the IT systems for machine automation and in production).

The development of simulatable reference models for both vertically and horizontally integrated (information) systems needs either a shared semantical basis for different modelling languages or a unique modelling and simulation language such as Petri nets. The usefulness of Petri nets for the different tasks has been demonstrated in several publications. Exemplary for a large number in this field (Aalst and Stahl, 2011) can be referred for the application of Petri nets to business process and workflow management and (Zhou and Venkatesh, 1999) can be referred to the application of Petri nets to flexible manufacturing systems.

A Petri net-based approach to integrate processes across the different layers of the automation pyramid according to figure 2 has been demonstrated by (Haag and Simon, 2019). Hereby, also IoT components of the environment have been integrated into the process simulation and execution.

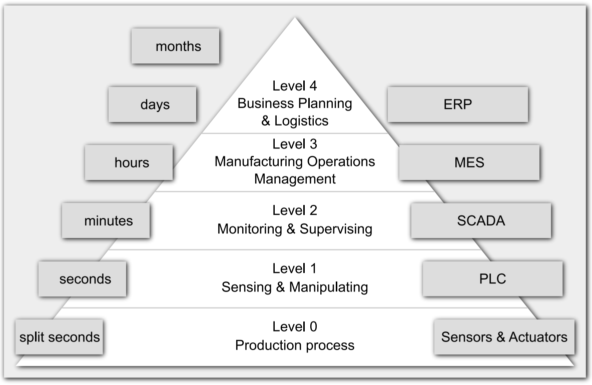


Figure 2: The automation pyramid according to the ISA 95 model (ANSI/ISA, 2005)

Actually, it needs more than processes to describe integrated information systems. Data structures typically defined with the aid of class diagrams (Hay, 2011) are needed to specify information classes that can be instantiated by objects. Combined with the structural organization of an enterprise represented in an organigram, the responsibility and obligation to conduct specific tasks and the right to use the relevant information for this completes the view on an integrated information system. (Scheer, 2000) described this in the architecture of integrated information systems (ARIS) several years ago as shown in figure 3.

The data models and organizational models exemplarily developed in the following sections can be located on the requirements level. Because of the use of Petri nets, the process models can be seen as examples of all three levels: requirements definition, design specification, and implementation description.

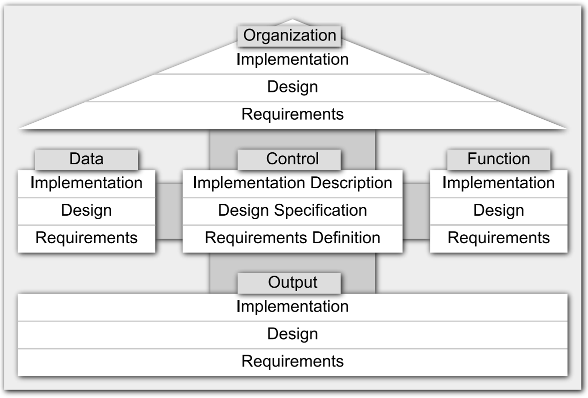


Figure 3: Architecture of integrated information systems adapted and summarized from (Scheer, 2000, p. 1)

In addition to this, process maps offer a further view on enterprises and visualize the interaction of its processes.

TOWARDS SIMULATABLE PROCESS MODELS

A short case which is introduced first might help to give a descriptive demonstration on how to integrate simulatable process models into reference models.

In our example (which has two real-world counterparts which must not be named here), the growing business volume of an online retailer for bicycle products causes an increased amount of returns. In the initial growing phase of the company the returns have been sufficiently handled with Excel. Now the process gets more expansive and complex at the same time. Mainly three variants have to be handled by the employees:

A wrong product has been delivered. Then the wrong item must return into the storage while a replacement is sent to the customer.

A defect product has been delivered. If the product exceeds a certain value and can be repaired, it is given to the own workshop and sent back to the customer after repairing has been finished. If the value is below this border, it is wrecked and a new product is sent to the customer. If it cannot be repaired and the critical value is exceeded, it is sent back to the producer and also in this case a new item is sent to the customer. In this case the claim must be settled with the producer in parallel to sending the product back.

Exceptional situations occur. Sometimes processes fail. A first example is that customers sometimes recognize wrong products after they have opened the packaging. In this case the product cannot return into the storage immediately but needs to be checked and repackaged first. If a damage is recognized throughout this check, the managing director decides on the further procedure. A second example occurs if employees believe that products can be repaired but realize after disassembling that this was wrong. In this case, resending the original product must be examined closely and again the managing director is involved.

A correct process execution depends highly on the distinct know how of the employees. Unfortunately, the growing business forces the company to deploy experienced personnel in core routines of the company like sales and marketing while handling the return process has been rated as a less important process in the past and, thus, is mainly staffed with temporary employees. For these employees, a clear and unambiguous process is needed. This was the initial reason why the company wanted simulatable business processes: the intention was to use them for trainings.

The case includes all elements of the architecture of an integrated information system with respect to figure 3:

Organizational roles inside the enterprise are the managing director, a clerk who decides on how to handle a return, service technicians in the workshop, and employees in the storage. Probably also employees of the purchasing department might be involved. External roles participating in the process are customer and producer.

Data objects are needed concerning the complaint and its current state in the return process, the customer, and the kind of product.

Important **functions** of the process are “check the returned good”, “repair the product”, “deliver a repaired product” or “deliver a substitute” to the customer. The wrecking of a return is omitted in order to reduce the complexity for this paper.

Output documents attended to the process are delivery receipts and supply notes attached to the product.

Although it is possible to model the entire behavior in a single but complex **process** model, it is more reasonable to divide it into the parts “classify a complaint”, “repair a product”, and “replace a product” which need to be reasonably chained. Like others, these processes are objectives of a continuous improvement process. And the two latter processes use standardized support processes like a centralized purchase.

On the base of this scenario, a reference model for returns has been developed with the aforementioned web-based modelling and simulation environment Process Simulation Center (P-S.C). With the aid of a tiny mockup language, models for the different views are specified and can be linked to each other. The following concentrates on the actual models that have been built with the aid of the tool without discussing the detailed specification. The reference model focusses on the mentioned facts and is an excerpt of the entire model which would blow up the scope.

The initial model for the described case is a process map of the mentioned processes as depicted in figure 4. The primary processes that immediately address a customer problem are centered in the middle segment. As can be seen, repair and replacement process follow the classification process. Which one occurs is chosen in the classification process as demonstrated later on. The upper segment is typically reserved for the management processes. The lower segment is reserved for so called secondary or support processes.

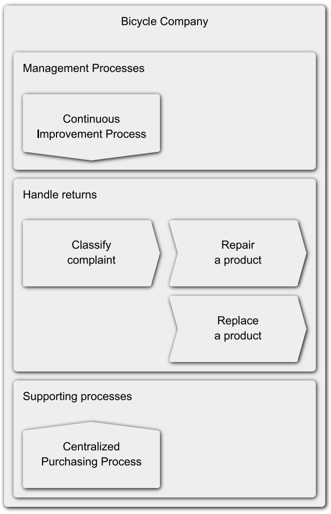


Figure 4: Process map of the exemplary company (rendered with P-S.C)

The second important view is on the organizational structure of the enterprise as shown in figure 5. With respect to the limited space, central departments like purchasing and central storage are bundled graphically into a single unit. The managing director for the supply chain is seen as part of a general management team which is not further described here. External roles involved in the process are not shown in the (internal) organigram.

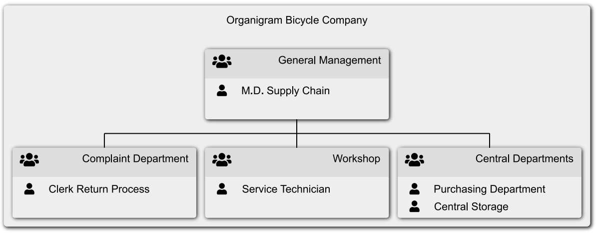


Figure 5: Organizational structure of the exemplary company (rendered with P-S.C)

As part of the specification language for processes it is possible to define datatypes and associate them with places – a Petri net element to store information. Process and data flow can be combined in a single model with the aid of this concept as explained in the next two sections.

Figure 6 depicts a simple data structure for complaints, customers and products. Each return is uniquely associated with a customer and may contain one or more products of given product types. The same product type might occur in several returns caused by the same or by different users. Currently, the company does not distinguish between the individual products but is completely satisfied with the product type level.

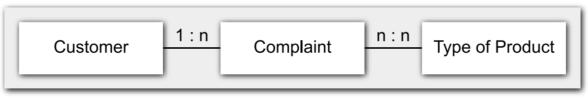


Figure 6: Simple data structure for handling returns

A more detailed view on the attributes used for the distinct data objects will be given in the next section when this information is used to control the business process.

SIMULATABLE PROCESS MODELS

In this section, exemplary processes of the case are modelled as Petri nets which we assume to be known (Reisig, 2013). In a stepwise approach, the core process structure is defined first and extended by data-flow concepts afterwards.

The authors have chosen Petri nets as modeling language for several reasons:

An **execution semantic** is formally defined on base of the so-called firing rule for transitions. This semantic can be seen as a dominant reason for the influence of Petri nets on the development of workflow management systems in the past (Aalst and Hee, 2002).

Distinctive information objects, named tokens, that flow through Petri nets are crucial for process control and to predict the quantitative process behavior. The best-known approaches are Predicate/Transition Nets (Pr/T-nets) as defined by (Genrich and Lautenbach, 1981) and Coloured Petri Nets as defined by (Jensen, 1992).

As tokens may also contain **time information** schedules can be examined or planned.

The authors chose to use Pr/T-Nets in the following.

Figure 7 shows a first version of process "Classify complaint" and needs to be explained since the Process Simulation Center draws Petri nets in a modern, compared to classic Petri nets unusual way.

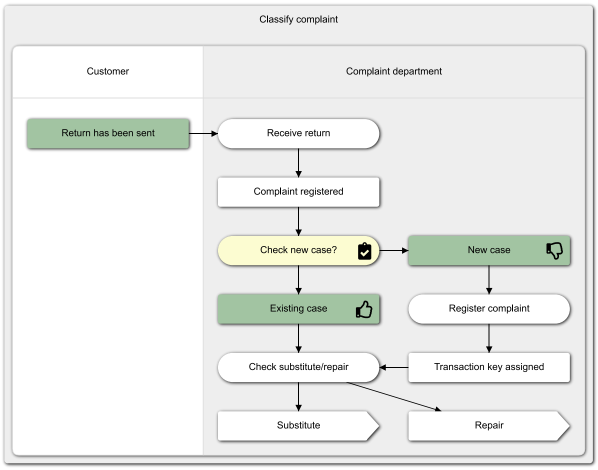


Figure 7: Initial version of process "Classify complaint" (rendered with P-S.C)

Places and transitions are stretched such that the label can be put into the nodes. Places have round left and right borders (like "Receive return") while transitions are rectangles (like "Complaint registered") with one exception: models can be chained such that the firing of a transition opens another net where simulation can be continued. These special transitions are drawn as process arrows (like "Repair").

Enabled transitions and marked places are graphically emphasized: An enabled transition is drawn green and a marked place is drawn either green or yellow. The latter is chosen if the place is the reason for a conflict situation where two transitions compete against each other concerning tokens. Moreover, transitions and places can be supplemented by icons dependent on their enabling status or the number of tokens on the place.

Places are chosen to describe activities that happen or the coming to a decision. Important events or the results of decisions are depicted as transitions. Swim lanes are used to express responsibilities.

The model depicted in figure 7 describes the following process: after the customer has sent the return, it is received by the complaint department and registered first. Due to some mishaps in the past, it is checked whether this really is a new case or whether it has been registered already (the situation indicated by the shown marking). After a new complaint has possibly been registered, the clerk of the complaint department decides on whether the return must be substituted or repaired. Dependent on this decision, the next process begins.

In the next section, this model is enriched by information concerning the returned goods and their processing. This is done for two reasons: it can be checked how to automize the process and it can be the base for the simulation of different process behavior after a digital transformation process has occurred.

INFORMATION CONTROLLED SIMULATION

In Pr/T-Nets, places are typed and can be marked with tuples that match this type structure. Hence, places correspond to tables of a database and their tokens to the records within a database table.

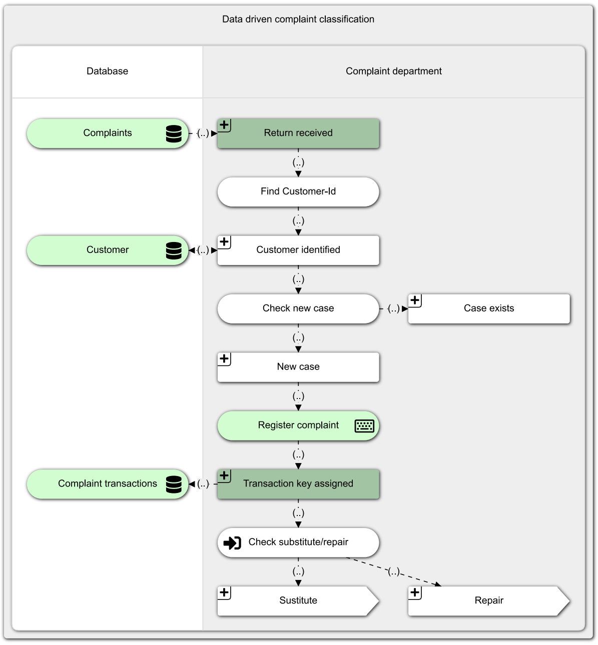
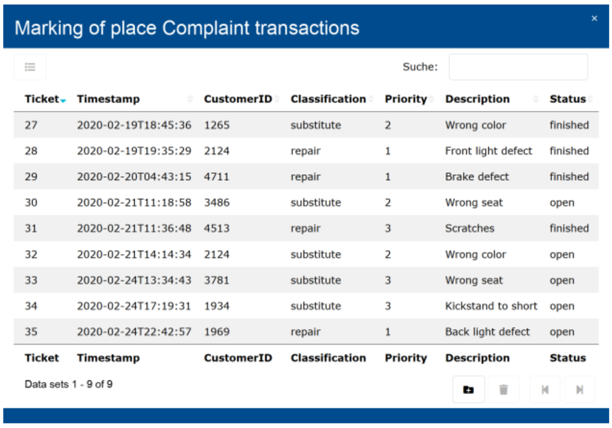


Figure 8: Data driven complaint classification process (rendered with P-S.C)

In figure 8, all places are typed. The places in swim lane "Database" contain the information concerning the incoming complaints, the customers (in order to identify the right customer-id), and complaint transactions (used for the documentation of all handled complaints). Figure 9 is a screenshot showing the content of latter place.



Marking of place Complaint transactions

Suche:

Ticket	Timestamp	CustomerID	Classification	Priority	Description	Status
27	2020-02-19T18:45:36	1265	substitute	2	Wrong color	finished
28	2020-02-19T19:35:29	2124	repair	1	Front light defect	finished
29	2020-02-20T04:43:15	4711	repair	1	Brake defect	finished
30	2020-02-21T11:18:58	3486	substitute	2	Wrong seat	open
31	2020-02-21T11:36:48	4513	repair	3	Scratches	finished
32	2020-02-21T14:14:34	2124	substitute	2	Wrong color	open
33	2020-02-24T13:34:43	3781	substitute	3	Wrong seat	open
34	2020-02-24T17:19:31	1934	substitute	3	Kickstand to short	open
35	2020-02-24T22:42:57	1969	repair	1	Back light defect	open
Ticket	Timestamp	CustomerID	Classification	Priority	Description	Status

Data sets 1 - 9 of 9

Figure 9: Screenshot of the marking of place "Complaint transactions"

Also, the places of swim lane "Complaint department" are typed and carry the information concerning the current complaint handled. Clicking the plus-symbol enlarges the transitions in order to show transition conditions and select-criteria that control the sequence in which the complaints are handled. Different strategies can be followed: a first-come-first-serve strategy handles the complaints corresponding to their automatically generated ticket number. Another strategy could be to follow the priority criterium instead.

Finally, place "Check substitute/repair" has an extra symbol. It indicates that the information concerning the current complaint is exported to the next net opened after transition "Substitute" or "Repair" are fired. The idea behind this concept has been explained in (Simon, 2018) already. The selection which of these two transitions fires depends on the value of attribute "Classification".

The nets "Repair a product" and "Replace a product" are defined in a similar way.

FROM SIMULATION TO EXECUTION

The definition of unambiguous business rules that standardize the process execution is crucial for process automation and hence for the digital transformation of enterprises. The conflict situation shown in figure 7 is a good example for a process model which is still incomplete and the Process Simulation Center helps to find such situations. Whenever the simulation must stop because a conflict occurs which can only be solved by the operator of the software, the same would occur in the real-world process.

To find out how well the process is automated so far, the P-S.C can work with real world data which can be imported with the aid of a CSV interface.

In the concrete case of the demonstrated return process, students of a logistics company had to take the reference process (which – in practice – is of course more elaborated) and adapt it stepwise to a real-world return process in their company. For this they had to adapt the model on all levels concerning the architecture of integrated information systems shown in figure 3:

Organizational roles are labeled differently and in addition to the clerks who decide on how to proceed with the returned goods there are also employees who transport the goods from the loading zone to the complaint department and further on to the main storage. A supervisor coordinates the work of the team.

Data objects are used differently in several aspects since in the real-world example the logistics company works as a sub-contractor for a producer. Hence, the internal data must always be combined with the purchaser's data. As a further consequence, returns are typically bundled into larger lots that must be distinguished in the information perspective.

Furthermore, the logistics company is interested in the consequences of applying different strategies to the return process which is currently reorganized. Therefore, each step within the process is assessed concerning the average processing time. This time information is also considered in the complaint transaction record.

More **functions** exist in the real world than shown in figures 7 and 8. As described in the beginning, it is also possible that some returned goods are wrecked since it is not reasonable to restore low-grade goods. In order to increase the readability of this paper, these details have been omitted.

Output documents of the real-world process have been used as a source to complete the data objects needed in the simulation of the said process.

Although the same **processes** have been considered as described here, the management was also interested in measuring the process behavior. For this reason, the students established key performance indicators (KPI) to measure the process and defined them with the aid of a standardized KPI-sheet.

The application of the simulatable reference model in the modelling environment demonstrated the advantage of this approach. The stepwise refinement approach enabled the students to define not only a simulatable but also executable process definition within four weeks. Moreover, they could predict the behavior of optional reorganizations in advance.

At the beginning of this paper, the following questions have been formulated: What are the consequences of a digital transformation in practice? And which of the many options to automate processes in administration and production is the one which fits best? The simulatable models helped the students and their company to precisely answer these questions for a concrete field of application in advance. The application to further processes is planned for the future.

FURTHER RESEARCH

The current state of research opens manifold further research questions:

The **number of reference models** is increased constantly in order to apply this approach to a larger number of cases. Especially branches of industry partners of the university are considered first. The former section also showed a demand for inter-organizational reference models.

Another approach is to increase the **number of reference models** with respect to established ERP systems and to develop simulatable processes for them.

In a combination of the research presented here and research conducted in the past, the **automation of manufacturing processes** is also an aim of the future work. The purpose of this is to make vertical integration processes more illustrative for students and partner companies.

Finally, it is the aim to **combine the research and teaching of modelling and simulation techniques**. Modern pedagogic approaches called problem-based learning and research-oriented learning try to substitute classical ways of fact-based learning and to develop and train the scrutiny of students. Simulatable models help students to explore the world they have to work in and to derive an appropriate solution for a given problem from an existing one (Simon and Haag, 2020).

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