PATTERN RECOGNITION FOR THE INTEGRATION OF MECHANICAL SIMULATIONS IN PRODUCT DEVELOPMENT WORKFLOWS

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Abstract

The emergence of computer-aided systems and especially numerical methods has revolutionized the product development process. Several types of simulations and calculations during the process are nowadays state of the art. In order to manage the mass of resulting data, simulation data management systems have evolved and spread across specific branches dealing with the interaction of design and simulation departments. In this paper, together with workflows from the development process of an industry partner in SIPOC and BPMN, development tasks are separated according to their department – design or simulation – in order to show the interaction along a process. As a result, three different patterns are recognized within the generated depictions: capsuled patterns, integrated patterns, and outside patterns. Specific behaviour towards simulation data management issues and particularly simulation requests can be stated for each of them. Consequently, this approach can support the implementation process of a simulation data management system by selecting suitable forms of simulation requests according to the workflow.

Keywords: Simulation, Process modelling, Integrated product development, Collaborative design, Simulation data management

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1 INTRODUCTION

In the second half of the twentieth century, the emergence of computer systems has changed the product development process from manual calculations and designs into their virtual equivalent. Countless different computer-aided systems have been developed and introduced in many areas of the companies. In research and development departments, for example, systems like Computer Aided Design (CAD) and Computer Aided Engineering (CAE) are employed to support the development process and to improve results (Vajna et al., 2009).

According to Maier et al. (2009), simulations have become more important within the development process and the corresponding software products are applied extensively. For instance, the amount of conducted simulations at an automobile manufacturer grew exponentially in the past decade – from about five thousand to fifty thousand simulations per month – leading to more than seven hundred terabyte of data overall. This evolution is caused by several reasons, among others the development of new CAE disciplines (Reicheneder, 2015).

The increasing number of simulations generates masses of data that have to be interpreted and transformed into results. To manage and control this data, simulation data management (SDM) systems administrate data, models, processes, documents, and metadata (Kleiner and Krastel, 2015).

In order to cover topics of simulation in the product development process, the research project FORPRO² was set up in 2013, involving six universities and several industry partners from different sectors, for example software, automotive, and mechanical engineering. The research project aimed at generating a framework that enhances the design and quality of new emerging products - leading to higher efficiency in the value chain (Lindemann and Rieg, 2013).

With the planned introduction of a simulation data management system, the industry partner of this paper intended to avoid problems like recalculation of simulations, loss of data, and legal issues. Due to the fact that various systems are already on the market, they have to be matched with the requirements of the firm. However, in order to effectively use such systems, internal work sequences have to be taken into account, too. Therefore, processes have to be analysed and structured to adapt the software system to the specific needs of the company.

This paper introduces topics related to simulation data management systems and identifies workflow patterns as well as their impact on simulation data management systems and simulation requests.

2 STATE OF THE ART AND RESEARCH

The application of simulation methods rearranges phases of the product development process. Thus, significant research has dealt with the challenge of integrating simulations into the product development process.

Albers and Nowicki (2003) combine the concept and design phase and propose the use of multi body simulations and calculations with the support of finite element methods. The following detailing phase optimizes the product shape and brings it to the right size. Validation, the last simulation-supported phase, includes life cycle calculations and hardware in the loop simulations. Within the production implementation phase and the production phase, no simulation tool of the product development is integrated in their approach.

According to Charles and Eynard (2005), a simulation task can be subdivided into three main elements: pre-processing, solver processing, and post-processing. CAD data, which is prepared for simulations as a data set, represents input for the pre-processing step. Within the solver processing, the simulation takes place and results are generated. Concluding, the key results are extracted in the post-processing step.

As the costs of simulations decrease whereas the costs of physical prototyping increase, Norris (2010) shows evolvements of simulations within companies:

- Increasing number of simulations.
- Higher complexity of simulations.
- More data per simulation.
- Integration of nearshore and/or offshore developments.

The challenges stated above are treated by SDM systems, a technical approach to handle simulations. In general, the SDM system transfers data onto the internet or intranet throughout the entire simulation process. It picks the necessary data and CAD geometry from the PDM (Product Data Management)

system at the beginning of the simulation process and provides it to a pre-processor (Ducellier et al., 2006). The prepared simulation model and input deck are returned to the SDM system and then forwarded to the solver. Generated results within the solver are sent to the SDM as output deck, which is distributed to the post-processor that generates a report of the simulation. At the end of the simulation process, results and feedback reach the PDM system. Many systems also include functions for partly-automated documentation and automated feedback, for example when a design is changed, so that simulations are not based on out-of-date geometries. As Section 4.2 shows, however, the requirements for notifications and documentation vary regarding the nature of the workflow they are part of.
The connection of PDM, SDM, and CAE applications is shown in Figure 1. All the generated data that is necessary for the simulation process is stored within the SDM system; the PDM system just contains results. This separation of PDM and SDM is utilized in most commercial solutions due to the very different requirements and user groups of PDM and SDM (ProSTEP iViP, 2008).

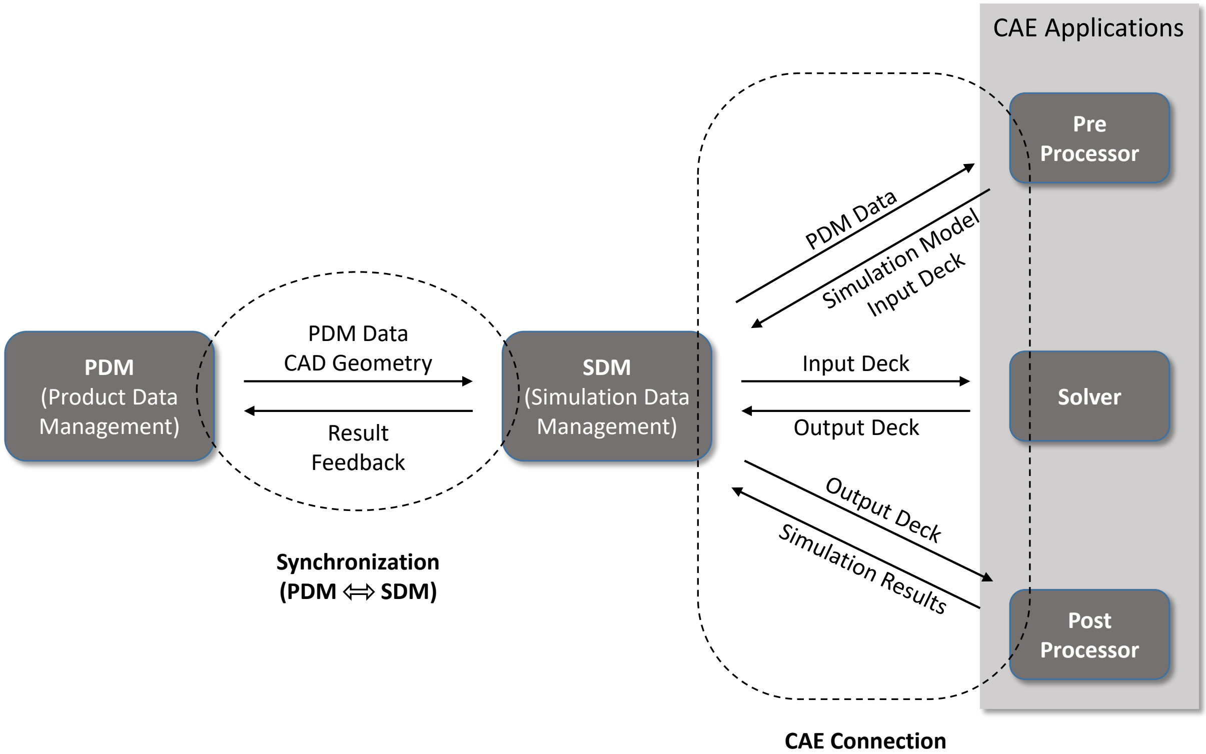

Figure 1. SDM within software environment according to ProSTEP iViP (2008)

The initial point of simulation, independent of the SDM system integration, is the simulation request. Research on simulation-oriented requirements with impacts on simulation requests and documentation was carried out in a previous paper. It describes in detail the proposal of a simulation assignment template, including a title page and requirement templates according to Rupp et al. (2009). The title page contains information about general metadata, input and output, simulation type, deadline, description, and planning of verification and validation. Requirements templates describe material properties, boundary conditions, and threshold values (Schweigert et al., 2015; Schweigert et al., 2016).
To efficiently integrate simulations and simulation requests in the development process, however, process analysis is necessary. Regarding the internal processes of a company, pattern recognition can be used to structure existing workflows and get insights on their connection to SDM systems. According to Kissel (2014), patterns describe properties of substructures. Those properties serve as conditions to cluster different patterns. Examples and specific details are given in Robinson et al. (2013).
Thus far, pattern recognition has not been used in the context of simulation data management within workflows. This paper works on that research gap and presents the key findings of the cooperation with an industry partner.

3 METHODOLOGY

In order to get an initial impression of SDM systems and their capabilities, a market overview was conducted. Several software solutions were examined according to their fulfilment of the requirements stated in literature and those identified in collaboration with the industry partner. The market research was based on advertising material, online search, and interviews with software vendors. Especially the personal contact to providers supported a detailed investigation and the focus of specific products.

In addition to these insights on SDM systems, it was important for the industry partner to reflect internal workflows for an appropriate application of the software. Therefore, development processes of several product groups were investigated that had been documented either as SIPOC processes or BPMN processes. The data acquisition of both description types had already been finished prior to this research. SIPOC (short for Supplier Input Process Output Customer) is a method for process documentation that gives an overview over the entire process on a high level and displays the results as a summarizing table (Rasmusson, 2006).

Other processes were formulated in the BPMN (Business Process Model and Notation) modelling language. Using activities and events according to Dijkman et al. (2008), the process tasks are represented by activities and connected with sequences and message flows. Gateways branch and bound the sequence and introduce iteration loops. With this modelling language, the entire process can be turned into petri nets in order to examine it further (Van der Aalst, 1998).

The information of the sources was translated into an overview that distinguished between tasks of the design department and the simulation department respectively. Therefore, a vertical description for workflows was used and each process task was assigned one by one to the performing department. In total, about ten workflow descriptions of product groups were investigated. As the information of some of them was available in both SIPOC and BPMN processes, the generated results were compared with each other and enabled adjustments for the final version. Based on the workflow description, different patterns were derived within several workshops. The effects of the identified patterns on simulation data management were discussed in follow-up meetings.

Concluding, the developed results were evaluated in an interview with the industry partner. The approach and the insights were presented to an expert and the outcome was discussed.

4 RESULTS

This chapter presents the recognized simulation workflow patterns at the industry partner and shows how they affect SDM systems. This includes the connection of workflow patterns and simulation requests.

4.1 Simulation Workflow Patterns in Development Processes

The workflow patterns were identified from the existing sources at the industry partner. They are grouped and labelled as "capsuled pattern", "integrated pattern", and "outside pattern". Figure 2 shows each structure. Within the illustration, the design department is located at the left side and the simulation department at the right side, distinguished by a dotted line. The workflow starts at the top of the figure and continues downwards. The thick line represents the position of single tasks within the workflow and whether they are executed by the design department or the simulation department. The dashed boxes show the specific character of a pattern. Due to the fact that capsuled patterns may occur at the beginning, at the middle or at the end of a workflow with different purposes, they are marked several times.

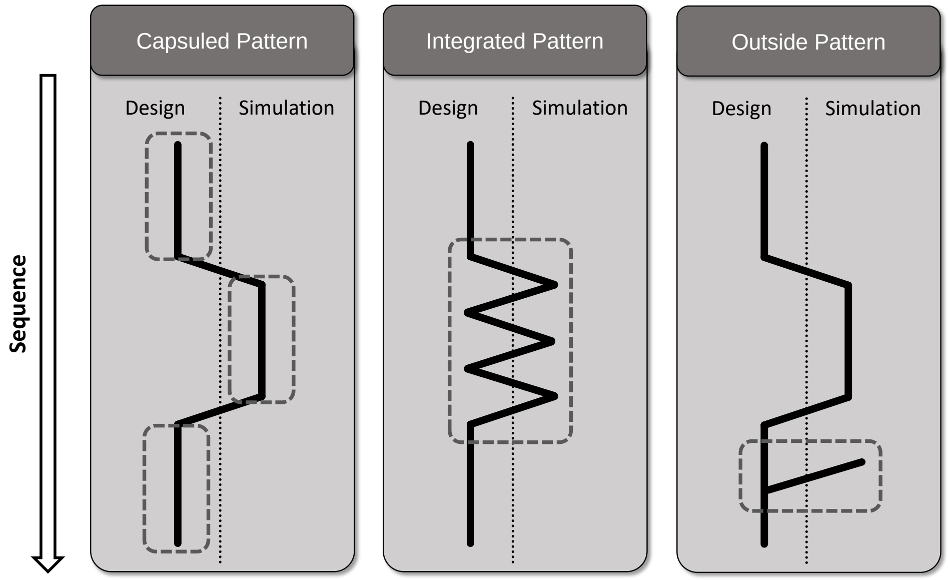

Figure 2. Identified workflow patterns

Capsuled patterns represent a sequence of several tasks that either is located at the design department or the simulation department with no interaction between the two. An exchange of data does not exist among them within this section. Just at the beginning and at the end of the pattern, communication is necessary between the disciplines. Three sub-types occurred:

- *Pattern at the beginning of a workflow*: The purpose is to generate an initial concept or layout, which is carried out by the design department. If a simulation task is at the beginning, initial parameters are generated that are necessary for the concept phase of the design department.
- *Pattern in the middle of a workflow*: This pattern occurs, if several tasks are carried out by the same department without external support in between. The content might be the same as the capsule at the beginning or end, depending on the entire workflow.
- *Pattern at the end of a workflow*: The final capsule at the design department includes several steps of drawing, which conclude the workflow. Alternatively, the simulation can finish the process through the verification of the generated results by conducting different types of analyses.

The group of **integrated patterns** is characterized by the alternation of tasks between design and simulation departments. Integrated patterns may occur at any position of the workflow. Each element is followed by a task that is conducted at the other department. Generated results have to be transmitted in order to either check the design or consider insights from simulation in the further design process.

Outside patterns describe elements that are necessary for further progress without having a specific predecessor in the workflow. Their input relies mostly on external sources or general assumptions within the development process. Thus, the task position of outside patterns within a workflow is not defined precisely as the input data does not have to be generated at a preceding step. The task just has to be performed before its output is needed for succeeding tasks.

Figure 3 shows a specific workflow of the industry partner. This product group contains all three recognized patterns, marked in the dashed boxes. In contrast to that, in general most workflows only include one or two kinds of patterns. In this figure, the sequence of tasks is from left to right. Simulation tasks are placed above the dotted line, design tasks below it.

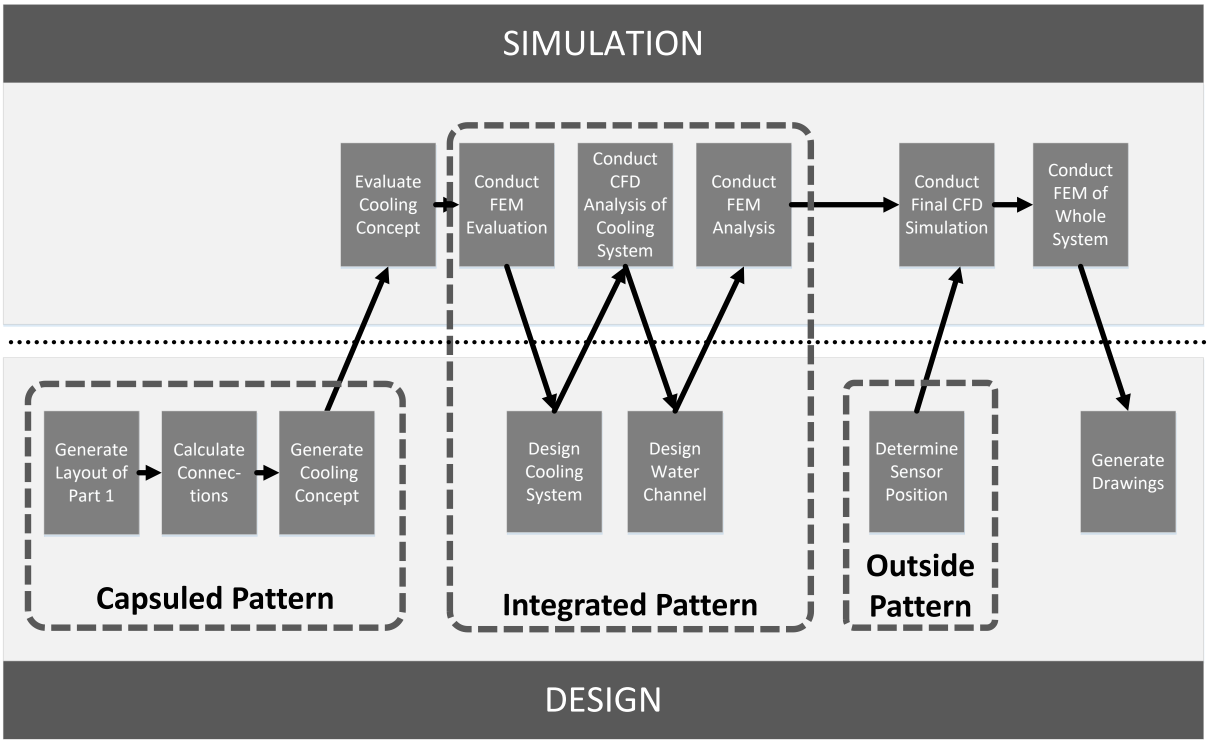

Figure 3. Patterns in a specific workflow of the industry partner

4.2 Impacts of Patterns on SDM Systems

Data is the main element that is distributed within SDM systems. However, interviews with the industry partner showed the handling, administration, and implementation within workflows require that several topics are taken in account. The list below and Table 1 make no claim to be complete, additional topics might be important in other circumstances, too.

- *Documentation*: Requirements at the beginning, the execution in the middle, and results at the end of the simulation process have to be documented.
- *Notification*: When workflow tasks are completed, the engineer of the next step must be informed so that he or she can start working.
- *Access Rights*: The engineer that has to conduct investigations needs access to the relevant data.
- *Monitoring*: The product development process is complex and contains many individual tasks. To receive an overview of the current status, it should be possible to track the progress of the process.
- *Checks*: Several different properties have to be taken into account before a workflow task is finished and its results are distributed to the successor.

Table 1 . Influence of workflow patterns on SDM

	Pattern		
	Capsuled	Integrated	Outside
Documentation	Inside: Medium Outside: High	High	Medium
Notification	Inside: Medium Outside: High	High	High
Access Rights	Inside: Medium Outside: High	High	High
Monitoring	Inside: Low Outside: High	High	Medium
Checks	Inside: Low Outside: High	High	High

Capsuled patterns show a diverse behaviour between the inside and outside of the pattern. All topics at the inside are of low or medium importance. Towards the outside, they become important though. Access rights can be based on a user group for example. As within the capsule editors are in the same department, they are also in the same user group. When data is distributed to another department, it is important that access rights include also the recipient from this point of time on. In SDM systems, this topic is more important to handle outside of a capsuled pattern than inside. Also documentation is essential towards the outside of a capsuled pattern in order to transmit information across departments.
To the contrary, at integrated patterns, each issue shows high importance for the workflow as there is a high degree of dependency between the departments. Therefore, after each step, all topics have to be considered and no simplifications can be implemented.
Issues of outside patterns are also considered to be more important. As they are not critical in time, however, some elements can be regarded as less important.
At integrated patterns and outside capsuled patterns, transfer points of the workflow represent data distribution to other departments. As this is a sensitive process, it has to be treated thoroughly. However, capsuled patterns can be handled easier within SDM systems. Therefore, the focus has to be on the identification of capsuled patterns in order to enable simplifications in the implementation process of such a system.

4.3 Impact of Patterns on Documentation of Simulation Requests

Simulation requests including their documentation are important elements of the cooperation between design and simulation departments within the product development process. Three specific documents of industry partners with different company sizes were investigated, shown in Figure 4. In addition to the written forms, the simulation request can be formulated orally.

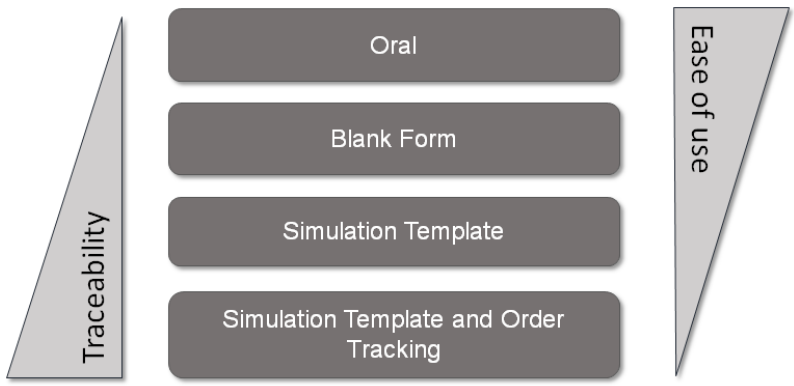

Figure 4. Forms of simulation request

In an oral simulation request, the engineers of different departments talk to each other and exchange all necessary information. Blank forms are the easiest way of written simulation requests – the commissioning engineer just fills out a document containing details of the simulation. Within simulation templates, the process is more structured, interactive, and detailed for the ordering engineer. In addition, order tracking elements can accompany the simulation process and occurring results can be monitored there. In general, traceability and quality of documentation increase with the complexity of the simulation request and vice versa. If traceability is very important, only complex solutions are suitable within the process. For each product and each firm, an appropriate trade-off has to be found. Figure 5 shows the basic contents of simulation requests as applied by the industry partners. The parameter list is an optional part to provide specific information like material properties or load values.

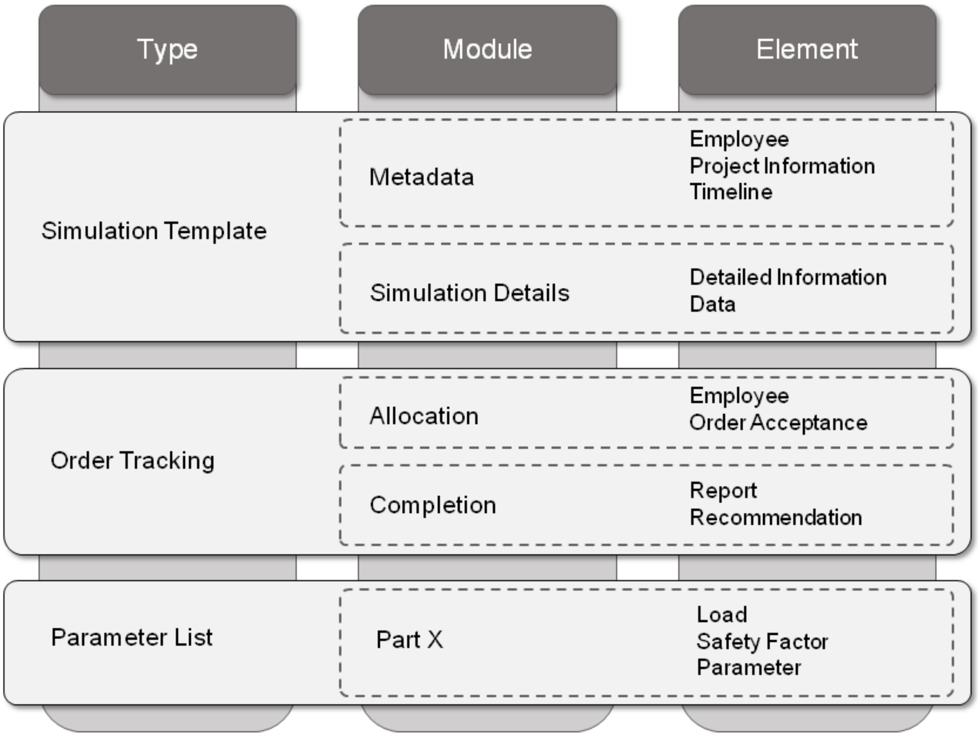

Figure 5. Discovered types, modules, and elements of simulation requests

The forms of simulation requests are related to workflow patterns and SDM systems. Each of them is suitable for a different kind of workflow pattern. In addition, they depend on the firm size. Table 2 shows appropriate simulation requests in relation with the company size. They correspond to the first line of Table 1.

Table 2. Documentation depending on workflow pattern and firm size

	Pattern		
	Capsuled	Integrated	Outside
Large Enterprise	Inside: Blank Form Outside: Simulation Template and Order Tracking	Simulation Template and Order Tracking	Simulation Template
Small and Medium Enterprises	Inside: Oral Outside: Simulation Template	Simulation Template	Blank Form

The complexity of a simulation request corresponds to the firm size. For example, oral requests turn into blank forms inside a capsuled pattern when the firm size is switching from mid-sized to large enterprises. The same situation occurs at integrated patterns: at big concerns, order tracking is added to the simulation templates. This characteristic is due to varying communication channels depending on the company size. Within small firms, design and simulation departments consist of only a few employees, who even might be located in the same room or at the same floor. For them it is easier to formulate requests orally than filling out documents. In contrast to that, hundreds of engineers work within the design and simulation departments of big companies. As they are more separated from each other, communication as well as simulation requests need to be standardized and traceable.

The comparison of the documentation between different workflow patterns shows that the requirements for simulation requests are high at transfer points. Above all, those points occur at integrated patterns and towards the outside of capsuled patterns. The reason for this situation is the tendency of more separation between two different departments. In turn, inside of capsuled patterns, if tasks are carried out by one department, the barriers among them are lower.

5 CONCLUSION

5.1 Discussion

The generated workflows are the basis of the pattern recognition, but the resulting list of patterns might not be complete. Although two different sources were taken into account, not all product groups of the industry partner were investigated. Additional patterns might occur when investigating workflows of further product groups or at other firms and branches.

Nonetheless, the recognized patterns are valid at the industry partner, as they occur in different assembly groups. The application on other firms depends on the internal structure on the one hand and the entire firm size on the other hand – above all the size of the research and development department. The recognized patterns can be valid for other firms as well, but adjustments might be necessary. If these patterns should be independent of the firm, more investigation has to be conducted. The impact of workflow patterns on SDM systems behaves analogously to the recognition of patterns.

Since different sources for the documentation of simulation requests were used in this research, the connection of documentation and firm size seems valid and can be applied on firms of different sizes. The trade-off between traceability and complexity has to be conducted individually. The relation of documentation and workflow pattern is most suitable at the specific industry partner of this paper due to the fact that the workflow patterns might need adjustments at other firms.

As the data basis was not acquired within this research, the results depend on the quality of the information provided by the industry partner. Nevertheless, both sources, BPMN tables and SIPOC processes, were compared to each other and the outcome led to adjustments of the workflows. In addition to that, the generated workflows were evaluated with experts from the industry partner.

5.2 Outlook

Future work might be conducted on the data acquisition at the industry partner. This includes the following tasks:

- Data acquisition with focus on the distinction of simulation and design departments.
- Completion of all product groups with the presented method.
- Gathering of information about performance of every single workflow (e.g. total duration, person hours spent, number of iterations, etc.).

Taking this additional information into account, new patterns might be recognized or the stated workflow patterns might be adjusted. In addition to increase the lot size, it would be interesting to align the detected patterns with workflows of a larger range of companies.

The simulation tasks within generated workflows might be attributed to different simulation sub-departments. At one specific workflow, the simulation department consisted of both, mechanical simulation and thermodynamics. This could lead to additional insights on the cooperation of design and specific simulation departments.

Some elements of the generated workflows occur several times at different assembly groups. The block elements might have specific input or output, or rather predecessors and successors. A pattern recognition that is based on single tasks, not on the sequence of tasks, would describe the behaviour and the impact on the workflow in more detail.

Not all simulation and calculation tasks are executed within the simulation department. For example, some simulations are located at the design department via CAD-integrated systems. The setting of these allocations should be studied including its impact on the workflow and the organizational structure.

In general, further research on this topic can contribute to an enhanced version of the introduced concepts and make them more applicable for industry due to their higher granularity. As a consequence, the implementation process and the utilization of SDM systems can be improved.

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