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Investigating low data consistency in work planning processes - causes, measures, and opportunities

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Abstract

Digital transformation increases the need for interdisciplinary collaboration along the product lifecycle. It is currently hindered by a low data consistency resulting from the use of heterogeneous systems and data models. Especially in work planning, where several data models are combined, this decreases efficiency. Systems Lifecycle management (SysLM) offers a solution to this remedy. However, a sudden switch to SysLM is not possible in brownfields. Thus, it is necessary to examine the challenges and opportunities to derive case-specific measures that enable its adoption in work planning.

Keywords: data consistency, system lifecycle management, industry 4.0, information management, product lifecycle management (PLM)

1. Introduction and motivation

Changing customer requirements, smaller batch sizes due to increasing individualization, shorter innovation cycles, and an increase in product variants pose a variety of challenges for companies. These issues can have an impact on competitiveness when it comes to customer satisfaction (Bremer, 2020; Eigner et al., 2016). In order to meet these challenges, companies require a high level of adaptability to allow for more frequent changes to products (Bremer, 2020) and production (Wiendahl et al., 2014). The digital transformation can provide a remedy here by establishing Industry 4.0. The implementation of Industry 4.0 takes place by means of "horizontal integration" (networking of systems in the value chain within and outside a company), "vertical integration" (networking of systems and plants across the levels of the automation pyramid), and "consistency of engineering along the entire value chain" (Cimini et al., 2017). This requires increased interdisciplinary collaboration between individual disciplines throughout the various phases of the lifecycle, such as work planning and engineering, which will be the focus of this contribution. For example, knowledge feedback from product lifecycle phases downstream of development can contribute to the improvement of future products (Sendler, 2013). Furthermore, the time-consuming and cost-intensive construction of prototypes can be avoided through the use of virtual product development and validation methods (Sendler, 2013; Straub and Riedel, 2006). The basis for this collaboration is cross-disciplinary data consistency (PTC, 2020; Straub and Riedel 2006; Zehbold, 2018). In most companies, the transformation toward increased data consistency takes place in the brownfield environment. This requires an incremental and orderly approach. The aim of this paper is to analyze processes with low data consistency, to elaborate the causes for poor data consistency and identify measures to increase consistency. From this, further need for action for the development of support can be derived. To this end, the next section narrows down the scope of the study and provides a brief overview of the state of the art in digital data management and the associated challenges. This is followed by a specification of the objective and the derivation of specific research questions. Finally, there is an overview of the survey concept and then the presentation of results generated by the survey.

2. Narrowing down the scope and identifying the state of the art

Figure 1 shows the interrelationships between the development and production of a product. During the product creation period, product and production development takes place in the product lifecycle phases of (technical) design and work preparation. The latter represents the link between development and production, which are interdependent in many ways (Biffl et al., 2016; Bremer, 2020). One part of work preparation is work planning (Arndt, 2021). Work planning comprises all one-off planning activities that ensure the production-oriented design of a product (Arndt, 2021). Work planning is therefore the development-side part of work preparation. At this point, digital product, process and factory models must be linked together (Ferrer et al., 2016). If this is done inadequately, start-up and coordination problems can occur at the transition to production, which can lead to considerable additional costs (Zehbold, 2018). For this reason, work planning is considered central to the design of digital data consistency for promoting effective and efficient interdisciplinary collaboration.

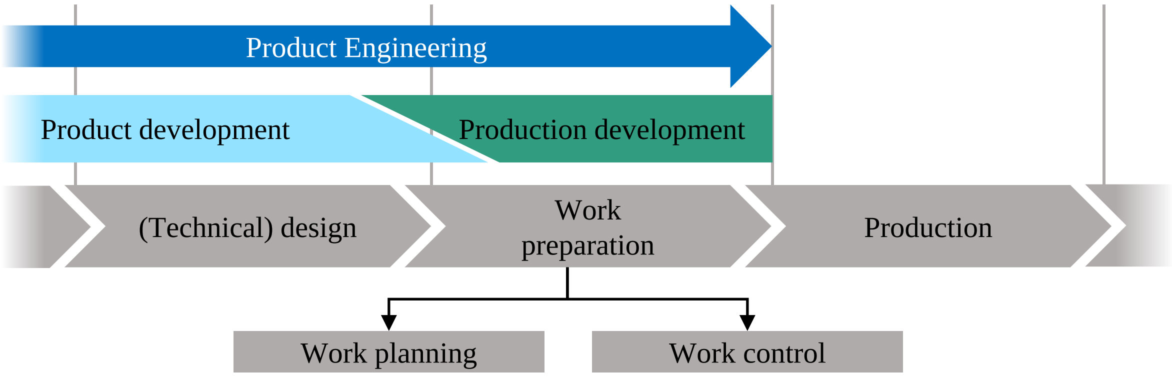

Figure 1. Context of work planning based on (Acker, 2011; Arndt, 2021; Eigner and Stelzer, 2009; Watermeyer, 2016; Wiendahl, 2019)

Until now, a great amount of manual effort is still required to link the data models in work planning due to heterogeneous system landscapes and grown data models in legacy systems. The reason for this is that the individual disciplines along the lifecycle work in different monolithic systems. Although product lifecycle management (PLM) has been propagated as a solution for many years, the PLM vision has not been implemented throughout all lifecycle phases. Characterized by the age of the third industrial revolution, various monolithic systems with different data models have emerged for the various disciplines. Traditionally, development in a company therefore works with product lifecycle management (PLM) systems, while production, logistics, and human resources prefer the use of production planning and control (PPC) or computer integrated manufacturing (CIM) systems as well as enterprise resource planning (ERP) systems (Eigner et al., 2017). PLM represents a holistic management and organizational approach that allows the bundling of all information along the product lifecycle with suitable IT systems (Zehbold, 2018). Nevertheless, most PLM systems in productive use at companies are predominantly only used in development and only for managing product 3D models, drawings, and product master data (Eigner, 2021). Over the years, highly customized PLM software solutions have been developed that contain special and complex data models (Bleisinger et al., 2022) which are difficult to integrate with other grown models. For some time now, the established vision has therefore been that PLM should evolve into System Lifecycle Management (SysLM) (Eigner, 2021; Zehbold, 2018). As a central backbone, SysLM should ensure the consistency of engineering throughout the entire product lifecycle. This makes it digital, consistent, and interdisciplinary (Eigner, 2021). SysLM bundles all available digital models in the various disciplines and brings them together from a variety of authoring systems by creating effective links between them. The idea of creating such holistic digital models as a representation of the real world is also referred to as “digital thread”. A digital thread connects several

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digital models or digital twins from different disciplines across the entire value chain (Daase et al., 2023). In the long term these holistic concepts could change collaboration in companies at an organizational, procedural, and systemic level (see Figure 2).

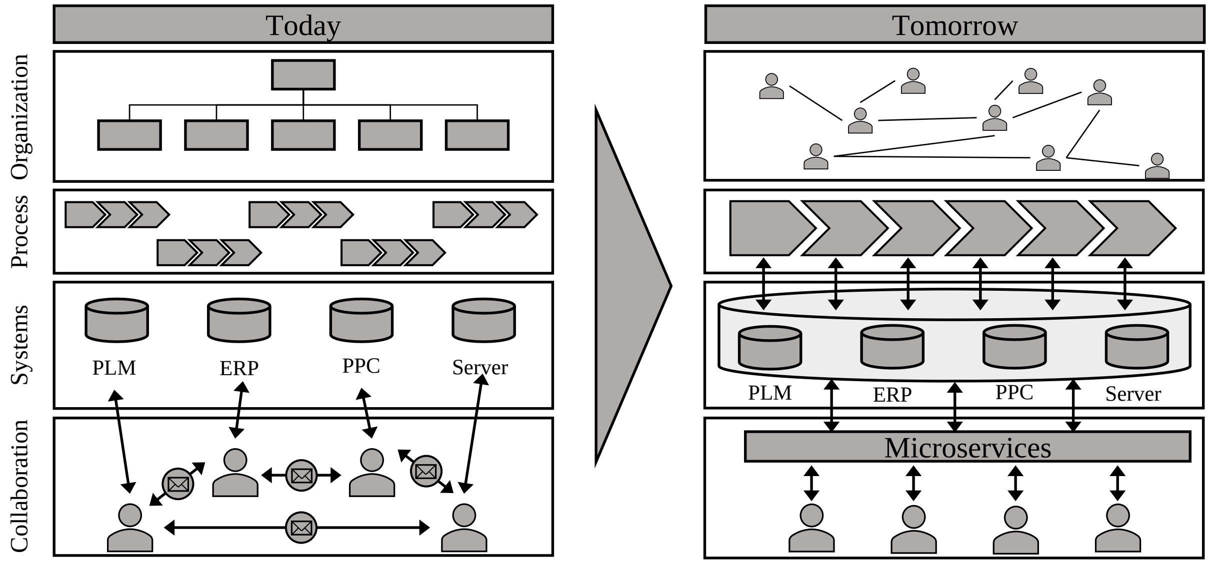

Figure 2. Current and future collaboration inspired by (Eigner et al., 2016)

Organizations will become less hierarchical, processes will become more comprehensive, and systems will be replaced by microservices (in the cloud) that access central data layers or data navigators (see Figure 2). However, the aim is not to create huge new monolithic systems that act as a "single source of truth", but to implement a data model as the backbone of end-to-end engineering that makes the data available in an understandable form (semantic linking) across disciplines (Eigner et al., 2016). There are already several approaches aiming to support this transformation. For example, ontologies can be used to create semantic consistent representation of knowledge (Noy and Mcguinness, 2001). Another possible solution is provided by enterprise architecture frameworks. There are numerous approaches for creating an enterprise architecture. Typically, they aim to close the gap between Business and IT by describing the architecture of an enterprise across different layers (Matthes, 2011). Although the previous two approaches are well suited to document knowledge in an explicit way and support the digital transformation of an enterprise, they cannot provide direct support for improving interdisciplinary work on an operational level.

3. Generating a concrete definition of the problem

The current state of the art emphasizes the importance of efficient data management and accessibility throughout the entire lifecycle due to the impact of the digital transformation. This ensures that the right data is available to the right employees at the right time, in the right quality, and in the right place (Ferrer et al., 2016; Zehbold, 2018). The consistent provision of data also ensures efficient and effective collaboration between different disciplines. Work planning in particular, as part of work preparation at the interface between development and production, can benefit from this development. Ideally, work planning can make extensive use of virtual product and process models that do not require any manual effort to maintain data (PTC, 2017) and avoid the costly and time-consuming creation of prototypes as much as possible. These models are currently fragmented and are not integrated into a consistent data backbone (leading to manual data maintenance). Software manufacturers have recognized the need for improved data management across the entire product lifecycle and are developing software solutions that further develop conventional PLM systems into comprehensive (SysLM) solutions (Eigner, 2021). However, it is not possible to deduce from previous publications and the state of the art how these SysLM solutions can be established in brownfield environments. An application-focused design of a corresponding comprehensive data model is also missing. In order to develop a suitable procedure for

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the design of a consistent data model between development, production, and work planning, this article aims to answer the following research question (RQ):

- RQ: What strategy is required to increase data consistency within work planning on a case-specific basis?

To answer this research question, three sub-questions (SQ) were identified to address the different sections of RQ:

- SQ1: Which **processes** in work planning have low data consistency?
- SQ2: What are the **causes** of low data consistency in work planning?
- SQ3: What **measures** could lead to an increase in data consistency in work planning and what opportunities arise from this?

4. Methodology used for data collection

To answer the above research questions, workshops were held at a commercial vehicle manufacturer with employees from the work planning department. In the area of commercial vehicles in particular, the wide range of vehicle types and the possibility of customer-specific vehicle design results in a large number of variants with enormous complexity – and these must be handled in series production. Figure 3 shows the company divisions to which the participants belong (Figure 3 left) as well as their age (Figure 3 center) and professional experience (Figure 3 right). The participants work at several hierarchical levels (from clerk to team leader). The diversity of age, experience, area, and hierarchy is considered important at this point in order to enable the broadest possible view of the topic from different perspectives. A total of N_{WS1}=23 participants were interviewed in WS1. N_{WS2}=12 of those N_{WS1}=23 also participated in WS2.

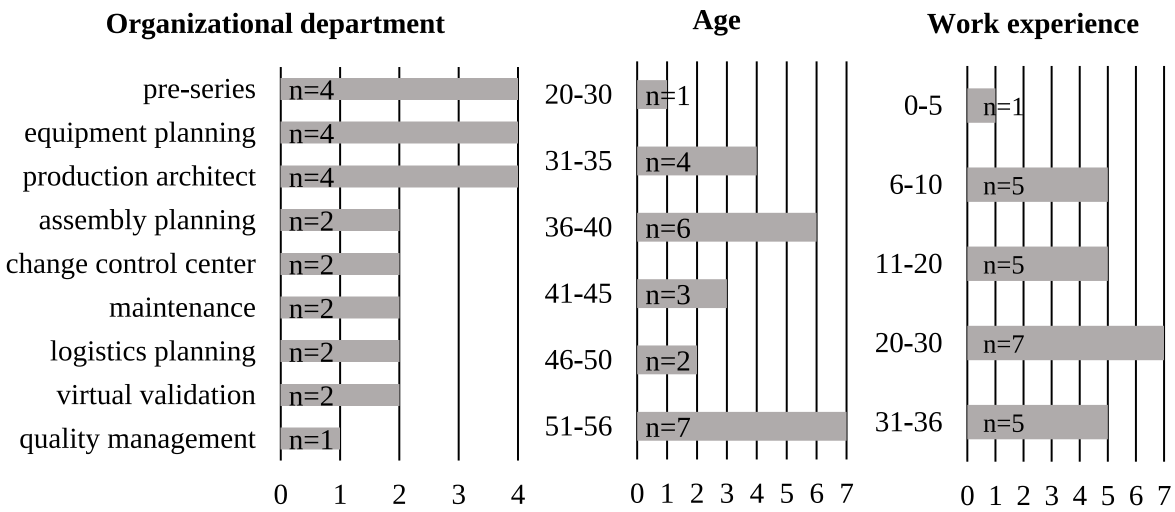

Figure 3. Organizational department (left), age (center), and work experience (right) of the N=23 participants

The data collection for this article was carried out in a two-stage process (see Figure 4) with the help of workshops. Processes suffering from low data consistency were identified in an initial workshop (WS1) with small groups of 2 to 3 participants per session. The aim of WS1 is to answer SQ1. The groups were created such that the participants shared similar tasks in their respective professions. In order to identify the processes in WS1, the brainstorming method was used as it is widely established and easy to apply. This allowed the participants to focus on the processes without having to ensure exact adherence to a more complicated method. The brainstorming phase was followed by a joint review of the processes in which duplicates were removed, thematic clusters were formed, and prioritization was carried out in the context of the task (focus on data consistency in work planning processes). The remaining processes were then described in more detail with the help of profile templates. The process profile template asks about the involvement of target groups and participants in the process as well as the information that flows in and out of the process and the IT systems used. In addition, the participants were also able to

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name known weaknesses. WS1 was conducted on 11 occasions for 90 minutes each time, with a total of N_{WS1}=23 people being interviewed. After successful completion of all sessions for WS1, the authors prioritized and narrowed down the identified processes. This again enabled the elimination of cross-session duplicates and allowed for the processes to be further narrowed down so as to focus on work planning. A total of 12 processes were followed up. These processes were examined in a second workshop (WS2), which sought to answer SQ2 and SQ3 by focusing on the causes of low data consistency, measures to increase data consistency, and the opportunities provided by increased data consistency. The chosen approach was therefore brainwriting conducted in accordance with method 635, since this enables the participants to generate a large number of ideas in a short time and achieve optimal utilization of synergies. WS2 was carried out with two groups of 6 people each over a period of 90 minutes. The method was applied by presenting 6 of the 12 processes in each session. In the first round of brainwriting, each participant had to answer three questions about one of the 6 processes in 5 minutes. The answers were then passed on to the next participant. In the next round, the participants were asked to further develop the answers that had been passed on to them. If that was not possible, participants could generate new ideas for the process. The ideas were therefore passed on a total of 5 times within the group, meaning that each participant could answer the questions for each of the 6 processes or further develop the existing answers. The questions to be answered by the participants were as follows:

- What are the **causes** of low data consistency in the given process?
- What **measures** could be taken to increase data consistency in this process?
- What **opportunities** would arise in this process as a result of increased data consistency?

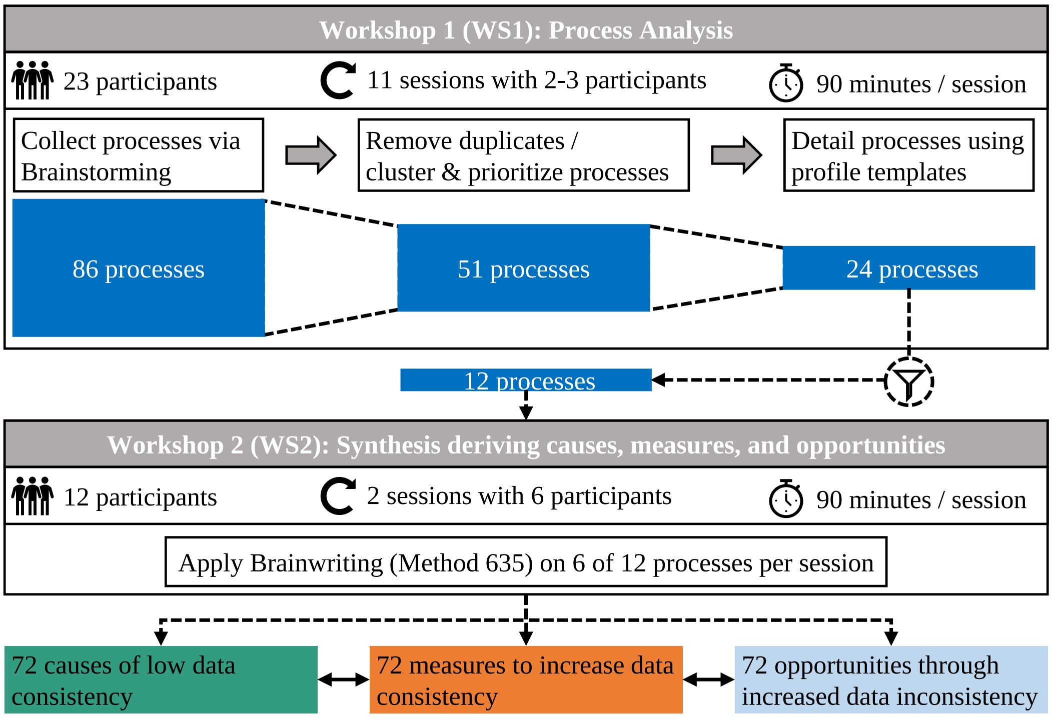

Figure 4. Diagram of the data collection procedure used

In two meetings, the 12 participants were each able to generate or further develop 72 causes, measures, and opportunities for the selected 12 processes. The results and findings are presented in the next section.

5. Evaluation of the results

This section contains the evaluation of the results from the workshops that were explained in Section 4. It also engages in critical discussion of the results with regard to their generalizability and the conclusions that can be drawn from them for further work.

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5.1. Results of process collection with regard to low data consistency in work planning processes

The evaluation of the recorded processes has shown that they can be classified into 8 overarching categories (see Figure 5). It can be observed that the two most common process types belong to the categories of “data linking” and “data management”. The more detailed description of the processes in the profiles shows, that the linking of data is mainly performed manually, and that manual data synchronization means regular manual data management is required. The profiles also show that the two subsequent categories, “information searching” and “coordination”, are partly related to the first two categories. Due to difficulties in linking and managing data, there is a need for coordination with different departments. And since information is not linked and managed consistently, it must be looked up. In total, these four categories affect 68% of the examined processes. Some, though not all, of these processes are administrative rather than value-adding in character and result in data redundantly being stored on several separate systems.

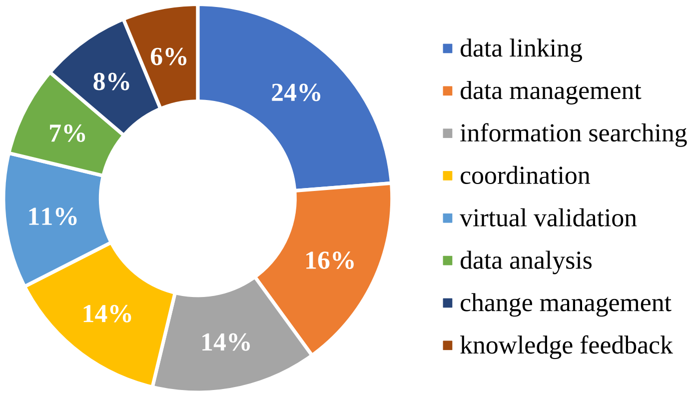

Figure 5. Categories of processes with low data consistency identified during the workshops

In line with the statements provided in the state of the art (see Section 2), it is possible to identify significant potential for reducing waste in planning processes through the introduction of end-to-end data management. With regard to data linking in particular, it was noticeable that product, process, and resource data for a large number of planning processes had to be linked manually time and again. The frequent changes result in higher data maintenance costs. In some cases, a targeted search for information and contact persons is required for the correct implementation of changes. To answer SQ1, it can be stated that processes with low data consistency mainly involve tasks requiring the combination of data from different sources and disciplines. Data handling is performed manually for the most part in this context, meaning that additional manual work is required to maintain the data and coordinate the usage of data.

5.2. Results relating to the causes of a lack of data consistency in work planning

A total of 72 causes for a lack of data consistency were derived from the brainwriting session. Each session identified several often interconnected consistency issues and causes. After removing duplicates, the results were aggregated to aspects representing low data consistency. The procedure for this aggregation is described below using an example. For the process “virtual validation of operational resources”, one participant provided the following answer for possible causes leading to low data consistency: “Not all operational resources are documented with 3D data until the deadline for virtual validation and even if the 3D models are at some times not accurate enough.” This answer was then allocated to the aspects of “data availability”, “data quality”, and “time management”. After this procedure was carried out for all the collected results, it was possible to derive 21 aspects of low data consistency. These aspects can be further divided into the 3 categories of “technology”, “organization”, and “culture” in accordance with the Technology-Organization-Environment (TOE) Framework in Tornatzky and Fleischer (1990). The previous statements can be seen as the answer to SQ2. Figure 6 lists the aspects as well as the frequency with which they appeared in the analyzed processes. The

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number of appearances demonstrates that, from a technological viewpoint, the most important aspects are “data quality”, “system and media discontinuity”, and “data consistency”.

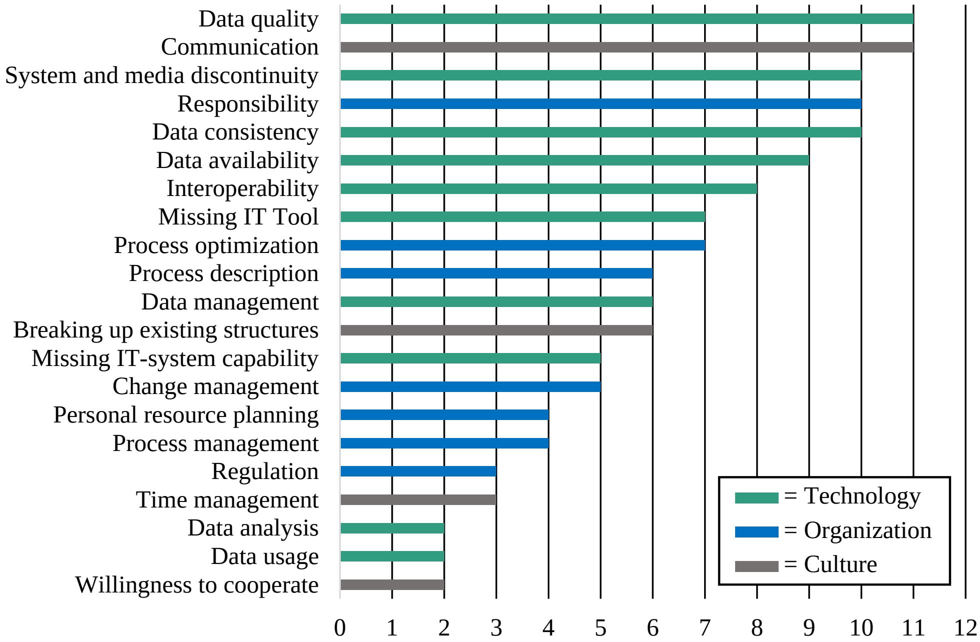

Figure 6. Aspects of low data consistency and their frequency in the analyzed processes

The missing knowledge of “responsibility” for tasks or in processes is the most important aspect for the category “organization”. In terms of cultural aspects, “communication” was mentioned very frequently. This does not refer to communication between departments or employees, but instead relates to the way exchanged knowledge is documented and to the need for communication in the first place. Since all these aspects were brought up in a highly interconnected manner rather than separately, it can be concluded that there is no single category that is the defining cause of data inconsistency. The cause is rather the combination of these mixed categories, which underlines the need for a comprehensive cross-system and cross-discipline solution instead of a short-sighted software system.

5.3. Measures for increasing data consistency in work planning processes and the resulting opportunities

Based on the recorded causes of low data consistency, the participants in the workshops were asked to derive measures that would be suitable for optimizing the processes and thereby increasing data consistency. The participants were encouraged to further develop the ideas of their predecessors in line with the 635 method that was used. The collected measures are featured in Figure 7. The measures were additionally grouped into layers that consecutively establish data consistency in work planning. The resulting scheme is also shown in Figure 7 and poses the answer to SQ3.

The “basis layer” of data consistency is formed by qualifying and sensitizing employees as well as through the consistent and clean documentation of knowledge. The fulfilment of the measures listed in the basis layer leads to higher availability of knowledge and focuses the right mindset toward data consistency among qualified employees.

The “architecture layer” is located on top of the basis layer. This layer guarantees the correct structure within an organization throughout an interdisciplinary development process and additionally ensures that there are no bottlenecks due to overloaded central departments. In addition, the architecture layer aims to establish process standards for documentation within a limited number of IT systems.

Important operational processes are then embedded in the “process layer”. Change management and project management must specifically be considered here. To achieve data consistency, the change management process should directly include affected departments and thereby relieve the central

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planning and changing departments. For this purpose, it appears necessary to link monolithic systems such as PLM, work planning, and resource planning. Besides change management, it is important to make use of project management (tools) throughout the interdisciplinary development process to ensure that the maturity of the data grows over time.

Finally, the "data layer" forms the last layer for achieving data consistency. It is essential to establish data governance within the data layer, ensuring standards in data handling, navigation to data, elimination of local or non-machine-readable files, and to close the gap between IT systems. The data layer is completed using a data backbone. This backbone ensures the linking of relevant data for product, process, and (operational) resource (PPR) and including it in a central data management system (PLM/SysLM) while also increasing the use of 3D models. Beyond this, it is also necessary to link data semantically to generate different views of data rather than creating new high-maintenance structures. The levels build on each other and are highly interconnected.

Figure 7. Architecture of measures to increase data consistency in planning processes

The opportunities that can be expected as a result of implementing the measures above include possible improvements in the areas of transparency, data availability, requiring fewer employees, shorter response times, increased efficiency, time savings in planning activities, avoidance of errors, and increased standardization in processes. Overall, these points fit into the magic triangle of quality, costs,

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and time (Wiendahl et al., 2014). This result is in line with the expectations of optimizing business processes at the company to maintain customer satisfaction and therefore underlines the hypothesis that increasing data consistency can have a positive impact on a company's competitiveness.

5.4. Discussion of the results

In this paper, it is important to note that the data collection was based on one company only. This focus on a single company context could potentially lead to a bias in the results, as the generalizability of the findings to the broader context could be limited. It is therefore important to consider this limitation and take appropriate precautions when interpreting the results to avoid over-generalization. The paper addresses low data consistency and related processes, causes, and measures. Processes that already have a high level of data consistency in the company were therefore not analyzed but may pose a challenge for other companies.

6. Conclusion & outlook

The goal of this article was to investigate what could be a potential strategy for increasing data consistency in work planning by systematically identifying causes, measures, and opportunities in relation to data consistency. An initial investigation into the state of the art and research has shown there is currently an evolutionary development of PLM systems toward SysLM systems that aim to capture, manage, and make available all the data generated during a product lifecycle. This approach is to be understood as a holistic concept, which is closely related to the idea of creating a digital thread. Such concepts cannot be implemented immediately in brownfield environments, as they prevail in most companies due to grown IT structures. The paper therefore uses an investigation at a commercial vehicle manufacturer in order to derive specific causes, measures, and opportunities for low data consistency. The focus in this regard was on work planning, since product, process, and factory models must be linked in this lifecycle phase. This linking process represents a major challenge in itself. The study shows that the processes identified as suffering from low data consistency can be divided into 8 categories. Data management and data linking represent a large proportion of these and are largely considered to be non-value-adding due to manual execution. In terms of the causes leading to low data consistency, 21 aspects were identified. These can be divided into the superordinate categories of “technology”, “organization”, and “culture”. The derivation of measures has shown that the development of an extended PLM system is not sufficient for overcoming the challenges on the way to complete data consistency. Many adjustments are necessary within companies to ensure that the technical, organizational, and cultural obstacles can be overcome together. To answer the RQ, a possible strategy identified by the investigation resulted in a scheme made up of a “basis layer”, “architecture layer”, “organizational layer”, and “data layer”. Each layer addresses measures that need to be taken to achieve data consistency in the process categories derived from the workshops. The layers therefore build on one another and are interconnected. Based on the findings, it seems appropriate for future research to design a methodological support to implement the derived measures, which supports interdisciplinary work planning through digital workflows. The development of the support requires the creation of a process model in conjunction with a data model that links product, process, and resource information. This enables the creation of semantic consistent digital model as part of a digital thread. As proof of functionality, the support should then be applied to a variety of work planning processes in order to confirm the generic functionality.

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