Managing IT Complexity in the Manufacturing Industry – An Agenda for Action

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ABSTRACT

Growing information systems (IS) often come along with growing IT complexity, because of emerging rag rug landscapes. This development causes rising IT costs and dependencies, which hinder the maintenance and expansion of the IS landscape. This article outlines the current research on published and presented methods to manage the rising IT complexity in a literature review. Because definitions of "IT complexity" vary a lot in literature, this paper also includes a definition of the term. In addition to that, it delivers a presentation of the used research methodology. Subsequently, it presents the findings in literature, highlights the research gap and – based on the literature analysis – presents the steps that need to be taken. A discussion of the results and a summary complete the article.

Keywords: Literature Review, IT complexity, Simplicity, Reduction, Information Systems, IS Landscape, Platform

1. MOTIVATION

IT complexity has been seen as a challenge for the management of information technology (IT) in general, and information systems (IS) specifically, for some ten years now [21]. While research activities in this context mostly focus on IT complexity either as a mathematical problem [32], or in the banking and insurance sector with its specific IS landscape [5], the authors have recently been experiencing many challenges due to increasing IT complexity in the manufacturing industry.

The reason for this increase can be found in the ongoing development of IT, coming along with initiatives such as the implementation of Internet of Things (IoT) devices on the shop floor (also known as Industrial IoT, IIoT [15]). In Europe, such initiatives are summarized with the German-coined term "Industrie 4.0"[3]. Introducing a new technology in the enterprise leads to an extension of IS and several new interfaces [10]. At the same time, IT departments still have to maintain legacy systems.

Drawn from the experience of the authors from one of the various projects with manufacturing companies, the following case study shows the challenges faced there:

The company uses several IS for the same purpose, i.e. four different CAx (Computer-aided technologies) systems and five ERP-like (Enterprise Resource Planning) systems, some of them self-developed. Acquisitions brought in subsidiaries with their own IS landscape. In addition, proprietary solutions have been built for specific cases to provide invoice information to customers, which leads to a need to integrate those systems to foster end-to-end processes. Requests from customers to provide IIoT-based services such as predictive maintenance are putting additional pressure on the IT department. This IS landscape leads to multiple versions of the same data in various systems. It also results in a loss of perception, high costs for licenses or maintenance, and poor support for business processes.

The reason for these problems with IT complexity can be found in an insufficient management of the IS landscape, often due to a lack of funds for the IT department, sometimes also due to a lack of knowledge on how to manage IT. This is a common problem for companies of the manufacturing industry, especially when they are small or medium-sized enterprises (SME).

To solve the issue, three steps have been taken: (1) discover the existing IS landscape, (2) develop paths for consolidation, (3) implement a software-defined platform, the single source of truth (SSOT) as a single access point for all information and data stored in the company's ISs. Main goal of this platform is to aggregate existing data for relevant business purposes and thereby help to solve multi data storage issues. This platform also enables a separation of the IS landscape in two layers and enables a "two-speed IT" approach [1, 30]. Using that, IT departments can fulfill new business requirements such as new analysis or interfaces using the platform without changing the core systems beneath.

2. STATE OF THE ART

For the literature review, the process evaluated by [31] is used to ensure that the search process is transparent and reproducible. The research question is: *What methods to manage IT complexity do already exist?* It also includes a definition of the term "IT complexity", based on the definition of complexity by [25] and the IT complexity definition by [5].

Definition: *IT complexity describes the complexity of IS landscapes, driven by the interdependent variety of its elements and the unsettling dynamic of technological requirements and development. Variety and dynamic result in a diffusing perception of the IS landscape, on the basis of which decisions are made that again lead to rising IT complexity.* [5, 26]

Subsequently, relevant search terms (see Table 1) were defined and conceptualized. These terms are the basis for the search process. With an evaluated Boolean, *Google Scholar*, *wiso*, *IEEE*, *Web of Science*, *SpringerLink*, *EBSCOhost* and *OCLC* were scanned.

	ADJ	**AND**	**OR**
IT Information technology Information system*	Complexity Heterogeneity Reduction Diversity Synergy Simplicity	Method* Model* Concept* Theory* Function*	control* measure* assess* present* manage* master*

Table 1: Search terms

Table 2 shows the results of the process. Including a backward search, 50 relevant articles were identified.

	Hits	*1st Screening[1]*	*2nd Screening[2]*	*Irrelevant*
Google Scholar	72	16	9	63
wiso	137	26	14	123
SpringerLink	43	4	0	43
IEEE	27	5	2	25
Web of Science	53	6	1	52
EBSCOhost	9	0	0	9
OCLC	18	2	0	18
Sum	**401[3]**	**60**	**26[4]**	**333**
Backward	**42**	**32**	**24**	**18**

Table 2: Results of the search process

Starting with evaluating the drivers of the complexity, researchers nowadays try to present solutions to this problem, because a rising IT complexity is always connected with inflexibility, non-transparency and higher IT costs that narrow the competitive advantage [12, 18, 24]. Several approaches arose in literature in the last decades that will be presented in the following.

The results of the literature analysis are divided in seven categories. **Standardizations** include tools like Enterprise Architecture Management (EAM) and Service-Oriented Architectures (SOA) as well as the use of standardized components and best-of-breed solutions. SOA has been widely used for more than ten years already. It facilitates the access to the provided services, untangles a “spaghetti infrastructure” and thereby reduces the IT complexity [29]. Referring to the production industry, EAM can be a supporting tool [2]. John Zachman already established the idea of this approach in 1987 as an enterprise architect at IBM, who had already realized that complex systems need to be controlled [34]. Current EAM tools deliver several possibilities to illustrate and design the enterprise architecture (EA) to get a transparent view on the used IS within the various departments [13]. It shows the numerous relationships of business processes, IS and the IT infrastructure. Well-known tools are ARIS (Architektur integrierter Informationssysteme[5]), Enterprise Architect or TOGAF (The Open Group Architecture Framework).

Measuring methods are the second category. Those involve a developed model by [27], that is based on the entropy measure to quantify heterogeneity. Moreover, [8] present a key figure of complexity including components, dependencies and the homogeneity of the used IS. Counting the Source Lines of Code (SLOC) is mentioned as a method to quantify complexity, in which elements of the 4+1 architectural view model are used as an extension [7, 16]. A self-developed tool by [18] is particularly addressed to the financial service industries. They identified measurable complexity indicators and made them visible and comparable [18].

Some authors broach the issue of implementing modern **technologies**. [12, 22] talk about autonomic computing and self-managed systems; an emerging trend since the beginning of the 21st century, especially pushed forward by IBM. More recently, [20] recommend in-memory databases such as SAP HANA, that enable ultra-fast search via high data volumes.

[4, 11, 13, 21, 22] highlight the importance of **process** management in the context of complexity reduction. Modelling, integrating and optimizing as well as standardizing represent the mentioned approaches.

More overall solutions concern the arrangement of the **enterprise architecture** in general. Managing the interfaces leads to less point-to-point connections [21], reduces interdependencies [23] and increases performance [11, 21, 23]. Second, the suggestion of a global process platform with standardized processes by [21] is seen to help managing IT complexity. [28] emphasizes the importance of a well-planned EA as the basis to deliver business value and therefore introduces a model of partitioning, simplification and iteration.

Several analyzed literature presents **general recommendation actions** for enterprises to reduce IT complexity without giving a step-by-step guide. [14] speaks about a consolidation of the IT systems whereas [13] propose to reshuffle the IT organization. Both agree on avoiding redundancies within the system and shutting down applications and legacy systems when introducing a new system. At last, reducing the rate of releases has a positive impact on IT complexity [23, 33].

In the category of **process models**, the literature search delivered only one result. [33] presents a five-step model (IT complexity check) to make the relationships between objects, processes and IT systems visible. Moreover, it supports by identifying the core processes of the enterprise and developing a strategic IT masterplan that is aligned to the overall business strategy.

The following **Figure 1** shows a classification of the named categories in a chart with the parameters “level of detail” and “applicability to enterprises”. It then highlights the gap in the field of a highly detailed and applicable method for the reduction of IT complexity.

[1] Title and abstract
[2] Whole text
[3] Includes redundant hits
[4] Without redundancies
[5] German for „Architecture of integrated IS“

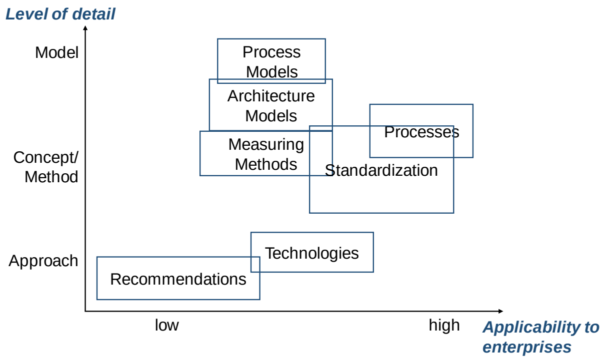

Figure 1: Classification of the categories

3. RESEARCH GAP

The state of the art shows that there are existing models, methods and approaches to tackle IT complexity.

EAM in general has been criticized, because it needs a lot of time and work to chart the whole architecture of the enterprise. This leads to no positive short term effect and, in addition to that, [17] showed an empirical argument that "EAM needs to be mature in order to have an effect [on IT]" [17]. Furthermore, the Forbes Magazine recently called the success of EAM tools "surprisingly paltry" and states that "cost savings and responsiveness benefits that EA has purported to deliver have been few and far between" [6]. [28] states that the success of the EA framework TOGAF is highly dependent on the knowledge and experience of the IT staff or consultants. Especially SMEs often stay behind the globalized leaders with the application of new technologies on the one hand and possibilities to operate with the complex IS landscape on the other hand.

In the financial area, a SOA is recommendable and leads to a clearly structured and transparent IS that reduces redundancy and inefficiency [9]. Self-developed tools like the one by [18] do not deliver concrete methods for enterprises and can only be used with support and guidance of the developers. Both are not adaptable to the manufacturing industry, because these often use a wide range of standardized systems like ERP, CRM (Customer Relationship Management), and SCM systems (Supply Chain Management) and face a global connection with suppliers, customers and producers that all have different IS. Splitting the standardized IS in a SOA would lead to an even higher IT complexity.

The mathematical approach by [27] does not include dynamic effects in EA, which are included in the author's definition, and, moreover, the data collection for this model is extensive according to the author's statement [32] and based on a high theoretical approach[5]. Therefore no direct support for enterprises is given. The tool by [18] does not offer an open process model for simplification. It is just applicable in cooperation with CAPCO and until now has only been tested in the financial sector. The approach by [7] is vague within the description. He recommends to count and observe, but does not present a solution for reduction. The key figure of [8] is easy to understand and adopt, but represents only a limited aspect of the extensive field of IT complexity.

Technological solutions do not reduce the IT complexity, but ease the impact. In-memory databases can lead to a faster running business with more efficiency but do not obtain well-managed data. Whereas process management is a main part of IT complexity reduction. Its importance is not disputable, but it does not affect all the aspects of IT complexity and therefore has to be accompanied by other solutions like a reorganization of the EA. The process model of [33]unites several aspects (processes, systems, relationships), but stays too general referring to the explanation and therefore cannot be seen as a detailed method to support enterprises. General recommendations in various aspects can awaken the importance to deal with this topic and can serve as a foundation to tackle this matter. But as they often consist of keywords and short, superficial explanations of those they cannot be seen as a support for this problem.

Companies in the manufacturing industry have to build on their existing IS landscape as they have no sufficient resources to completely rebuild their landscape, especially if they are SMEs. In addition, today's business applications such as ERP systems have the ability to cover most of the manufacturing companies' requirements and are easily customizable. Still, the IT complexity challenges remain and research has to be performed on this subject in order to develop a new and sustainable approach for the manufacturing industry.

Therefore, this research follows two main objectives: The first objective is to design IS architecture patterns to reduce IT overcomplexity. This concludes an approach for all dimensions of complexity. Firstly, *interdependent variety* by implementing SSOT. Secondly, *unsettling dynamics* by not implementing changes from business requirements in business applications, but in apps using the SSOT. Lastly, *lack of perception* can be addressed by a structured capturing of a representation of the current state of the IS landscape.

The second objective is to enable manufacturing companies to use the data stored in various systems for decision making. This realizes the concept of the digital shadow [25], which has the goal to aggregate raw data, enable multi-access, being always real-time and combine data from different systems. A platform supporting digital shadows gives companies the ability to use data to achieve transparency over their processes and to forecast events on their shop floor. The necessary technology to do so is ready to use, but companies also have to implement management methods, processes and organizational structures. These also have to be developed in this research.

4. STEPS TO GO

To achieve results regarding the objectives the research will develop a method to tackle IT complexity in their IS architecture (see Figure 2). IS architectures can be categorized by different levels depending on their role: Beginning from creating or storing data in hardware, via connecting and networking to the application that manipulates data, up to visualization and business processes. Also, IS can be ordered along the product lifecycle. This applies to the manufacturing industry, other industries have to choose different main business processes here. In the example in Figure 2, we see CAD and PDM (Product Data Management) systems in the phase of development, an ERP system and machines (M) producing data in the production phase, and a CRM system in combination with a SharePoint application in the phase of sales. All of these IS contain or use data, that is not interconnected, sometimes even stored multiple times in the same company. Therefore, the method developed in this research will enable companies in the manufacturing industry to implement a software-defined platform in their existing IS architecture. In total, four phases are planned to design this method.

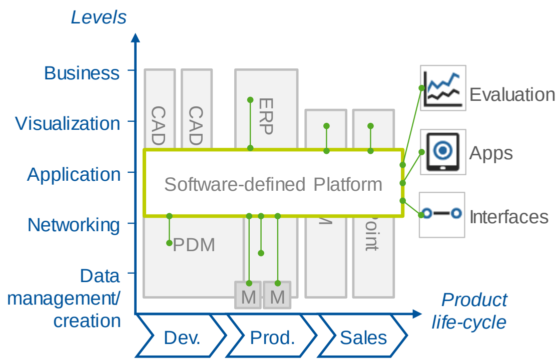

Figure 2: Implementation of a software-defined platform in an IS landscape

Phase 1: Describe types of software-defined platforms

This first model structures platform concepts by an examination of existing platforms from software vendors and in literature. The model will contain dimensions such as application area, technical layer, data handling or functionality. Relevant platform concepts for this examination have the following characteristics:

- Enable access across multiple domains
- Enable data analysis and data aggregation
- Enable management of dependent data records

For relevant concepts, requirements on IT security, availability and implementation will be raised.

Phase 2: Describe types of IS architectures

The second model will describe the classification of IS and their placement within technical layers. A main task will be the development of appropriate layers, being not too technical for managers and at the same time still having sufficient accuracy. The aggregation of all IS is the IS architecture, in which IS of real case examples will be classified. From there, standard types of companies will be derived based on the IT types of [19]. Using that, companies can get transparency over their IS landscape and subsequently a better view on their IT complexity.

Phase 3: Explanation of the gap

This phase will identify the gap between the current state of the IS landscape (phase 2) and the target state (phase 1). The requirements for platform integration, for the prevention of IT complexity and of best practices will be merged. Those requirements then need to be structured and built up as dimensions to describe the gap. Such Dimensions and sub-dimensions might be:

- Data: Data quality, level of redundancy, data topicality
- Information techniques: Real-time (or near real-time) availability, worldwide access, internal and external interfaces, data storage
- Organization: Clear responsibility for data and platform
- Processes and Culture: End-to-end thinking, IT as enabler, strategic approach

Using these, companies will be able to derive the changes needed to implement a platform and reduce IT complexity at the same time.

Phase 4: Organization of the integration

This last model summarizes the above and will give recommendations. First task for companies is to lay a solid foundation regarding organization and responsibilities, transparency on the current state of the IS landscape and the IT strategy. Second task is to describe the goal (using the model from phase 1) and the current state (using the model from phase 2) and combine those by using the gap analysis (model from phase 3). Phase 4 will show how to perform an implementation process by choosing the right division of the company to start with, choosing a software vendor and building migration and integration paths.

5. DISCUSSION

Several researchers and practitioners presented different solutions for managing, measuring and controlling the growing IT complexity of the EA. Nonetheless, recent literature underlines that there are still a lot of enterprises that have difficulties with reducing the complexity [20, 24]. From the authors' point of view, this is connected to the non-existence of a practical model that proposes a step-by-step guide to handle this challenge. Especially SME, with limited financial and human resources, need a supportive model to not fall behind the globalized enterprises in the growing competition.

Experiences from the manufacturing industry show that a platform design can efficiently help to reduce the complexity of IS. E.g. a PLM system collects and provides all necessary data along the whole product lifecycle and can easily be adapted by SMEs. Or an IIoT platform gives central access to all sensor data from a companies' production line. To give practical and understandable support for SMEs, practice-oriented research has to be done that takes the limited resources and requirements of these enterprises into consideration.

6. CONCLUSION

This paper summarizes the results from a profound literature survey on the state of the art of IT complexity. It shows a research gap, especially on the practical application of models for SMEs, and gives an outlook on how to tackle IT complexity by integrating a software-defined platform in the IS landscape.

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