An Empirical Study on Spreadsheet Shortcomings from an Information Systems Perspective

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Abstract. The use of spreadsheets to support business processes is widespread in industry. Due to their criticality in the context of those business processes, spreadsheet shortcomings can significantly hamper an organization's business operation. However, it is still unclear, what actual and typical shortcomings of spreadsheets applied as information systems are. Therefore, in this paper we present the results of an empirical study on spreadsheet shortcomings from an information systems perspective. In this sense, we focus particularly on how spreadsheets perform in their respective business context. The result of our work is a list of 20 shortcomings which typically occur in practice.

Keywords: Spreadsheet · Case study · Shortcomings · Business process support · Decision support system

1 Introduction

Spreadsheets are among the most common tools for business-users. They enable business users to get knowledge out of their domain-specific data by analyzing and visualizing it in an end-user-friendly way. Studies have shown that spreadsheets are used in a huge majority of firms in the US and Europe [4,12]. Their area of application is manifold, ranging from financial reporting to workload planning to general administration [15], either as throwaway calculations, or as well-designed business information systems [9]. In addition, spreadsheets not only are regularly used for a variety of purposes, but in many cases they are also critical and important to organizations [6,8]. For these reasons, spreadsheet-related problems can have a considerable impact on an organization's business operation and thus potentially lead to significant financial losses [5,17]. As a consequence, many researchers studied spreadsheet errors in order to propose approaches for either reducing the risk of their occurrence or for identifying, classifying, and fixing spreadsheet errors [16].

However, in addition to their error-proneness, spreadsheets in business suffer from shortcomings with respect to the support of respective business processes. For example, legal regulations like the Sarbanes-Oxley Act [21] in the US or Basel

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II [3] in the EU stipulate requirements concerning the retention and management of information within organizations. However, those requirements cannot be met by prevalent spreadsheet software, which negatively affects the organization's risk and compliance management [10,14]. Furthermore, those shortcomings also imply a significant lack of efficiency and thus potentially result also in financial losses. While there is a general agreement that spreadsheets in business suffer from this kind of shortcomings [10,14], there is still little research about them, i.e., it is still unclear which shortcomings with respect to the application of spreadsheets as information systems are common in practice.

Therefore, the present work shows the results of an empirical study about spreadsheet shortcomings conducted in two German companies. We discuss types of shortcomings which occur in practice, and why spreadsheets are applied in the respective cases despite suffering from those shortcomings. The contribution of this work is the identification, description, and categorization of 20 shortcomings obtained from nine cases of spreadsheet applications.

The remainder of this paper is organized as follows: Sect. 2 discusses related work in the field of spreadsheet research. Thereafter, Sect. 3 outlines the details of the conducted study, whereas the identified shortcomings are described in Sect. 4. Finally, in Sect. 5 we discuss and conclude the results of the study and this paper's contribution, and propose follow-up research activities.

2 Related Work

Due to their dissemination and popularity in practice, spreadsheets already have been subject of research for some decades [12,16].

In particular spreadsheet errors were investigated extensively in the past. Panko and Halverson [13] outline that spreadsheet errors are widespread, wherefore they propose to classify those errors in order to be able to assess approaches for reducing the risk of errors. Thereby, they differentiate between quantitative and qualitative errors. Quantitative errors are either omission errors, logic errors, or mechanical errors, while qualitative errors are primarily design errors which potentially lead to quantitative errors in the future. Based on this classification, Rajalingham et al. [18] derived a taxonomy as a framework for the systematic classification of spreadsheet errors. This taxonomy also considers the roles of users interacting with the spreadsheet (developers as well as end-users) and furthermore defines different kinds of qualitative spreadsheet errors, e.g., semantic and maintainability-related errors. Therefore, qualitative spreadsheet errors as defined by Panko and Halverson [13] as well as by Rajalingham et al. [18] do not directly lead to incorrect values in spreadsheets, but negatively affect the spreadsheet's usability, maintainability, and related aspects. In this sense qualitative errors are consequences of those shortcomings in the same way as quantitative spreadsheet errors usually are consequences of qualitative spreadsheet errors. The present paper adds a new dimension to the taxonomy as proposed by Rajalingham et al. [18] which also includes causal relationships to qualitative errors.

Grossman et al. [9] urge on perceiving spreadsheets as information systems focusing on business processes instead of personal productivity tools. They highlight the importance of spreadsheet information systems for business, and also show that they are used for a variety of purposes and in a plethora of areas. Consequently, spreadsheets which support business processes also inherit common information system requirements regarding information management, collaboration support, etc. However, the focus of spreadsheets is solving problems [20]. This mismatch of what spreadsheets were primarily designed for and how they are applied in practice is supposed to be a major cause for the shortcomings as described in the present paper. Panko and Port [14] outline that spreadsheet errors are a serious issue, but also point out further concerns which are not related to spreadsheets as such, but to their application for supporting business processes. They explicitly name privacy, security, and compliance as issues raised by spreadsheets. Those issues are induced by the application of spreadsheets in regulated areas like financial reporting, so that they become subject of legal regulations (e.g., Sarbanes-Oxley Act [21]) and thus have to fulfill respective requirements. However, since spreadsheets are not focused on supporting business processes [20], spreadsheet software usually does not address those legal regulations. This is another cause for shortcomings from an information systems perspective as described in this paper.

While Panko and Halverson [13] as well as Rajalingham et al. [18] describe the consequences of spreadsheet shortcomings when applied as information systems, and Grossman et al. [9] as well as Panko and Port [14] outline their causes, there is very little scientific research about which concrete shortcomings actually exist in practice, and in particular there is no work providing an overview over those as targeted by the present paper. For example, Nardi and Miller [11] claim that collaboration support is an essential concern of spreadsheets applied as information systems, and thus they already highlight one concrete shortcoming from an Information Systems perspective. Furthermore, the papers by Rothermel et al. [19] as well as Ayalew and Mittermeir [2] is about testing and debugging spreadsheets, i.e., they address also one common shortcoming of spreadsheets, namely lacking support for Application Lifecycle Management (ALM).

3 Case Studies

In order to identify common shortcomings of spreadsheets with respect to the support of business processes, we conducted nine case studies in two German companies. Thereby, we observed the usage and context of each spreadsheet, and also asked for shortcomings in the respective use cases. We applied the research methodology of exploratory case research in a multiple-case setting [22].

The first cooperating company is a logistics company with more than 100 000 employees worldwide. In the context of this study, we cooperated in particular with an division of this company which provides IT services to the its business units. The second company operates in the financial sector and is part of a big investment and insurance group, also with more than 100 000 employees

worldwide. Both companies are internationally active, but located in Germany. In the remainder of this paper, we refer to the former company with "Company 1", and to the latter one with "Company 2". For identifying proper use cases, we asked both companies for spreadsheets they apply as information systems for supporting business processes. We identified four cases in Company 1 and five cases in Company 2. The cases are summarized in Table 1.

For each of the identified use cases, we contacted the responsible designers and users of the respective sheet, and conducted interviews for discussing the context and usage of the respective spreadsheet. On the one hand, we asked them about the life-cycle and design context of the spreadsheet, e.g., "What is the rate of change of the spreadsheet's content and structure?". On the other hand, we were interested in user-related as well as data-related aspects, e.g., "Which users and roles provide input for the spreadsheet or consume its output?". Aside from this context information about the actual usage of the spreadsheet, the interview primarily focused on concrete shortcomings of the respective spreadsheet which its users face in their daily work and hinders them in conducting their business activities. The final part of the interview dealt with why spreadsheets are used in the respective cases despite suffering from the identified shortcomings. In order to gain a better understanding of shortcomings and to have an additional source of evidence, we also asked for the respective spreadsheets themselves as well as—if available—documentations of those spreadsheets and their usage.

4 Shortcomings

By conducting the case study as outlined in Sect. 3, we observed shortcomings for each of the nine cases of spreadsheet information systems. Due to the open-ended nature of the questions about shortcomings in the conducted interviews, we had to interpret and consolidate those shortcomings in order to be able to derive a set of shortcomings which are common across those cases. The result of the consolidation is a list of 20 common shortcomings as listed in Table 2. For the sake of simplicity, we use a positive form for naming the shortcomings, e.g., "Separation of Data, Schema, and Logic" instead of "No Separation of Data, Schema, and Logic".

Furthermore, we categorized those shortcomings into six classes capturing different kinds of aspects of a spreadsheet information system. Those classes are *Readability and Understandability*, *Extendability*, *Manageability*, *Collaboration and Multi-user Support*, *Data*, and *Processes*. The following section describes each of the identified categories and their shortcomings in detail (order has no relevance).

4.1 Readability and Understandability of the Spreadsheet

This category of shortcomings deals with the readability and understandability of spreadsheets. In particular for users which are not the authors of the spreadsheet it is usually very difficult to understand the design of the spreadsheet. In this context, the design of a spreadsheet refers to its semantic structure and formulas, which in turn constitute a potentially complex network of semantic dependencies between the cells of the spreadsheet.

Table 1. An overview of all observed cases of Companies 1 and 2.

Code	Case Description
Company 1	
1.A	The spreadsheet in this case supports Human Resource (HR) managers to estimate capacities and to determine shortages and surpluses of HRs for a given year. Thereby, HR demands are primarily induced by current and planned projects, which in turn require specific roles and skills. These demands are compared with available HR capacities and visualized as a time-series chart.
1.B	In this case's spreadsheet, IT cost records for the whole company are imported from a financial reporting system and mapped to the responsible IT divisions. The output of this spreadsheet is a chart visualizing the distribution of the company's IT costs over the respective IT divisions.
1.C	The spreadsheet in this case documents all stakeholders of a given project and assesses them by three different dimensions, namely power of the stakeholder, his willingness to engage, and his mindset towards the respective project.
1.D	Similar to case 1.C, this case's spreadsheet documents the risks as well as corresponding mitigation and contingency actions for a given project. Those risks are assessed by their probability of occurrence on the one hand, and by their potential impact on the other hand.
Company 2	
2.A	The spreadsheet in this case enriches financial data imported from a database with manually inputted data and provides the generated information representing returns of investments (ROIs) as an input for another software system.
2.B	Based on data obtained from simulation software, which generates various scenarios, this case's spreadsheet creates a visual report consisting of multiple charts on the one hand, and providing its output for the import by other software systems on the other hand.
2.C	The purpose of the spreadsheet of this case is to calculate cash-flows based on current interests rates and to compare the resulting data with the results from another system.
2.D	In this case's spreadsheet, time-series data obtained from a database is enriched by information which has to be manually extracted from a report from a financial services provider. The resulting data is exported to a database.
2.E	The spreadsheet in this case imports pre-processed scenario-data from a numerical computing software and generates multiple charts summarizing certain aspects of the respective scenarios.

SC01: Formatability and Commentability of Formulas: In prevalent spreadsheet applications, formulas cannot be formatted (e.g., by line-breaks, indents, etc.) or annotated with comments. It is neither possible to visually highlight that certain code elements semantically belong together (e.g., separating those elements from the others through a line-break), nor to add comments allowing the author of the spreadsheet to explain certain parts of the formula.

SC02: Named Cell Addressing: There are three commonly used cell addressing schemes for spreadsheets [1]: A1-style (columns are referenced by letters, rows by numbers), R1C1-style (both columns and rows are referenced by numbers), and named addressing (cells are directly referenced by a unique name). While coordinate-based addressing schemes (which includes both the A1-style and the R1C1-style) are a defining feature of spreadsheets, they negatively affect a formula's readability. In contrast, by using the named addressing schema, the reader of a formula is already able to derive the semantics of referenced cell by the identifier in the formula.

SC03: Transparency of Information Flow: Spreadsheet formulas referencing other cells constitute a network of semantic dependencies between the cells of a spreadsheet and thus represent information flows. In prevalent spreadsheet applications these semantic dependencies are usually not transparent, i.e., it is difficult for the spreadsheet users to get an overview of the information flows between the cells of a spreadsheet. As a consequence, it is hard for the users to determine the provenance of a formula's input on the one hand, and to evaluate the impact of changes of a certain cell or formula on the other hand.

4.2 Extendability

This category is about extending the functionality of spreadsheet software by new components, e.g., to be able to integrate custom data sources, to perform custom calculations, or to display the spreadsheet's data in a tailored visualization.

SC04: Integration of Custom Data Sources: For many use cases of spreadsheet applications, the data from different kinds of data sources has to be integrated. While common data sources like SQL databases and CSV files are integrable by prevalent spreadsheet software, more specialized data sources (e.g., HR information systems as in case 1.A, or object-oriented databases as in case 1.C, c.f., Table 1) are not connectable to spreadsheets. In addition to that, common spreadsheet software does not provide an appropriate infrastructure for extending the set of integrable data sources, so that the integration of additional data source through macros is burdensome.

SC05: Extendability of Computational Expressiveness: Prevalent spreadsheet software already provides a rich set of operations which can be used in formulas, including simple arithmetic operations, conditionals, and advanced statistical methods. Additional functionality can be implemented by macros. However, as the case study has shown, the imperative paradigm of macros is considered as being not suited for the definition of spreadsheet operations by the interviewed spreadsheet designers. Instead, they would prefer a functional programming language. Furthermore, in prevalent spreadsheet software, macros are directly attached to spreadsheets, which hinders the independent development of them.

SC06: Custom Visualizations: In common spreadsheet software, users are able to create charts in order to visualize a spreadsheet's data appropriately with respect to its consumers. Thereby, those spreadsheets provide a certain set of visualization types (e.g., line charts, pie charts, etc.), which are easily configurable by end-users. However, spreadsheets are not providing an infrastructure for extending the set of available visualization types by custom ones.

4.3 Manageability

Shortcomings of this category capture the difficulties when designing and maintaining spreadsheets. In this sense, manageability and flexibility—as one of the defining features of the spreadsheet paradigm—are often contradictory qualities, which is the main reason for the existence of the following shortcomings.

SC07: Managed Evolution of Spreadsheets: After an initial design phase, a spreadsheet's structure still evolves over time, e.g., formulas are changed, or columns are added. In particular when having multiple instances of a spreadsheet, and the intention to merge them in future, the unmanaged evolution of spreadsheets becomes a huge challenge for the respective spreadsheet user.

SC08: Separation of Data, Schema, and Logic: One of the defining features of the spreadsheet paradigm is that data, schema, and logic are not separated from each other, which is the main driver for the flexibility of spreadsheets. The schema of a spreadsheet table is simply determined by the column headers, and its logic is represented by formulas defined in single cells. As a consequence, although the data rows of one data table are semantically of the same type, they have to be defined separately, e.g., row-based formulas and cell-types have to be defined for each individual row separately instead of defining them once.

SC09: Modularity: In many cases of spreadsheet usages (e.g., in cases 1. A and 1.B, c.f., Table 1), certain components (e.g., mapping tables) have to be used multiple times in one spreadsheet, or even in multiple spreadsheets. In order to preserve the Single Source Of Truth principle, those components should be defined only once in such a way that they can be addressed multiple times. As our study revealed, this is already done in many cases. However, on the one hand it is not possible to refer to components of other spreadsheets. And on the other hand the look-up mechanism of prevalent spreadsheet software (e.g., *VLOOKUP* in MS Excel) is cumbersome and error-prone.

SC10: Application Lifecycle Management: Prevalent spreadsheet applications do not support proper Application Lifecycle Management (ALM) for their formulas. In this context, ALM includes in particular testing [19], debugging [2], and central maintenance of spreadsheet formulas.

4.4 Collaboration and Multi-user Support

Due to its early emergence long before the days of collaborative information management, spreadsheet software was designed to be a single-user application. Consequently, prevalent spreadsheet software still suffers from shortcomings related to collaboration and multi-user support as described in the following.

SC11: Collaborative Spreadsheet Design: In prevalent spreadsheet software, components like formulas or visualizations are not shareable, i.e., they cannot be provided to other users so that those are able to reuse the respective functionality. On a related note, spreadsheet software does not maintain the roles of users with respect to those components, e.g., ownerships or responsibilities of certain formulas.

SC12: Element-Based Access Control: Prevalent spreadsheet applications do not support access control on the level of single spreadsheet elements, e.g., rows, cells, and formulas. Thereby, spreadsheet designers are neither able to prevent read access to certain individual elements (e.g., a formula) by certain users, nor to specify that only certain users are able to edit certain elements.

SC13: Element-Based Historization: Similar to SC12, spreadsheet applications do not support element-based historization and tracing of user-activities within the spreadsheet. In this sense, the spreadsheet software is not able to provide information about which cells, formulas, and visualizations were changed at which time by which users, or how a cell's value has evolved over time.

SC14: User-Specific Views: In a collaborative information system, users with different roles require different views on the same data, depending on their specific information demand. However, prevalent spreadsheet applications usually do not support the definition of user-specific or role-specific views. This means, that a spreadsheet provides the same view to each user, regardless of the respective information demand.

4.5 Data

Spreadsheets are used by their end-users in order to process, analyze, and visualize a manageable amount of data of a limited complexity. However, today's business processes for which spreadsheets are applied impose both a considerably bigger size and higher complexity of data to be analyzed. As a consequence, this circumstance leads to the following shortcomings of spreadsheets applied as information systems.

SC15: Complex Data Types: Spreadsheets only support basic cell types, e.g., strings, dates, and numbers. This means that managing linked data and complexobjects (e.g., network-like or hierarchical data structures) is a major

challenge in spreadsheets. Furthermore, the result of a formula is also restricted to be of one of those simple types, which impedes the definition of complex calculations and thus makes the analysis of complex data objects even more difficult.

SC16: Scalability: Contrary to the initial design of spreadsheets for the analysis of small-scale data sets, many business processes which are supported by spreadsheets impose the processing of huge data tables. However, prevalent spreadsheet applications either allow just a limited grid size and thus just a limited number of data sets, or calculations based on large-scale data suffer from an enormous loss of performance and even stability.

SC17: Spreadsheet Queries: Analyzing large-scale data sets requires both a query language for defining operations like filters, projections, and aggregations of data entries, and a respective query processing engine which is able to handle a huge data set. Prevalent spreadsheet software usually supports neither of those. One reason for this is the lack of an explicit data schema which could form the basis for a model-driven spreadsheet query language [7].

SC18: Custom Spreadsheet Meta-data: In certain cases of spreadsheet applications, a spreadsheet not only contains usage data, but also meta-data which is not directly related to the data of the spreadsheet, but to the spreadsheet itself. While usually default attributes like the last editor of the spreadsheet or the last modification date are already available and automatically maintained, prevalent spreadsheet software does not support the definition of custom meta-data attributes (e.g., owner of the spreadsheet).

4.6 Processes

Spreadsheet applications heavily rely on manual interaction through end-users and usually lack proper automation and process support. consequently, prevalent spreadsheet information systems suffer from the following shortcomings.

SC19: Support for Automation: Spreadsheets primarily serve as decision support tools [20]. In this sense, based on a manual input and manual definition of calculations, knowledge obtained from the spreadsheet leads to respective actions, which in turn have to be triggered manually by the user. Therefore, applying spreadsheets for decision support requires a significant effort which could be reduced by proper process and data management automation [10].

SC20: Reasoning of Derived Actions: When using spreadsheets as decision support systems, certain actions are triggered based on the knowledge obtained from the analysis of the spreadsheet's data. However, prevalent spreadsheets do not support the automated documentation of derived actions considering the respective context. This would enable the reasoning of derived actions and evaluating them in the respective context at a later point in time.

Table 2. A consolidated list of all obtained shortcomings. Each shortcoming is mapped to the cases in which it occurred. An empty cell means that there was no evidence that the shortcoming occurred in the respective case, i.e., the use case might still suffer from this shortcoming.

Shortcoming		**Cases as described in Table 1**								
		1.A	**1.B**	**1.C**	**1.D**	**2.A**	**2.B**	**2.C**	**2.D**	**2.E**
Readability and Understandability										
SC01	Formatability and Commentability of Formulas	X				X			X	
SC02	Named Cell Addressing	X	X							X
SC03	Transparency of Information Flow			X		X				
Extendability										
SC04	Integration of Custom Data Sources	X	X				X			
SC05	Extendability of Computational Expressiveness					X	X	X	X	X
SC06	Custom Visualizations		X	X		X	X	X	X	X
Manageability										
SC07	Managed Evolution of Spreadsheets					X	X		X	
SC08	Separation of Data, Schema, and Logic					X	X	X	X	X
SC09	Modularity	X	X							
SC10	Application Lifecycle Management					X	X	X	X	X
Collaboration and Multi-user Support										
SC11	Collaborative Spreadsheet Design					X	X	X	X	X
SC12	Element-based Access Control	X		X	X	X	X	X	X	X
SC13	Element-based Historization	X	X	X		X	X	X	X	X
SC14	User-specific Views	X		X						
Data										
SC15	Complex Data Types	X	X			X	X		X	X
SC16	Scalability	X	X				X	X	X	X
SC17	Spreadsheet Queries								X	
SC18	Custom Spreadsheet Meta-data	X								
Processes										
SC19	Support for Automation					X				
SC20	Reasoning of Derived Actions	X		X						

5 Conclusion

In this paper, we described 20 shortcomings of spreadsheets when applied for the support of business processes. Thereby we conducted an empirical study involving nine cases in two companies. We investigated concrete usages of spreadsheets by interviewing the responsible designers and users (c.f., Sect. 3). Based on the results of each single case, we performed a cross-case consolidation and derived common shortcomings of spreadsheet information systems (c.f., Sect. 4).

While the present work already reveals 20 shortcomings spreadsheets typically face when applied for supporting business processes, there might be additional shortcomings we didn't identify, in particular in different contexts and organizations. However, although the list of shortcomings is presumably not complete, it captures most aspects whose relevance were already outlined by related research [9,10,13,14,18]. Furthermore, in this work we have not done an assessment of shortcomings regarding their frequency or impact. Although several shortcomings occurred in multiple cases of our study, we consider the set of nine cases as too small to be an empirical foundation for such an assessment.

Many of the identified shortcomings are well-known in practice [10]. Therefore, tool vendors already provide extensions to existing spreadsheet software which address certain shortcomings of spreadsheets, e.g., *Slate*[1], *think-cell*[2], and *Google Sheets*[3] address *SC03: Transparency of Information Flow*, *SC06: Custom Visualizations*, and *SC11: Collaborative Spreadsheet Design* respectively. Moreover, many shortcomings are subject of current research activities. For example, Cunha et al. [7] developed model-driven spreadsheet queries and thus address shortcoming *SC17: Spreadsheet Queries*. Nevertheless, there are still shortcomings which are neither addressed by practitioners nor by researches. The reasons why spreadsheets are used in the companies which cooperated in our study despite suffering from those shortcomings are manifold: Previous knowledge in spreadsheet development as well as end-user empowerment were the most common arguments for using them. Also the possibility of prototyping an information system in order to iteratively establish knowledge processes is one of the main drivers for using spreadsheets.

Based on the results of the present paper, in the future we want to focus on certain spreadsheet shortcomings—in particular those of the manageability category. Thereby, we want to propose concepts for an innovative spreadsheet addressing the manageability-related shortcomings. Furthermore, by conducting a quantitative study with the results of the present qualitative study as its foundation, we aim to assess the shortcomings with respect to their frequency of occurrence and impact on the compliance efforts of the respective companies.

[1] https://www.useslate.com.
[2] http://www.think-cell.com.
[3] https://docs.google.com/spreadsheets/.

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