Communications of the Association for Information Systems

Volume 48 Article 37

4-29-2021

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Gerit Wagner
HEC Montréal, Canada & Regensburg University, Germany, gerit.wagner@hec.ca

Julian Prester
UNSW Sydney, Australia

Guido Schryen
Paderborn University, Germany

Recommended Citation
Wagner, G., Prester, J., & Schryen, G. (2021). Exploring the Scientific Impact of Information Systems Design Science Research. Communications of the Association for Information Systems, 48, pp-pp.
https://doi.org/10.17705/1CAIS.04837

Communications of the Association for Information Systems

Research Article DOI: 10.17705/1CAIS.04837 ISSN: 1529-3181

Exploring the Scientific Impact of Information Systems Design Science Research

Gerit Wagner
HEC Montréal, Canada
Regensburg University, Germany
gerit.wagner@hec.ca

Julian Prester
UNSW Sydney, Australia

Guido Schryen
Paderborn University, Germany

Abstract:

While design science research has established its position as a prominent field of research in the IS community, there is a lack of transparency regarding the impact of recent information systems design science research (IS DSR) papers. This lack of insight arguably poses challenges to an informed discourse and limits our ability to communicate the progress that IS DSR has achieved. Therefore, after mapping impactful IS DSR papers, we develop a scientometric study to address the lack of insights into factors that affect the scientific impact of IS DSR papers in top IS journals. In this study, we focus on active, IS-specific DSR areas and consider papers published in the AIS Senior Scholars' basket of journals between 2004 and 2014. Specifically, we develop a model that explores factors that affect IS DSR papers' scientific impact. Our findings show that theorization and novelty significantly explain scientific impact. We discuss our work's implications and derive recommendations intended to shape future knowledge creation in IS DSR.

Keywords: Design Science, Knowledge Dissemination, Scientific Impact.

This manuscript underwent peer review. It was received 12/23/2019 and was with the authors for 8 months for two revisions. Tuure Tuunanen served as Associate Editor.

1 Introduction

Information systems (IS) design science research (DSR) pursues dual objectives (Gregor & Hevner, 2013; March & Smith, 1995; Simon, 1969, p. 3): 1) developing useful artifacts that one can deploy in practice and 2) producing generalizable knowledge contributions to a cumulative body of design knowledge. Given these objectives, a vivid methodological and theoretical discourse has developed on how knowledge development in IS DSR should occur (e.g., see Hevner, March, Park, & Ram, 2004; Goes, 2014; Gregor & Hevner, 2013; Kuechler & Vaishnavi, 2012; Venable, 2006). In particular, a considerable part of the discourse revolves around two characteristics, novelty and theorization, which the pragmatic-design and design-theory camps exemplify (see Gregor & Hevner, 2013). Although undoubtedly useful, this focus on methodological, ontological, and epistemological aspects, which characterizes emerging branches of study[1], coincides with an IS DSR landscape and IS DSR clusters that lack transparency (Baskerville, Baiyere, Gregor, Hevner, & Rossi, 2018). By impactful papers, we refer to IS DSR papers that advance substantial knowledge contributions and, therefore, exert an impact on subsequent knowledge development as high citation scores evidence (e.g., see Hassan & Loebbecke, 2017). Specifically, we lack insights into recent and impactful papers that actually *do* IS DSR and not papers that simply *describe* how one should conduct it. For instance, existing scientometric maps of IS DSR tend to capture primarily methodological and theoretical papers on IS DSR (e.g., Akoka, Comyn-Wattiau, & Prat, 2016; Fischer, 2011; Piirainen, Gonzalez, & Kolfschoten, 2010) rather than papers that apply IS DSR[2], which emphasize the lack of empirical insights into the IS DSR landscape. Therefore, we first explore IS DSR papers that have exerted a strong impact on subsequent research and, thereby, shaped the evolving IS DSR landscape in top IS journals. However, such an analysis on its own only makes the research landscape more transparent and provides limited insights into *why* certain papers impact future research work and characterize IS DSR. A scientometric map—although an important exploratory step in itself—typically provides readers with prominent papers' titles but leaves them speculating about which characteristics make papers impactful. Thus, we dig deeper and analyze the characteristics that explain the impact that IS DSR papers have had on subsequent research by answering the following research question (RQ):

RQ: Which factors affect IS DSR papers' scientific impact?

To answer this research question, we examine 115 IS DSR papers that the AIS Senior Scholars' basket of journals published between 2004 and 2014. We initially explore our sample's thematic structure and construct a map of impactful IS DSR papers based on the bibliographic coupling technique. In our main analysis, we develop a scientometric model that draws on various characteristics to explain which factors affect IS DSR papers' scientific impact. By identifying generalizable characteristics that impactful IS DSR papers share, we derive more actionable insights for prospective authors, who, in Gregor and Hevner's (2013, p. 337) words, strive to position their "research for maximum impact". These insights not only help explain what has driven knowledge development and diffusion in past IS DSR papers but also indicate which characteristics will likely drive IS DSR papers' scientific impact in the future.

This paper proceeds as follows: in Section 2, we review related work on scientometrics and design science. In Section 3, we formulate hypotheses and develop a model that explains IS DSR papers' scientific impact. In Section 4, we provide descriptive statistics for our sample and overview the impactful IS DSR papers. In Section 5, we test our research model that explains IS DSR papers' scientific impact based on novelty and theorization. In Section 6, we discuss the current IS DSR landscape and the road ahead. In Section 7, we conclude the paper.

2 Related Work

In this section, we first define IS DSR. Next, we review related works on scientometric analyses that focus on citations as indicators for both scientific impact and knowledge diffusion (Grover, Raman, & Stubblefield, 2013; Mingers & Xu, 2010; Stremersch, Verniers, & Verhoef, 2007)[3]. In the scientometric literature, we focus on research that addresses the paper level[4] and present theories that can explain

[1] The terminology is based on Hassan (2011).
[2] In this paper, we refer to these papers as IS DSR papers.
[3] Hassan and Loebbecke (2017) comprehensively review different perspectives of scientometric research in IS.
[4] As such, we exclude, for example, research on authors, journals, and institutions.

citing behavior. We use these theories as a framework to identify impactful IS DSR papers' characteristics in Section 3.

2.1 Framing Information Systems Design Science Research

Recent IS DSR papers build on a long DSR tradition that has evolved over several decades. This intellectual foundation comprises an expanding discourse on DSR and distinct clusters. Prominent DSR clusters include Scandinavian IS development (Iivai & Lyytinen, 1998), the German Wirtschaftsinformatik (Aalst et al., 2018), and North-American research programs such as information systems design and optimization systems or group support systems (Nunamaker, Twyman, Giboney, & Briggs, 2017).

To position their research, design scientists frequently refer to Simon (1969), who distinguishes the natural sciences from the sciences of the artificial, which have their foundations in design logic. While the former focuses on "how things are", the latter focuses on "how things ought to be…[and on] devising artifacts to attain goals" (Simon, 1969, p. 114). In the ensuing discourse, we envision both paradigms as mutually informing each other rather than a dichotomy that might harm IS research's progress (March & Smith, 1995). We can recognize efforts to pursue an integrated body of knowledge in work from theorists and methodologists (e.g., Iivari, 2007; Kuechler & Vaishnavi, 2008).

Consistent with the literature (e.g., Vaishnavi & Kuechler, 2004), Venable and Baskerville (2012) define design science research as "research that invents a new purposeful artifact to address a generalized type of problem and evaluates its utility for solving problems of that type" (p. 142). In information systems, researchers conduct design science research to build various socio-technical artifacts (Bostrom & Heinen, 1977a, 1977b; Gregor & Hevner, 2013; Niederman & March, 2012), which they commonly distinguish according to March and Smith's (1995) DSR output framework. Various studies in the extant literature have modified and extended this framework, which contains constructs, methods, and models (Alturki, Gable, & Bandara, 2011; Drechsler & Dörr, 2014; Dwivedi, Purao, & Straub, 2014; Offermann, Blom, Schönherr, & Bub, 2010). Notably, March and Smith's (1995, p. 263) concluding call for "generalizations or theories explaining about why and how (or even if) any of these artifacts work" points to design theory (see Gregor & Jones 2007; Iivari, 2020; Schuster, Wagner, & Schryen, 2018; Walls, Widmeyer, & El Sawy, 1992), which researchers have discussed widely.

2.2 Explaining Scientific Impact

Explaining what distinguishes more impactful IS DSR papers requires a scientometric model that includes both factors tailored to the specific paper type (e.g., Tams & Grover, 2010; Wagner, Prester, Roche, Benlian, & Schryen, 2016), and factors that affect citing behavior in general, such as visibility and reputation (e.g., see Mingers & Xu, 2010, Tahamtan, Afshar, & Ahamdzadeh 2016). Thus, we review two prominent citing-behavior theories from the general scientometric literature that IS researchers have applied in their scientometric studies (Grover et al., 2013; Mingers & Xu, 2010). As we do not know about any work that has systematically analyzed IS DSR papers' scientific impact, we use these theories as a framework to derive both general and paper-specific factors that affect scientific impact. Based on this framework, we derive IS DSR papers' specific characteristics in Section 3.1. We include general factors that affect citing behavior as control variables when we develop the research model (see Section 3.2).

The normative theory and the social constructivist theory constitute the two established theories that explain citing behavior (Hassan & Loebbecke, 2017). The normative theory, which Merton (1973) mainly advanced, defines a citation as an author's acknowledging that they have used other authors' work for intellectual purposes. In this view, citations represent an intellectual or cognitive influence that the cited paper has on the citing paper. This normative perspective has motivated many citation analyses and led researchers to develop scientific impact measures that, consequently, all rely on the normative theory's validity (Thornley et al., 2015).

The competing social constructivist view (Gilbert, 1977) contends that authors cite in order to persuade their readers. Hence, this view sees citing as a rhetorical system through which researchers try to convince the scientific community about their own work's value and relevance. In socially and economically conditioning the audience, they may rely on a journal's impact, their own prestige, their self-interest, or the target audience (Gilbert, 1977). In essence, this theory posits that authors can socially construct citations to support their own arguments rather than to acknowledge the cited work's intellectual contribution. The social constructivist theory questions using citation counts as a measure for papers' quality or impact (Knorr-Cetina, 2013).

Researchers have conducted many studies to empirically test the validity of both theories (Bornmann & Daniel, 2008). Citation network approaches provide evidence for a significant positive correlation between the number of citations and paper quality and, thus, support a normative view of citing behavior (Baldi, 1998; Stewart, 1983). Interview and questionnaire-based studies that have asked authors about why they cited certain papers have also concluded that Merton's normative theory better explains their results (Shadish, Tolliver, Gray, & Gupta, 1995; Thornley et al., 2015).

3 Hypotheses and Research Model

In order to explore and explain IS DSR papers' scientific impact, we develop a research model that distinguishes impactful IS DSR papers' characteristics as high citation scores evidence (e.g., see Hassan & Loebbecke, 2017). To do so, we analyze IS DSR papers' novelty and theorization and theorize that these two factors affect scientific impact (Baskerville et al., 2018). To test our hypotheses, we develop a comprehensive research model (see Section 3.2), which shows that, after controlling for effects related to journal and author visibility, these characteristics significantly affect scientific impact. We structure our research model according to the framework that the two prominent theories of citing behavior constitute (see Section 2). The control variables concur with the social constructivist theory, which contends that authors cite to persuade readers and reviewers by, for example, selecting authoritative sources that support a given argument or citing potential reviewers' and editors' papers. The main variables, which correspond to the hypotheses that we introduce in Section 3.1 and 3.2, concur with the normative theory of citing behavior, which contends that authors cite to credit cognitive intellectual influences.

3.1 Hypothesis Development

As normative citing behavior is associated with attributing intellectual and cognitive influences, corresponding factors commonly include a paper's generality (Ellison, 2002), its agreement with the literature (Uzzi, Mukherjee, Stringer, & Jones, 2013), the rigor of its research methodology (Judge, Cable, Colbert, & Rynes, 2007), and its contribution's novelty or originality (Grover et al., 2013). Considering that research varies wildly in type (e.g., literature reviews, case studies, and opinion papers), we evidently cannot compare different types directly and need to develop factors specific to IS DSR papers[5]. To tailor an appropriate model for IS DSR papers' specific characteristics, we draw on the DS literature that discusses IS DSR papers' various qualities and desirable properties. Overall, we contend that two factors intellectually or cognitively influence other researchers and affect scientific impact: 1) the research contribution's novelty type and 2) the theorization level.

3.1.1 Novelty Types

Researchers have shown a paper's novelty, or innovativeness, to correlate significantly with scientific impact (Grover et al., 2013; Judge et al., 2007; Stremersch et al., 2007; Uzzi et al., 2013). One reason why concerns the fact that conventional papers can cite plenty of alternative works but novel papers make unique knowledge contributions that provide a foundation for subsequent research streams (Tams & Grover, 2010). Put differently, novel papers have the distinct advantage of being the first to explore new questions or advance new approaches. Researchers have widely discussed the type of novelty that one should expect from an IS DSR paper. This discussion has encompassed questions about what distinguishes routine, professional, commercial, or industrial design from design science. The common stance that design science research—in contrast to routine design—should make novel contributions to knowledge reflects this distinction's importance (e.g., Baskerville, 2008; Gregor & Hevner, 2013). For instance, in advising doctoral students, Davis (2005) emphasizes that routine or industry design does not suit a research paper because it rarely makes "a contribution to knowledge other than actually doing something that everyone knows can be done and at least conceptually how to do it" (p.18). Similarly, Niederman and March (2012) emphasize three conditions that each qualify a design-oriented paper as design science: 1) demonstrating that building an artifact is technically feasible despite doubts about its feasibility, 2) developing an "innovative solution to an important problem", and/or 3) substantially improving the established "understanding of the problem space for an important class of problems" (p. 11). Gregor and Hevner's (2013) framework, which distinguishes IS DSR based on a problem's and

[5] The fact that scientometric studies tend to focus on different genres reflects the need for researchers to adapt scientometric models to specific paper types (e.g., Tams & Grover, 2010, Wagner et al., 2016).

proposed solution's novelty, also reflects novelty types[6]. While routine design describes applying known solutions to known problems, improvement describes developing novel solutions to known problems, exaptation describes transferring known solutions to new problems, and invention describes developing new solutions to new problems (see Figure 1).

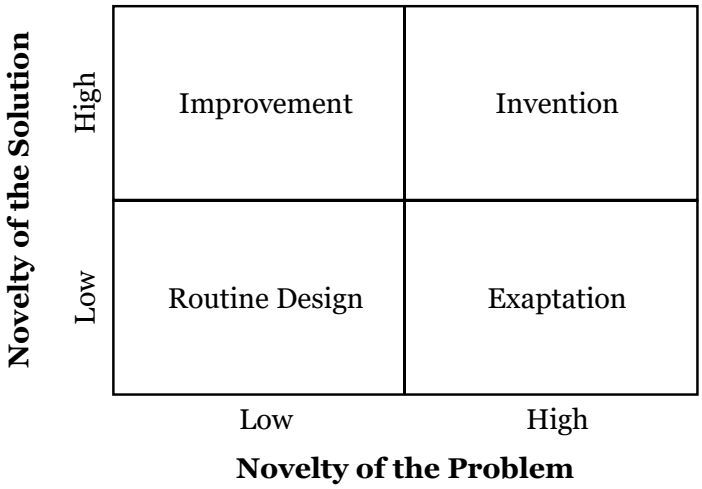

Figure 1. IS DSR Paper Novelty Types (Based on Gregor & Hevner, 2013)

Gregor and Hevner (2013, p. 348) provide examples, which also served as a basis for our coding. For example, we coded 1) routine design when a paper applied a "well-known solution…to a well-known problem", 2) improvement when a paper proposed a "more fine-grained model or method" to a well-known problem, 3) exaptation when a paper extended systems development principles "to a new class of information systems", and 4) invention when a paper conceptualized and addressed "a new problem…based on a novel solution". However, we still need to understand the extent to which the effects of novel ideas apply to the IS DSR domain and their actual strength. Hence, we explore a hypothesis for novelty type (Gregor & Hevner, 2013):

H1: Novelty type affects IS DSR contributions' scientific impact.

3.2 Theorization Level

Scientometric research has shown that a broader audience cites more general research contributions (Siering, Zimmermann, & Haferkorn, 2014; Tams & Grover, 2010). Further research has found that influential papers tend to demonstrate familiarity with existing research by drawing on established research contributions (Uzzi et al., 2013), and research has suspected a strong connection to the existing knowledge base to affect IS DSR papers' scientific impact (Gaß, Koppenhagen, Biegel, Maedche, & Müller, 2012). In this vein, the IS DSR papers span different theorization levels and provide insights that might apply to specific problem contexts or that might have a more general nature and apply to various problems and contexts.

In its least theoretical form, IS DSR papers offer contribution such as prototypes and instantiations, which tend to depend on a particular context's idiosyncratic aspects (Baskerville, Kaul, & Storey, 2015). Constructs, models, and methods (March & Smith, 1995) represent nascent theorization (Gregor & Hevner, 2013), while researchers generally achieve high theorization with (partial) information systems design theories (Walls et al., 1992) and theoretical contributions to information systems design that identify and explain a design's underlying mechanisms. Specifically, a design theory comprises four components: 1) meta-requirements (that describe a class of goals), 2) meta-design (that describes a class of artifacts that researchers intend to meet the meta-requirements), 3) kernel theories (natural or social science theories that inform the design requirements), and 4) testable hypotheses (for verifying whether the meta-design is effective) (Walls et al., 1992, pp. 42-43). In this regard, methodologists have argued that researchers should back IS DSR contributions' generalizability by appropriately tying these

[6] Gregor and Hevner (2013) refer to the framework's constituent dimensions as solution domain maturity and application domain maturity. We prefer to frame it as novelty because maturity might also be associated with generalizability or design theory.

knowledge contributions to existing bodies of knowledge (Dwivedi et al., 2014; Gregor & Hevner, 2013; Kuechler & Vaishnavi, 2008). As design-oriented contributions often address phenomena and contexts that *natural science* research has analyzed, researchers should leverage them in corresponding research and kernel theories (Gregor & Hevner, 2013). These recommendations also align with what Hevner (2007, p. 87) envisions as the essential contribution of the *rigor cycle*, which "provides grounding theories…from the foundations knowledge base into the research". By drawing on established works (e.g., kernel theories and prior meta-design principles), as one aspect of theoretical IS DSR contributions, researchers who author IS DSR papers may signal that their work provides a solid foundation that other researchers can build on.

One can derive theorization level from the design theory components that Walls et al. (1992) propose. We coded design theories' four components (i.e., meta-requirements, meta-design, kernel theories, and testable hypotheses). While we considered different terminology that authors used in describing these components in their IS DSR papers, we focused on how they expressed their contribution and described their design artifact in generalized terms (not necessarily referring to Walls et al. (1992) for the description). Therefore, we define the theorization level as the number of Walls et al.'s (1992) design theory components that an IS DSR paper expresses. Papers that present more design theory components, therefore, achieve higher theorization levels. This operationalization ranges from nascent design theories in the form of constructs, models, or methods on a contextualized level to complete design theories that cover all four components. Because IS journals generally do not publish pure instantiations such as prototypes and all papers in our sample describe their design method in generalized terms, we take nascent design theories as a baseline level. However, for higher theorization levels, we require those contributions to go beyond the specific context or use case that they describe. Table 1 summarizes the four design theory components that constitute the theorization level.

Table 1. Design Theory Components (Based on Walls et al., 1992)

Component	Description	Coding operationalization
Meta-requirements	The class of goals to which the design theory applies	Does the artifact fulfill requirements in generalized terms?
Meta-design	The class of artifacts hypothesized to meet the meta-requirements	Does the artifact follow design principles in generalized terms?
Kernel theories	Natural or social science theories informing the design requirements	Is the artifact based on sound kernel theories?
Testable hypotheses	To test whether the meta-design meets the meta-requirements	Does the design formalize testable hypotheses?

In summary, given persistent calls for IS DSR at high theorization levels, which includes design theory (Arnott & Pervan, 2012; Gregor & Hevner, 2013; Walls, Widmeyer, & El Sawy, 1992), we explore the following hypothesis:

H2: More theoretical IS DSR contributions have a higher scientific impact.

3.3 Research Model

In Section 3.2, we contend that novelty and theorization constitute factors that influence researchers' decisions to cite an IS DSR paper. To estimate the effects of both characteristics, which concur with the normative theory of citing behavior, we develop a research model (see Figure 2) that includes additional variables that control for characteristics associated with constructivist citing behavior[7]. Thereby, our model accounts for complementary effects of the normative and constructivist theory of citing behavior as the literature discusses them. We provide details about how we measured and coded the characteristics in Appendix B.

We measure our dependent variable, scientific impact, according to the number of citations received. Notwithstanding the critique that citation counts might be subject to certain biases (Leydesdorff, 1987; MacRoberts & MacRoberts, 1989), researchers frequently use them as measures for scientific impact (Grover et al., 2013; Hassan & Loebbecke, 2017; Starbuck, 2005), scholarly influence (Straub, 2009), or

[7] To clearly distinguish the degree to which the factors stimulate normative or constructivist citation behavior, one would need to analyze the way citing papers use an IS DSR paper.

even research output quality (Acuna, Allesina, & Kording, 2012; Baldi, 1998; Garfield & Merton, 1979; Garfield, 2006; Stewart, 1983).

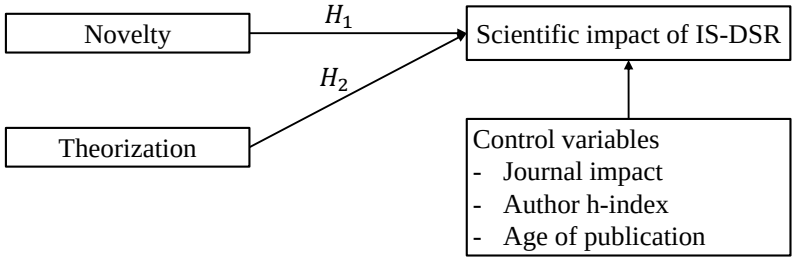

Figure 2. Research Model

Researchers have found the journal that publishes a paper to be the single most important factor that drives citations to a paper (Judge et al., 2007; Mingers & Xu, 2010; Peters & van Raan, 1994). They have found multiple factors related to the publication outlet to significantly influence the number of citations a paper receives, such as reputation, visibility, accessibility, or a paper's position in a journal issue (Bornmann & Daniel, 2008; Dalen & Henkens, 2001; Judge et al., 2007). As many of these factors relate to one another, scientometric studies commonly use the journal impact factor as a proxy. Originally proposed by Garfield (1964), the impact factor has attracted various actors' attention, such as the research community, governments, administrations, and funding and research councils (May, 1997; Seglen, 1994). Although Garfield (2006), who created the social science citation index (SSCI), concedes that the journal impact factor might not be a perfect measure, he concludes that the impact factor has become well established and that we have yet to find a better metric.

Researchers have consistently found author impact to affect papers' impact (Judge et al., 2007; Peters & van Raan, 1994). Due to the many ways in which an author may impact an academic discipline, one cannot easily measure it. Among several instruments that researchers have developed to measure authors' scholarly impact, the Hirsch family of indices has become the most prominent (Hirsch, 2005; Truex, Cuellar, & Takeda, 2009). In their paper, Bornmann, Mutz, Hug, and Daniel (2011), who conducted a meta-analysis on the h-index's validity as a measure for author impact, describe two dimensions of author productivity: 1) the quantity (as measured by publication counts) and 2) the impact of an author's publication volume (as measured by citation counts). The h-index measure combines both an author's productivity and impact.

As a publication's age plays an important role in accumulating citations over time (e.g., Grover et al., 2013, Mingers, 2008), we also control for the number of years since a paper's publication.

4 IS DSR Literature Corpus

Before discussing the main results of our research model, we discuss the IS DSR literature corpus that we analyzed in our study. Specifically, we describe the characteristics of our literature corpus using two different approaches with two different objectives in mind. First, we discuss the most impactful IS DSR papers based on citation numbers. In doing so, we provide answers to questions about what the impactful papers are, what journals publish impactful IS DSR, and what scientific impact means in our corpus in terms of citation numbers. Second, we map prominent topical clusters in our literature corpus based on a bibliographic coupling technique. This map illustrates the thematic clusters in the IS DSR literature and provides insights into the most impactful topics, the corpus structure, and its interconnections.

To explore IS DSR papers' scientometric impact, we focus on high-quality IS DSR papers in premier IS journals. Specifically, our scope covers IS DSR papers that journals in the AIS Senior Scholars' basket of journals published between April, 2004, and March, 2014 (Association for Information Systems, 2011). Prat, Comyn-Wattiau, and Akoka (2015), who conducted a table of contents scan, a keyword search, and an inclusion coding procedure, identified the IS DSR papers. We discuss potential ways to extend the scope in Section 6. We also refined the 121 IS DSR papers that Prat et al. (2015) identified by excluding design science papers focusing on methodology (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007), theory (Gregor & Jones, 2007; Kuechler & Vaishnavi, 2012), guidelines for evaluating design science (Burton-Jones, Weber, & Wand, 2009), or classification methods that primarily target researchers (Nickerson, Varshney, & Muntermann, 2013; Parsons & Wand, 2013). We excluded these papers based

on the rationale that they do not represent IS DSR papers but DS methodology or theory papers and, therefore, do not contribute to the research landscape we intend to explore (IS DSR papers that actually do IS DSR vs. papers that describe how one should do IS DSR). Furthermore, they would introduce heterogeneity into our explanatory analysis. The first and second authors conducted the exclusion coding, which resulted in a final sample with 115 IS DSR papers (see Appendix A).

We extracted citation data, which includes the reference lists that we used to construct the map of IS DSR and citation scores that we used as the dependent variable in the research model, from the Social Science Citation Index (SSCI), which we accessed through the Web of Science platform using the Core Collection. Over the past six decades, the SSCI has established itself as the primary data source for scientometric studies in various disciplines, which includes the IS discipline (e.g., Culnan, 1987; Karuga, Lowry, & Richardson, 2007; Raghuram, Tuertscher, & Garud, 2010; Taylor, Dillon, & van Wingen, 2010). Most importantly, it upholds its reputation for high quality and quantity through its standards in the journal-selection process, such as by indexing peer-reviewed journals exclusively[8].

4.1 Descriptive Statistics

Next, we summarize the IS DSR papers' descriptive statistics. We found that five journals (*Journal of the Association for Information Systems*, *European Journal of Information Systems*, *MIS Quarterly*, *Information Systems Research* and *Journal of Management Information Systems*) published more than 90 percent of the IS DSR papers. Overall, the scientific impact varied between two and 339 citations with an average of 53.3 citations, and many papers received few citations (60% had fewer than 30 citations). Table 2 shows the top 10 IS DSR papers with the highest scientific impact. We list all the papers in Appendix A. Consistent with previous scientometric research in the IS discipline (Hassan & Loebbecke, 2017; Loebbecke, Huyskens, & Berthod, 2007), a small number of IS DSR papers achieved noteworthy impact. Several IS DSR papers received only single-digit citations.

Table 2. Top 10 IS DSR Papers According to Scientific Impact

IS DSR paper	Citations
Hanseth, O., & Lyytinen, K. (2010). Design theory for dynamic complexity in information infrastructures: The case of building Internet. *Journal of Information Technology*, *25*(1), 1-19.	339
Krogstie, J., Sindre, G., & Jørgensen, H. (2006). Process models representing knowledge for action: A Revised quality framework. *European Journal of Information Systems*, *15*(1), 91-102.	290
Leimeister, J. M., Ebner, W., & Krcmar, H. (2005). Design, implementation, and evaluation of trust-supporting components in virtual communities for patients. *Journal of Management Information Systems*, *21*(4), 101-131.	231
Hickey, A. M., & Davis, A. M. (2004). A unified model of requirements elicitation. *Journal of Management Information Systems*, *20*(4), 65-84.	213
Kohler, T., Fueller, J., Matzler, K., & Stieger, D. (2011). Co-creation in virtual worlds: The design of the user experience. *MIS Quarterly*, *35*(3), 773-788.	197
Sun, S. X., Zhao, J. L., Nunamaker, J. F., & Sheng, O. R. L. (2006). Formulating the data-flow perspective for business process management. *Information Systems Research*, *17*(4), 374-391.	176
Arnott, D. (2006). Cognitive biases and decision support systems development: A design science approach. *Information Systems Journal*, *16*(1), 55-78.	170
Pries-Heje, A., & Baskerville, R. (2008). The design theory nexus. *MIS Quarterly*, *32*(4), 731-755.	164
Sun, L., Srivastava, R. P., & Mock, T. J. (2006). An information systems security risk assessment model under the Dempster-Shafer theory of belief functions. *Journal of Management Information Systems*, *22*(4), 109-142.	162
Chau, M., & Xu, J. (2012). Business intelligence in blogs: Understanding consumer interactions and communities. *MIS Quarterly*, *36*(4), 1189-1216.	161

[8] https://clarivate.com/essays/journal-selection-process/

4.2 Topical Cluster Analysis

Drawing on the scientometric literature (Boyack & Klavans, 2010; Jarneving, 2007a; Zupic & Cater, 2015), we map impactful papers in the IS DSR domain, which differs from its intellectual foundation as we describe in Appendix C. The resulting map represents the 115 IS DSR papers in our final sample and allows readers to explore their clusters and thematic structure. To map the IS DSR papers, we selected the IS DSR papers (see Section 4), retrieved their references, and determined papers' similarity based on the bibliographic coupling technique. We then applied a community detection algorithm to identify research clusters and finally visualized these clusters. We also provide details on the clustering procedure in Appendix C. A common set of references to a shared (intellectual) foundation characterize the thematic clusters in Figure 3, but the clusters may still be heterogeneous with regard to the design problem or solution.

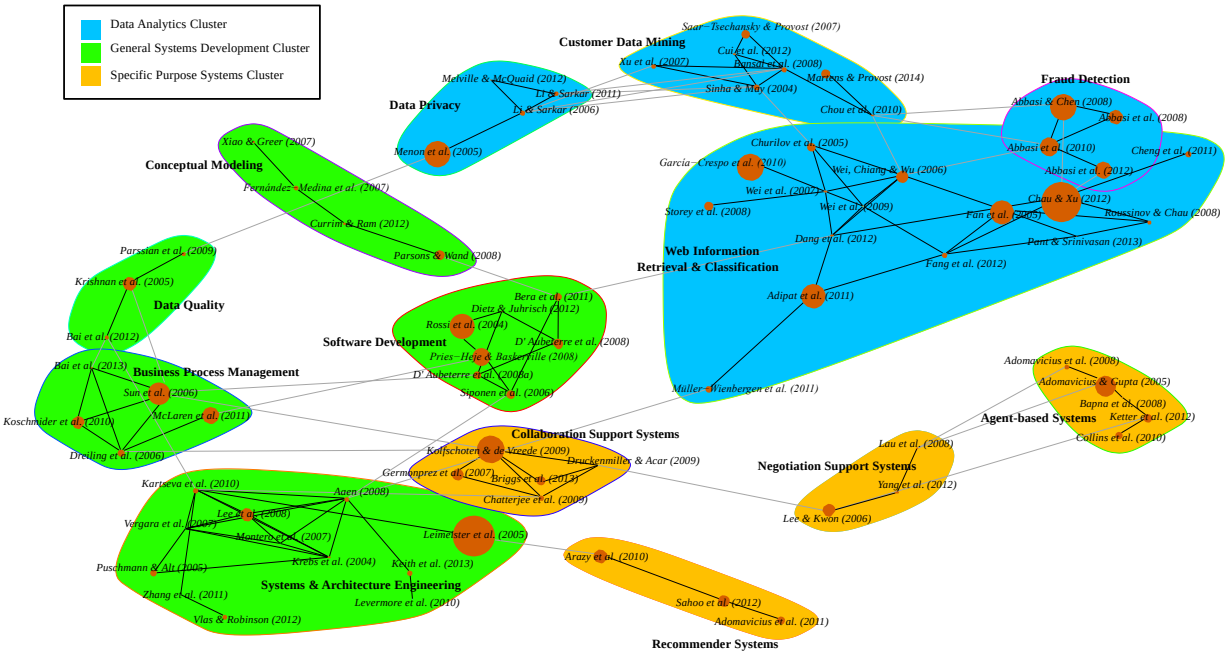

Figure 3. A Map of Impactful IS DSR Papers (2004-2014)

The data analytics clusters exhibit the divide between research concerned with data internal and data external to organizations. One can see the differences between these groups in their bibliographic couplings. They pertain to the nature of information (private vs. public), data ownership (ensuing issues related to control, responsibility, and legal obligations), and the systems used to manage data (e.g., customer relationship management systems vs. public blogging systems). These differences exist despite convergence trends with systems being integrated and people interacting with organizations in multiple roles, such as a customer of or participant in a public social network. The main cluster, Web information retrieval and classification (n = 17), represents research that primarily draws on public data to access, process, and visualize information to ultimately support decision making. It overlaps with the fraud detection cluster (n = 6), which represents research that addresses efforts to detect malicious, fraudulent users, interactions, or artifacts as a specific classification task. The customer data mining cluster (n = 7) represents research that analyzes internal organizational information, such as customer or employee data, and the data privacy cluster (n = 5) represents research that focuses on preserving the privacy or confidentiality of sensitive information that organizations manage and share.

Five distinct research foci characterize the general systems development clusters. The systems and architecture engineering cluster (n = 17) represents research on designing information systems, architectures, and infrastructures. It connects to the business process management cluster (n = 4) that represents research that suggests, for example, how organizations can adapt business models efficiently by drawing on model-based configuration and how social recommendations can inform the modeling process. Complementary research conceptualizes and analyzes data-flows and risks in business

processes. The data quality cluster (n = 3) represents research concerned with data quality and reliability. This cluster connects closely to the business process management cluster, which Bai, Krishnan, Padman, and Wang's (2013) paper exemplifies. The software development cluster represents research that advances software requirement elicitation and modeling and principles for secure software development (n = 9). The conceptual modeling cluster (n = 4) represents research that advances conceptual modeling in different application domains such as modeling spatial and temporal constraints, modeling secure data warehouses, and classifying entity types.

Finally, the specific purpose systems clusters comprise the collaboration support systems cluster (n = 4)[9], which represents research that advances collaborative technologies for practitioners, repeatable situations, and strategic decision making. Research in the negotiation support systems cluster (n = 3) addresses negotiations between various parties, which includes humans, agents, and businesses. The agent-based systems cluster (n = 5) represents research on agent-support in auctions, agent-support in sales management, and agent-based decision support systems. The recommender systems cluster (n = 3) contains a design theory for social recommender systems (Arazy, Kumar, & Shapira, 2010) and research on query languages for customizing recommendations based on preferences that change over time.

5 Analyses and Results

5.1 Results

Similar to several scientometric studies in the IS and other disciplines (Loebbecke et al., 2007), we found IS DSR papers to have slightly skewed citation counts (skewness: 0.68). We chose a negative binomial generalized linear model, which suits skewed distributions of count data. By applying a canonical logit link function, we could account for the fact that our dependent variable deviates from the normal distribution in a similar way as (log)-linear models applied in other scientometric studies (Bertsimas, Brynjolfsson, Reichman, & Silberholz, 2013; Grover et al., 2013; Mingers & Xu, 2010; Tams & Grover, 2010). We did not exclude outliers from the analysis to identify reasons for their high scientific impact, but we checked our model's robustness with respect to the exclusion of these outliers. We conducted checks for correlations and multicollinearity of all variables by examining correlation coefficients and generalized variance inflation factors (GVIF). We found no problems with multicollinearity. All GVIFs were well below the threshold (i.e., 2), which indicates that the factors sufficiently did not relate to one another and that collinearity did not influence the results. We specified the following generalized linear regression model:

$$log(citations) = \beta_0 + \beta_1 Journal\ impact\ factor + \beta_2 h\text{-}index + \beta_3 Age\ of\ publication + \beta_{4-6} Novelty + \beta_7 Theorization + \epsilon. \quad (1)$$

We present the estimation results for the hierarchical regression in Table 3. Extending the initial control model, Model 1 includes novelty, which we operationalized as three dummy variables. Because IS journals rarely publish DSR papers that develop routine design artifacts (see Table A1), we choose improvement as the reference group for the novelty variable. To calculate the main model (Model 2), we included the theorization variable, which we operationalized as a quasi-continuous variable spanning five theorization levels.

The resulting model explained 55 percent of the variance in citation counts (Nagelkerke R^2). In line with previous scientometric studies, our control variables significantly affected scientific impact. Even in the relatively homogenous set of journals we analyzed, IS DSR papers published in journals with a higher journal impact factor received significantly more citations. Author reputation and publication age positively influenced citations on a significant level. Model 1 shows that exaptation and invention were associated with a significantly higher scientific impact compared to improvement (the reference group). Because few IS DSR papers in our sample developed routine designs, novelty had no significant effects in that group. Overall, the effect sizes further corroborate novelty's importance. Notably, theorization had a highly significant effect on scientific impact with the effect size even surpassing the journal impact factor's effect size. Table 3 presents results of the three models including the main variables.

To test H1, we implemented a partial F-test. The coefficients in Table 3 cover only individual novelty types and make it necessary to implement a separate test that covers all novelty types. Specifically, we tested the difference between the control model and Model 1 to test whether including the novelty variable

[9] This cluster builds on previous works on group support systems (see Nunamaker et al. 2017).

resulted in a statistically significant improvement in R^2. We identified significant evidence that supported the novelty hypothesis (p = 0.008). Although additional analyses indicated that our sample did not have sufficient statistical test power to test hypotheses on the differences between novelty types, we further tested the relationship between novelty and scientific impact as robustness checks in Section 5.2. Complementing the hypothesis for the effect of all novelty levels, we provide individual novelty levels' effects in Table 3. To test H2, we conducted a one-sided test on the corresponding regression coefficient. Confirming this hypothesis, we found that theorization level had a highly significant, positive effect on scientific impact (t = 5.51***). We summarize the support we obtained for our hypotheses in Table 4.

Table 3. Hierarchical Generalized Linear Model Results (N = 115)

	Control model	Model 1	Model 2
Journal impact factor (control)	0.32***	0.35***	0.24***
h-index (control)	0.03**	0.02*	0.02**
Age of publication (control)	0.16***	0.18***	0.17***
Novelty[a]: routine design		-0.04	0.01
Novelty[a]: exaptation		0.59**	0.51**
Novelty[a]: invention		0.53*	0.40*
Theorization			0.29***
Nagelkerke R^2	0.38	0.45	0.55
Comparison with previous model (ΔR^2)		0.07**	0.10***

Note: the model includes an intercept. [a] Improvement is the reference group of novelty.
Significance levels: *** p < 0.001, ** p < 0.01, * p < 0.05 (two-sided tests).

Table 4. Overview of Support Provided for the Hypotheses

H1: Novelty type affects IS DSR contributions' scientific impact.	Supported**
H2: More theoretical IS DSR contributions have a higher scientific impact.	Supported***,[a]

Significance levels: *** p < 0.001, ** p < 0.01, * p < 0.05.
[a] One-sided test.

5.2 Robustness Analysis

We proceeded by examining sample characteristics that may have biased our results and plausible model configurations. Because our sample size limited our ability to include further variables in the main model, we focused our checks on the robustness of the literature sample and alternative configurations of the novelty variable. We estimated five models and analyzed changes in effect size and significance of the main variables. Table 5 shows the robustness checks, their underlying rationale, and the corresponding models.

Table 5. Summary of Robustness Checks

No.	Robustness check	Rationale	Model
1	Exclude high-impact outliers.	Skewed citation data might bias results towards high-impact outliers (Bornmann & Leydesdorff, 2017).	A
2	Exclude special IS DSR cases.	A heterogeneous or diverse literature sample might bias the results (Akoka, Comyn-Wattiau, Prat, & Storey, 2017; Prat et al., 2015).	B
3	Compare alternative orders between types of novelty.	Novelty types might follow an implicit order, which could better explain novelty's effect on scientific impact (Gregor & Hevner, 2013).	C1, C2, C3

Many scientometric research studies have shown that citation data follows a skewed distribution, a methodological problem in citation analyses (van Raan, 2014). For example, Bornmann and Leydesdorff (2017) have shown that, across several disciplines, the 10 percent most frequently cited papers account for nearly half of a discipline's citation impact. As our results and Table 2 show, we confirmed similar skewness levels in our IS DSR literature sample. To assess whether high citation impact papers affected the results from our main model, we tested Model A, which excluded outliers. We excluded four papers

that received more than 200 citations and, thereby, accounted for almost 20 percent of the total citation impact in our sample. We mark the excluded papers in Table A1 (Appendix). The results remained robust with minor changes in the significance of one factor of the novelty variable.

Despite excluding papers on the IS DSR theory and methods (e.g., Gregor & Hevner 2013, Gregor & Jones 2007), our sample included some special cases that could have biased the model coefficients. Therefore, we estimated Model B after excluding four special IS DSR cases. First, Hanseth and Lyytinen (2010) explained the design principles of information infrastructures based on the Internet, which they did not design in their paper. Second, one could consider Yang, Su, and Yuan's (2012) paper in which they explain the emergency response platforms implemented for the Beijing Olympic Games to involve action research. Finally, Pries-Heje and Baskerville's (2008) paper has a more generic nature than other IS DSR papers, and one could consider Krogstie, Sindre, and Jørgensen's (2006) semiotic framework an uncommon design contribution. We mark the excluded papers in Table A1 (Appendix). The results remained robust with minor changes in the significance of one factor of the novelty variable.

We found that IS DSR knowledge contributions' novelty has a significant effect on scientific impact. Although Gregor and Hevner (2013) present their DSR knowledge contribution framework, which serves as the basis for our novelty variable, as a 2 x 2 matrix without a rank order in the novelty types, an implicit partial order underlies the four quadrants. Consistent with Gregor and Hevner (2013), we consider routine design as the lowest novelty level because it combines high solution and application maturity. Similarly, we consider invention as the highest novelty level. Thus, we operationalized novelty as being quasi-interval scaled with routine design being the lowest and invention being the highest novelty level. However, determining whether improvement and exaptation have more novelty involves more difficult. Therefore, we checked three alternative model configurations: Model C1 considered improvement and exaptation as having an equal, second rank; Model C2 considered improvement to have a higher rank than exaptation; and Model C3 considered improvement to have a lower rank than exaptation. While the coefficients for the novelty variable that we implemented as a categorical factor (and operationalized with dummy variables) differed from the coefficients for the implementation as an interval variable, the effect sizes and significance levels of the other independent variables remained robust in all three alternative models. Only the model (among C1-C3) in which exaptation outranks improvement (C3) showed a statistically significant association with scientific impact. As the novelty variables in our main model (Model 2) suggest, exaptation even outranks invention in terms of scientific impact despite being lower in novelty. While one may not expect such a result from the IS DSR discourse perspective, the scientometric literature provides an explanation for this phenomenon. In fact, substantial evidence has shown that, rather than novelty (i.e., invention) alone, a combination of atypical knowledge with conventional knowledge leads to the highest scientific impact (Uzzi et al., 2013). Exaptation, which involves extending known solutions to new problems, corresponds to such a combination of the conventional and the novel.

Table 6. Robustness Checks: Generalized Linear Model Results

	Model A (n = 111)	**Model B (n = 110)**	**Model C1 (n = 115)**	**Model C2 (n = 115)**	**Model C3 (n = 115)**
Journal impact factor (control)	0.27***	0.25***	0.23***	0.21***	0.25***
h-index (control)	0.02**	0.02**	0.03**	0.03**	0.03***
Age of publication (control)	0.15***	0.16***	0.16***	0.15***	0.16***
Novelty: Routine design	0.07	0.07			
Novelty: exaptation	0.54**	0.60***			
Novelty: invention	0.51**	0.51**			
Theorization	0.25***	0.27***	0.30***	0.31***	0.29***
Novelty: RD < imp = ex < inv			0.25		
Novelty: RD < ex < imp < inv				-0.06	
Novelty: RD < imp < ex < inv					0.24**
Nagelkerke R^2	0.55	0.55	0.51	0.50	0.52

Notes: the model includes an intercept.
Routine design (RD), improvement (imp), exaptation (ex), invention (inv)
Significance levels: *** p < 0.001, ** p < 0.01, * p < 0.05 (two-sided tests).

In summary, we found similar results from the robustness checks compared to the main results, which Table 6 shows. Overall, the fact that alternative explanations did not substantially affect our main results suggests that our model provides a robust and parsimonious explanation for IS DSR papers' scientific impact.

6 Discussion

In this section, we discuss the current state of IS DSR and derive recommendations for the road ahead. Finally, we describe the study's limitations, which may offer opportunities for future research

6.1 The Current State of IS DSR

Based on our analyses, we contend that two intertwined parts currently characterize IS DSR: 1) the intellectual foundation, which comprises methodological, meta-level, and theoretical papers; and 2) impactful IS DSR papers that contribute to IS DSR domain knowledge[10]. In our exploratory analysis, we focus on this latter group of papers that actually do IS DSR and not those papers that describe how one should do it. In this context, we take stock of the most impactful recent IS DSR papers and uncover major clusters based on their similarity in reference sections (see Table 2 and Table A1).

To understand the factors that drive scientific impact in IS DSR papers, we dig deeper and analyze the papers' essential characteristics. Based on a scientometric model, we show that, after controlling for journal, author, and time-related effects, the novelty type and theorization level significantly affect IS DSR papers' scientific impact. Regarding the novelty type, IS DSR papers that we classified as exaptation or invention attracted significantly more citations, which suggests that researchers generally value these novelty types. As for routine design, which researchers sometimes consider as providing no major knowledge contribution (Gregor & Hevner, 2013), we did not find evidence for a lower scientific impact[11]. This finding concurs with the idea that IS DSR papers with low novelty might also have their merits—a stance that the fact that these papers have survived the peer review process at some of the most prestigious information systems journals supports. From a practitioner perspective, a certain focus on known, existing problems and established solutions might be valuable to ensure that research outputs are more readily applicable in a certain context and provide more immediate utility.

One can see our study as a step toward appreciating impactful theoretical IS DSR contributions and to dissociate them from less theoretical, more context-specific, or idiographic papers (Baskerville et al., 2015). Compared to existing surveys that have criticized the lack of theorizing in IS DSR (Arnott & Pervan, 2012; Dwivedi et al., 2014; Gaß et al., 2012), our insights into IS DSR published in top-tier journals may indicate a shift toward stronger theorization. In Lakatos's (1976) words, one could interpret our insights as useful in distinguishing design theories' hard core from design research that constitutes an auxiliary, observational, or idiographic protective belt. Support for H2 indicates that every theorization level beyond the common contributions of constructs, models, and methods (nascent theorization) was associated with a significantly higher number of citations. Although researchers may find it challenging to develop complete design theories that include all four components that Walls et al. (1992) describe, our results indicate that even proposing partial design theories makes a difference. Researchers have done so by deriving formal hypotheses that allow one to usefully evaluate whether a design contribution achieves its goals (Walls et al., 1992) or by substantially and explicitly drawing on kernel theories from existing descriptive bodies of knowledge (Gregor & Hevner, 2013; Walls et al., 1992).

6.2 The Road Ahead

Based on our exploratory and explanatory insights, we look at the road ahead of IS DSR and propose recommendations intended to shape future knowledge accumulation in IS DSR. As the challenges ahead require commitment from all IS- DSR stakeholders, we discuss in detail the how and why of each recommendation (we summarize the recommendations in Table 7).

R1: Connect IS DSR to the relevant body of knowledge and cite appropriate papers to achieve a more cohesive IS DSR literature.

[10] Researchers sometimes refer to these papers as IS DSR application papers (Fischer 2011). The scientometric literature sometimes refers to the current body of knowledge as the research front (Jarneving, 2007a).

[11] The routine design dummy variable in the regression models did not have a significant effect on scientific impact, which means that we found no evidence for a difference between IS DSR papers categorized as routine design and the reference group (improvement in models 1 and 2) in terms of scientific impact.

The recommendation to connect IS DSR to the relevant body of knowledge pertains to different types of papers. Beyond research on the types of problems that IS DSR addresses and the classes of solutions that it develops, this body of knowledge comprises design theories that offer meta-designs for general problems (Walls et al., 1992)[12]. Authors may omit relevant references due to various reasons: they may have had a motivation to emphasize their work's novelty by "underciting" earlier research[13], they may not have found the references, they may have judged the references as too trivial, or they may have had to exclude references during the review process. Authors can address these omission problems, which create unusual citation patterns in the IS DSR literature, by familiarizing themselves with related IS DSR papers (e.g., using the map in Figure 3) and scanning their reference sections. We further encourage authors to include references to existing IS DSR papers and general papers on the problem and solution space (Venable, 2006). Reviewers should not excessively scrutinize IS DSR papers' references; instead, when a paper does not represent a relevant body of knowledge in its reference section, they should suggest additional papers that authors ought to cite.

We make this recommendation based on the rationale that the IS DSR papers we examined exhibited comparatively low rates of bibliographic couplings, which indicate that papers use a shared knowledge base (Hevner et al., 2004). An average IS DSR paper that contained 60 references shared only three references (i.e., 4.8%)[14] with other IS DSR papers (after excluding random associations), which indicates weak connection to a common knowledge base. Better connections to the existing knowledge base would enable subsequent research to find relevant works more efficiently when relying on citations as a search tool (Hassan & Loebbecke, 2017). Such connections could also help researchers develop a more cohesive and cumulative body of design-oriented knowledge, a challenge that the literature has repeatedly highlighted (e.g., Chandra Kruse, Seidel, & Purao, 2016; Drechsler, 2012; Gregor & Hevner, 2013; Gregor & Jones, 2007). In this regard, we consider the second recommendation to be instrumental in circumventing the perils associated with fragmented adhocracies (Banville & Landry, 1989; Whitley, 2000) and, thus, in steering IS DSR toward a cumulative research tradition with a shared understanding of relevant problems and appropriate design solutions.

R2: Focus on novelty and theorization.

This recommendation should primarily encourage authors who develop IS DSR papers to go beyond the ordinary, to propose groundbreaking new IS DSR (relating to both the type of problem they address and the type of solution they offer), and to strive for theorizing their contributions. While putting highly novel papers on the IS DSR map requires innovation and creativity, authors can achieve theorization by integrating appropriate kernel theories, generalizing requirements and artifact design, and by formulating testable design product hypotheses (Walls et al., 1992). To support authors in theorizing, reviewers, theorists, and methodologists may provide developmental feedback and guidelines on how to formalize and abstract design-oriented knowledge. This recommendation may resonate with scholars who advocate for the design theory camp (e.g., Gregor & Jones, 2007; Markus, Majchrzak, & Gasser, 2002; Walls et al., 1992) as Gregor and Hevner (2013) refer to it[15].

We make this recommendation based on the rationale that IS DSR papers that offer high novelty and theorization have a unique scientific impact on subsequent research and, thus, on how design-oriented knowledge accumulates. Although consistent with previous analyses that have noticed a lack of theorizing in IS DSR (e.g., Arnott & Pervan, 2012), this observations may seem at odds with Gaß et al. (2012) who state that design theories play almost no role in subsequent IS DSR papers' knowledge base. We can attribute this phenomenon to time lags in the publication process and we are confident that—due to their strong scientific impact—future IS DSR will use these design theories. In the long run, the impactful design theories that appear today will constitute tomorrow's body of knowledge.

In emphasizing novelty and theorization as ultimate goals, we recognize that we should not expect every IS DSR paper to be completely novel and completely theoretical (e.g., see Iivari, 2007). Paving the path for the next innovative design theory may require exploratory groundwork and partial or incomplete theorizing (Gregor & Hevner, 2013). In collaboratively pursuing design theory, we face open challenges that involve, for example, codifying practical design knowledge into abstract design knowledge (e.g.,

[12] Design theories also include kernel theories and testable hypotheses (Walls et al., 1992).
[13] We thank the reviewers for this observation.
[14] IS DSR papers developing a design theory shared five references (i.e., 7.8%) on average.
[15] Although scientific impact may favor IS DSR papers that propose design theories, practical impact may still be an argument that supports the pragmatic-design camp (e.g., Hevner et al., 2004; March & Smith, 1995; Nunamaker, Chen, & Purdin, 1990) as Gregor and Hevner (2013) refer to it.

Lukyanenko & Parsons, 2013). We can explain these challenges based on the discipline's focus on wicked problems, its constant state of revolution (Hevner et al., 2004), its focus on short-term pragmatic concerns (e.g., Lyytinen, Baskerville, Iivari, & Te'eni, 2007), and/or its predilection for new technology waves (e.g., Gregor & Jones 2007). Nevertheless, we believe that endorsing efforts to strive for novel and theoretical design knowledge, which is relatively immune to change, represents the way forward for the IS DSR community.

R3: Familiarize stakeholders with IS DSR by referring to impactful IS DSR paper map.

The third recommendation envisions that the IS DSR community uses the impactful IS DSR papers map we developed (see Figure 3) to familiarize stakeholders with high-impact IS DSR output. These stakeholders may be (PhD) students, IS DSR paper authors, IS DSR project managers, general IS academics, IS practitioners from the industry, funding bodies, or colleagues from other departments. While stakeholders who lack familiarity with IS DSR would benefit from an overarching orientation on the focal topics, IS DSR researchers could use the map to identify new research opportunities (e.g., at the intersection of thematic clusters).

The map answers the question "what is IS DSR?" and, thereby, provides insights into the thematic structure and identity of IS DSR published between 2004 and 2014. One caveat, which concurs with insights we gained during our analyses and with existing scientometric maps of the whole IS discipline (Taylor, 2005), is that we should not expect IS DSR to emerge as a coherent cluster in the whole IS research network anytime soon. Although its intellectual base (which comprises papers on how one should do IS DSR) will have a higher chance to stand out on its own, the IS DSR literature appears to be too thematically diverse and too loosely connected for one to recognize it in maps of the IS discipline.

We make the third recommendation for two primary reasons. First, although a vivid discourse on the IS DSR paradigm exists (e.g., Arnott & Pervan, 2012; Goes, 2013; Gregor & Hevner, 2013; Prat et al., 2015; Rai, 2017), providing stakeholders with an interest in IS DSR with an overview of papers that deliberate on how one should do IS DSR may not be as convincing as referring to actual progress that specific IS DSR papers have achieved. In Hassan and Loebbecke's (2017, p. 17) words, being able to present an organized body of design oriented knowledge that comprises the most significant research in this area "would be beneficial for further legitimizing the field and enhancing its professional stature in the eyes of its stakeholders and industry" (p. 17). Second, the map in Figure 3 has the unique advantage that the IS DSR community can ascribe ownership to these papers because core IS journals publish them (the AIS Senior Scholars' Basket of Journals). In this regard, we critically observe the frequent use of relational database theory[16] (Codd, 1970) as an example in the IS DSR context. However, this theory comes from a reference discipline (i.e., computer science) (Keen, 1980; Moody, Iacob, & Amrit, 2010; Weber, 2003), and, in Keen's (1980, p. 11) words, "[t]he reference discipline is only a reference."—it does not contribute to how we understand IS DSR. Instead, we suggest using exemplars to which the IS DSR community can ascribe ownership because extensive borrowing does a disservice to the legitimacy of relatively young disciplines whose identity cannot be established "by fiat" (Weber, 2003, p. vi).

Table 7. Summary of Recommendations and Rationales

R1	**Connect IS DSR to the relevant body of knowledge by citing appropriate literature.** Rationale: • Improves the connection to relevant knowledge bases. • Supports a cumulative research tradition.
R2	**Focus on novelty and theorization.** Rationale: • Novel and theoretical IS DSR papers have a significantly higher scientific impact. • By being relatively immune to changes (e.g., in technology and context), theoretical IS DSR papers have a broader applicability.
R3	**Familiarize stakeholders with IS DSR by referring to the map of impactful IS DSR papers.** Rationale: • In contrast to the intellectual foundation, which contains papers on how one should do IS DSR, papers that actually do IS DSR dominate the map of impactful papers. • Being able to show progress in terms of actual primary research allows the IS DSR community to justify its research's legitimacy.

[16] This observation includes the present paper.

While we develop the recommendations based on the evidence from our analyses, we recognize that we likely still do not know much about IS DSR's scientific impact. We continue by pondering implications from the lack of evidence in the literature.

First, high scientific impact might not always indicate that an original IS DSR contribution diffuses more through subsequent research projects (Swanson, 2014). Potential differences between immediate and delayed impact suggest that efforts to gauge different types of direct or immediate impacts should critically reflect on the limitations that excluding indirect influences that materialize through other papers introduces. In particular, a focus on tangible impact on practice might underestimate the importance of IS DSR papers whose overly theoretical or abstract nature might limit their ability to have an immediate impact on practice but provide a foundation for multiple subsequent projects that, in turn, might have high practical utility. To refer to an IS DSR example from computer science, we would be surprised to find the paper on relational database theory (Codd, 1970) sitting on the desk of an industry database maintainer. Instead, we would more likely find a MySQL manual that draws on papers on query languages, which, in turn, relational database theory influences. Similarly, IS DSR papers' impact can take the educational route and diffuse into teaching practices, which the fact that Codd's work pervades today's database curricula exemplifies. In a nutshell, we need to go beyond objective and easily defendable measures of immediate impact (Niederman et al., 2015). For IS DSR authors in particular, these different paths underline the need to consider impact's multiple facets in communicating IS DSR (Gregor & Hevner, 2013; Saunders & Wiener, 2017).

Second, we caution evaluating committees who judge IS DSR's and ISR papers' relative merits that comparing scientific impact directly might not be an appropriate approach (Tremblay, van der Meer, & Beck, 2018). This suggestion recognizes that such committees also often apply scientific impact, which serves to indicate the extent to which knowledge has diffused into research and practice, as an evaluative measure. As such, scientific impact arguably pertains to design science researchers' careers as it affects hiring, tenure, and promotion decisions. As for IS DSR papers, which pursue two—possibly conflicting—goals (i.e., developing artifacts for practice and creating design-oriented knowledge), it remains an open question how their capacity to generate scientific impact compares to mainstream ISR papers that focus primarily on advancing scientific knowledge. Furthermore, ISR constitutes a bigger discipline (which includes IS DSR) and, therefore, may naturally attract higher citation rates (Garfield, 2006). Ignoring that IS DSR does not generate scientific impact on par with mainstream ISR might contribute to research evaluations that one could consider unfair because it skews hiring, funding, and promotion decision (Niederman et al., 2015). In turn, such practices could lead to reinforcing tensions between the IS DSR and ISR communities (e.g., see Österle et al., 2011; Baskerville, Lyytinen, Sambamurthy, & Straub, 2011).

In summary, we suggest that we need to firmly grasp the research landscape, which includes the intellectual foundation and the current body of impactful IS DSR papers in particular, to create a distinct identity and a cumulative research tradition in IS DSR (see Keen, 1980). While a discipline's identity is associated with its members' ability to name top papers and research themes (Keen, 1980), these papers' scientific impact, which one can consider to indicate overall progress in a research discipline, evidences the discipline's cumulative research tradition (Weber, 1987). Based on this notion, we expect that understanding underlying philosophical and methodological works and being able to point to influential theoretical papers can valuably substantiate claims regarding the impact that design science has in information systems.

6.3 Limitations and Future Research

As we consider it worthwhile to further investigate impactful IS DSR papers, we briefly discuss our work's limitations and deliberate whether they provide promising paths for further research. Our results do not represent IS DSR output in general as we limited our analysis to output from AIS Senior Scholars' basket of journals (i.e., to top journals in the IS discipline) over a 10-year period It does not cover conference proceedings, other journals, or a broader time period. If one included conference proceedings, one would need to control for publication outlet-related effects since conferences lack impact factors. Another issue pertains to differences in the paper types that might arise from page limitations or differing publication standards (Leukel, Mueller, & Sugumaran, 2014). These differences would require one to carefully assess heteroskedasticity to justify pooling papers from different publication outlets. We expect this issue to be more problematic for conference proceedings than for other top-tier (design science research) journals, which provides an opportunity to extend our dataset's scope. As for the time period we considered, we already stretched methodologists' recommendations (Jarneving, 2007b). Extending the time scope further

would aggravate problems due to isolated papers, which one could address by analyzing multiple time frames to capture how IS DSR has evolved.

With regard to Figure 3 and our analyses, we note that citations constitute a necessary but not a sufficient condition for cumulative knowledge development. Further analyses could review design knowledge and qualitative analyses to identify how IS DSR knowledge has progressed (which includes commonalities, differences, resolutions, and new questions that have emerged within each cluster). Such work could draw from Vom Brocke, Winter, Hevner, and Maedche's (2020) work on IS DSR knowledge accumulation and evolution as a guiding framework[17].

Beyond novelty and theorization, additional aspects might affect IS DSR papers' scientific impact. In particular, researchers have prominently emphasized the importance of evaluation activities (Hevner et al., 2004; March & Smith, 1995). In analyzing evaluation methods that the IS DSR papers in their sample used (which we used as the basis for our sample), Prat et al. (2015) found that they employed various different evaluation methodologies. Similar to IS DSR papers that have received few citations, influential papers covered various quantitative and qualitative evaluation methods. Overall, we know about no sufficiently general evaluation category that we could use to draw reliable conclusions.

Our analyses' correlational nature limits the degree to which we can infer causality. Almost all scientific impact analyses suffer from this limitation since "impact causality [of research] is difficult to establish and to evidence" (Niederman et al., 2015, p. 131). Similar to Mingers and Xu (2010), we have to acknowledge that scientific impact arises from probabilistic processes and complex interactions.

Complementary studies might explore broader DSR programs and the impact that IS DSR has on practice. While we focus on single IS DSR papers as the unit of analysis, one opportunity for future research would be to consider broader IS DSR projects. For example, researchers could examine what characteristics distinguish projects that produce a higher (cumulative) impact through IS DSR papers. Finally, while we focused on scientific impact as one particular type of impact (as a dependent variable), other types of impact (e.g., see Niederman et al., 2015; Swanson, 2014), most notably impact on practice (e.g., see Gill & Hevner, 2013), merit further research. In particular, we need to better understand how IS DSR papers impact different stakeholders, such as IS practitioners, managers, or policy makers. Although measuring the impact on practice constitutes an open challenge, assessment techniques would be invaluable for DS researchers (Niederman et al., 2015). One starting point could be to code the perceived relevance or "likely extent of use" as Arnott and Pervan (2012, p. 932) have suggested. Understanding impact's different types in a more nuanced way would be valuable to inform IS DSR papers' publication practices.

7 Conclusion

Our study offers two unique and valuable contributions for the IS DSR community and its efforts to develop a scientific body of knowledge. First, we explored recent and impactful IS DSR papers in top IS journals. To do so, we applied the bibliographic coupling technique carefully, which includes intellectual refinements such as qualitative analyses of bibliographic associations, and fine-tuned each step of our methodology. Second, we dug deeper into IS DSR papers' characteristics to explain why certain papers had more scientific impact. Our results show that novelty and theorization distinguish IS DSR papers that receive more citations. These insights come from a comprehensive scientometric model that controlled for journal visibility, the author reputation, and paper age.

The model naturally extends the exploratory map by going beyond idiosyncratic high-impact IS DSR cases and considers the general characteristics that many recent high-impact IS DSR papers share. While other scientometric studies have developed impact models without comprehensively exploring the dataset first (e.g., Bergh, Perry, & Hanke, 2006; Judge et al., 2007; Stremersch et al., 2007), we contend that the lack of transparency on the impactful IS DSR paper landscape necessitates this exploratory overview before digging deeper into IS DSR characteristics that explain scientific impact.

Based on the exploratory contributions, we discuss the current IS DSR landscape and envision the road ahead by proposing specific recommendations that we direct at all scholars interested in IS DSR. The data analytic clusters, general systems development clusters, and specific purpose systems clusters offer unprecedented insights into the active IS DSR areas. For the IS DSR community, the map that shows

[17] We thank the editor in chief and a reviewer for this observation.

papers that actually do IS DSR represent a unique resource to familiarize stakeholders with the latest research output. These insights may spark further discussions and reflections in the community about what kinds of IS DSR have scientific impact.

Acknowledgments

We thank Shirley Gregor for feedback she provided on an earlier version of this paper. We also thank Richard Schuster and Philip Empl for their comments and support. The Proceedings of the International Conference on Information Systems (2017) published a previous version of this paper. A grant from the German Science Foundation (DFG) for the research project “Epistemological Advances through Qualitative Literature Reviews in Information Systems Research” supported this research.

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Appendix A: List of IS DSR Papers

Prat et al. (2015) identified the IS DSR papers that we present in Table A1 and we refined them (see Section 4). We describe the coding scheme we used for novelty and theorization in Appendix B. We outline how we identified clusters in Section 4.2. We highlight papers manually assigned to clusters by adding an asterisk. We cross out papers whose topic does not fit into the respective clusters.

Table A1. IS DSR Papers

Design science paper	Theorization	Novelty	Cluster
Aaen (2008)	0	Improvement	Systems and architecture engineering
Abbasi & Chen (2008)	4	Improvement	Fraud detection
Abbasi, Chen, & Nunamaker (2008)	0	Exaptation	Fraud detection
Abbasi, Zhang, Zimbra, Chen, & Nunamaker (2010)	2	Improvement	Fraud detection
Abbasi, Albrecht, Vance, & Hansen (2012)	2	Improvement	Fraud detection
Adipat, Zhang, & Zhou (2011)	3	Improvement	Web information retrieval and classification
Adomavicius & Gupta (2005)	1	Improvement	Agent-based systems*
Adomavicius, Gupta, & Zhdanov (2008)	0	Improvement	Agent-based systems
Adomavicius, Bockstedt, Gupta, & Kauffman (2008)	2	Improvement	Isolated
Adomavicius, Tuzhilin, & Zheng (2011)	0	Improvement	Recommender systems
Albert, Goes, & Gupta (2004)	2	Improvement	Isolated
Alspaugh, Scacchi, & Asuncion (2010)	1	Invention	Isolated
Arazy, Kumar, & Shapira (2010)	4	Routine design	Recommender systems
Arnott (2006)	2	Exaptation	Isolated
Astor, Adam, Jerčić, Schaaff, & Weinhardt (2013)	2	Exaptation	Isolated
Bai, Nunez, & Kalagnanam (2012)	0	Invention	Data quality
Bai, Krishnan, Padman, & Wang (2013)	1	Improvement	Business process management
Bansal, Sinha, & Zhao (2008)	0	Improvement	Customer data mining
Bapna, Goes, & Gupta (2008)	0	Improvement	Agent-based systems
Bera, Burton-Jones, & Wand (2011)	1	Improvement	~~Software development~~
Briggs, Kolfschoten, de Vreede, Lukosch, & Albrecht (2013)	0	Improvement	Collaboration support systems
Brodsky, Egge, & Wang (2012)	0	Invention	Isolated
Butler, Feller, Pope, Emerson, & Murphy (2008)[b]	0	Improvement	Isolated
Castro, Meliá, Genero, Poels, & Calero (2007)	0	Improvement	Isolated
Chatterjee, Sarker, & Fuller (2009)	3	Invention	Collaboration support systems
Chaturvedi, Dolk, & Drnevich (2011)	3	Exaptation	Isolated
Chau & Xu (2012)	2	Improvement	Web information retrieval and classification

Chen, Sharman, Chakravarti, Rao, & Upadhyaya (2008)	1	Exaptation	Isolated
Chen, Sharman, Rao, & Upadhyaya (2013)	2	Routine design	Isolated
Cheng, Sun, Hu, & Zeng (2011)	2	Improvement	Web information retrieval and classification
Choi, Nazareth & Jain (2010)	1	Improvement	Systems & architecture engineering*
Choobineh & Lo (2004)	0	Improvement	Isolated
Chou, Sinha & Zhao (2010)	0	Improvement	Customer data mining
Churilov, Bagirov, Schwartz, Smith, & Dally (2005)	0	Improvement	Customer data mining*
Collins, Ketter, & Gini (2010)	0	Improvement	Agent-based systems
Cui, Wong, & Wan (2012)	0	Improvement	Customer data mining
Currim & Ram (2012)	0	Improvement	Conceptual modeling
Dang et al. (2012)	1	Improvement	Web information retrieval and classification
Datta, Dutta, Liang, & VanderMeer (2012)	0	Improvement	Isolated
D'Aubeterre, Singh, & Iyer (2008a)	3	Improvement	Software development
D'Aubeterre, Singh, & Iyer (2008b)	2	Improvement	Software development
Dietz & Juhrisch (2012)	0	Improvement	Software development
Dreiling, Rosemann, Van Der Aalst, Heuser, & Schulz (2006)	0	Improvement	Business process management
Druckenmiller & Acar (2009)	0	Improvement	Collaboration support systems
Fan, Gordon, Pathak, & Pathak (2005)	0	Improvement	Web information retrieval and classification
Fang et al. (2012)	1	Invention	Web information retrieval and classification
Fernández-Medina, Trujillo, & Piattini (2007)	0	Improvement	Conceptual modeling
García-Crespo, Colomo-Palacios, Gómez-Berbís, & Ruiz-Mezcua (2010)	1	Exaptation	Web information retrieval and classification
Germonprez, Hovorka, & Collopy (2007)	3	Invention	~~Collaboration support systems~~
Ghosh & Li (2013)	1	Improvement	Systems & architecture engineering*
Hanseth & Lyytinen (2010)[ab]	2	Improvement	Isolated
Hickey & Davis (2004)[a]	4	Improvement	Software development*
Jiang, Mookerjee, & Sarkar (2005)	2	Invention	Fraud detection*
Kartseva, Hulstijn, Gordijn, & Tan (2010)	0	Exaptation	Systems and architecture engineering
Keith, Demirkan, & Goul (2013)	0	Routine design	Systems & architecture engineering
Ketter, Collins, Gini, Gupta, & Schrater (2012)	1	Improvement	Agent-based systems
Kohler, Fueller, Matzler, & Stieger (2011)	0	Exaptation	Isolated
Kolfschoten & de Vreede (2009)	2	Routine design	Collaboration support systems
Koschmider, Song, & Reijers (2010)	2	Improvement	Business process management

Krebs, Dorohonceanu, & Marsic (2004)	1	Routine design	Systems and architecture engineering
Krishnan, Peters, Padman, & Kaplan (2005)	0	Improvement	Data quality
Krogstie, Sindre, & Jørgensen (2006)[ab]	1	Improvement	Isolated
Lau, Wong, Li, & Ma (2008)	2	Improvement	Negotiation support systems
Lau, Liao, Wong, & Chiu (2012)	1	Improvement	Web information retrieval and classification*
Lee & Kwon (2006)	1	Improvement	Negotiation support systems
Lee, Wyner, & Pentland (2008)	0	Improvement	Systems and architecture engineering
Leimeister, Ebner, & Krcmar (2005)[a]	2	Exaptation	Systems and architecture engineering
Levermore, Babin, & Hsu (2010)	2	Improvement	Systems and architecture engineering
Li & Sarkar (2006)	0	Improvement	Data privacy
Li & Sarkar (2011)	0	Improvement	Data privacy
Lin, Gray & Jouault (2007)	0	Invention	Isolated
Martens & Provost (2014)	1	Improvement	~~Customer data mining~~
McLaren, Head, Yuan, & Chan (2011)	1	Improvement	~~Business process management~~
Melville & McQuaid (2012)	3	Improvement	Data privacy
Menon, Sarkar, & Mukherjee (2005)	0	Improvement	Data privacy
Montero, Díaz, & Aedo (2007)	1	Improvement	Systems and architecture engineering
Müller-Wienbergen, Müller, Seidel, & Becker (2011)	0	Improvement	Web information retrieval and classification
Närman, Holm, Ekstedt, & Honeth (2013)	4	Improvement	Systems and architecture engineering*
Nunamaker, Derrick, Elkins, Burgoon, & Patton (2011)	4	Invention	Isolated
Oetzel & Spiekermann (2014)	1	Improvement	Data privacy*
Pant & Srinivasan (2013)	0	Improvement	Web information retrieval and classification
Parsons & Wand (2008)	1	Improvement	Conceptual modeling
Parssian, Sarkar, & Jacob (2009)	1	Improvement	Data quality
Pries-Heje & Baskerville (2008)[b]	0	Improvement	Software development
Puschmann & Alt (2005)	3	Improvement	Systems and architecture engineering
Reinecke & Bernstein (2013)	2	Improvement	Customer data mining*
Rossi, Ramesh, Lyytinen, & Tolvanen (2004)	1	Improvement	Software development
Roussinov & Chau (2008)	1	Improvement	Web information retrieval and classification
Saar-Tsechansky & Provost (2007)	0	Improvement	Customer data mining
Sahoo, Singh, & Mukhopadhyay (2012)	0	Improvement	Recommender systems
Schmeil, Eppler, & de Freitas (2012)	0	Improvement	Isolated

Sinha & May (2004)	1	Improvement	Customer data mining
Siponen, Baskerville, & Heikka (2006)	0	Improvement	Software development
Soffer & Wand (2007)	1	Exaptation	Isolated
Storey, Burton-Jones, Sugumaran, & Purao (2008)	2	Improvement	Web information retrieval and classification
Sun, Zhao, Nunamaker, & Sheng (2006)	1	Invention	Business process management
Sun, Srivastava, & Mock (2006)	2	Improvement	Isolated
Umapathy, Purao, & Barton (2008)	0	Exaptation	Systems and architecture engineering*
VanderMeer, Dutta, & Datta (2012)	1	Improvement	Isolated
Vergara, Linero, & Moreno (2007)	0	Routine design	Systems and architecture engineering
Vlas & Robinson (2012)	0	Improvement	Systems and architecture engineering
Wagelaar & Van Der Straeten (2007)	0	Invention	Systems and architecture engineering*
Wei, Chiang, & Wu (2006)	0	Improvement	Web information retrieval and classification
Wei, Hu, Tai, Huangm & Yang (2007)	0	Improvement	Web information retrieval and classification
Wei, Hu & Lee (2009)	0	Improvement	Web information retrieval and classification
Williams, Chatterjee, & Rossi (2008)	2	Improvement	Software development*
Wong, Ray, Stephens, & Lewis (2012)	0	Improvement	Fraud detection*
Xiao & Greer (2007)	0	Improvement	Conceptual modeling
Xu, Wang, Li, & Chau (2007)	0	Improvement	Customer data mining
Yang, Su, & Yuan (2012)[b]	1	Invention	Isolated
Yang, Singhal, & Xu (2012)	4	Invention	Negotiation support systems
Zappavigna & Patrick (2010)	1	Improvement	Software development*
Zhang, Liu, & Li (2011)	0	Improvement	Systems and architecture engineering
Zhao & Soofi (2006)	0	Improvement	Isolated
Zheng, Fader, & Padmanabhan (2012)	1	Invention	Web information retrieval and classification*

Note: [a] High citation impact outlier excluded in robustness check #1. [b] Special cases of IS DSR excluded in robustness check #2

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Appendix B: Measurement and Coding of Factors

To operationalize our model, we referred to established scientometric research (see Table B1). We measured scientific impact in terms of citations as the literature commonly suggests (Grover Raman, & Stubblefield, 2013; Judge, Cable, Colbert, & Rynes, 2007; Tams & Grover, 2010). We extracted citation data from the Web of Science as at 20 April, 2017.

Table B1. Factors of the Research Model

Factor	Measurement	References
Dependent variable		
Scientific impact	Total number of citations from the Web of Science as of 20 April, 2017	Merton (1973) Garfield & Merton (1979)
Main variables		
Novelty	Routine design, improvement, exaptation, and invention	Gregor & Hevner (2013) Grover et al. (2013)
Theorization	Meta-requirements, meta-design, kernel theories, testable hypotheses Number of expressed components of design theory coded	Walls, Widmeyer, & El Sawy (1992)
Control variables		
Journal impact factor	Journal impact factor provided by Thomson Reuters	Judge et al. (2007) Mingers & Xu (2010)
H-index of the first author	An author with h-index *i* has published *i* other papers (at time of publication of the IS DSR paper) that have at least *i* citations [a] (h-indices were calculated based on data provided by Scopus)	Hirsch (2005) Truex, Cuellar, & Takeda (2009)
Age of publication	Time since publication	Grover et al. (2013) Mingers & Xu (2010)

[a] As Scopus provides only the most recent h-indices, we used author publication lists to recalculate h-indices for the point in time when a IS DSR paper appeared. Thus, we corrected for the number of publications but not for citations because we lacked the necessary historical data to do so.

Similar to previous studies (Dwivedi, Purao, & Straub, 2014; Gregor & Hevner, 2013), to code the main variables, we relied on information that the authors reported. However, the rhetoric that the authors employed in describing aspects related to novelty and theorization may have affected the variables. Furthermore, independently assessing and interpreting those knowledge claims may introduce even more subjectivity and bias. One can expect that, to mitigate concerns related to self-reported knowledge claims, reviewers and editors would require authors to correct exaggerated novelty and theorization claims before publication.

Following established qualitative content analysis methodologies (Neuendorf, 2002), the first and second authors coded novelty and theorization. During an initial training phase, the authors refined the coding scheme using the original classification results that Gregor and Hevner (2013) presented where applicable and subsequently coded the IS DSR papers. Both coding sets included 30 overlapping IS DSR papers that the authors used to measure inter-rater agreement. Cohen's Kappa confirmed reliable inter-rater agreement in that all coefficients exceeded the 0.6 threshold. The third author discussed and reconciled disagreements in the shared paper set with the other authors.

In line with other scientometric studies (Bornmann & Daniel, 2008; Grover et al., 2013; Judge et al., 2007; Tams & Grover, 2010), we controlled for journal-related effects using the five-year journal impact factor that Thomson Reuters provides. Regarding author-related effects, we used the h-index as a measure for author reputation (Hirsch, 2005; Truex et al., 2009). Specifically, we controlled for the h-index of each IS DSR paper's first author since this author represents the most visible one and often receives the most credit (Peffers & Hui, 2003).

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Appendix C: IS DSR Clustering Procedure

In this appendix, we provide background information on science maps and the methodological procedures we applied to develop the IS DSR paper map that we display in Figure 3.

C1 Background on Scientometric Clustering Procedures

The scientometric literature offers two complementary techniques for exploring the thematic structure of scientific literatures: 1) a technique based on co-citation similarity measures and 2) a technique based on bibliographic coupling. Researchers refer to these techniques' output as the intellectual foundation and the research front, respectively (Smith, 1981). While co-citation similarity refers to the frequency with which papers cite two documents together, bibliographic coupling similarity refers to the number of references that different papers share (Persson, 1994). Co-citation, a connection extrinsic to papers, begins to evolve when papers accumulate citations, while bibliographic coupling, a static connection intrinsic to papers, finishes evolving at their publication (Smith, 1981). Both techniques assume that co-cited or bibliographically coupled papers contain related content (Smith, 1981) and that clusters of related papers represent thematically coherent research themes.

Co-citation analysis, which Small (1973) originally suggested, has become the predominant approach to visualize the structure of and change in research landscapes (Atwood, McCain, & Wiliams, 2002; Smith, 1981). As typical datasets contain thousands of co-cited papers that may—to a certain degree—be randomly associated through citations, a common approach involves filtering for papers that exceed a certain (normalized) co-citation threshold (Vladutz & Cook, 1984) and, therefore, have a higher chance to contain related content (Persson, 1994). This approach tends to exclude low-impact and recently published papers and favor older, high-impact papers that, in scientometric terms, constitute the intellectual base a discipline builds on (Persson, 1994). Combined with access to the popular Social Science Citation Index (SSCI) via the Web of Science platform, co-citation analyses offer an efficient way to explore the thematic structure of large paper sets. As a result, researchers have published several prominent co-citation analyses in information systems (e.g., Culnan, 1987; Culnan & Swanson, 1986; Hsiao & Yang, 2011; Ma & Yu, 2010; Raghuram, Tuertscher, & Garud, 2010; Taylor, Dillon, & van Wingen, 2010)[18] and its sister disciplines (e.g., Ramos-Rodríguez & Ruíz-Navarro, 2004; Vogel & Güttel, 2013).

Bibliographic coupling, which Kessler (1963) originally suggested, clusters citing papers that, in scientometric terms, form a given discipline's research front (Persson, 1994). This technique has received less attention in the literature (e.g., see Boyack & Klavans, 2010; Jarneving, 2007a; Persson, 1994). Hesitation to adopt bibliographic coupling may partly derive from the fact that, when introducing co-citation analysis, Small (1973) referred to example papers that were "only weakly tied by bibliographic coupling" even though "they were clearly related in content"[19] and speculated that the results of bibliographic coupling and co-citation would "differ quite significantly" (p. 268). Although this critique may have been justified in the specific case, one cannot conclude that co-citation analysis is always superior to bibliographic coupling. It rather depends on the age of the papers that one analyzes, which correlates with their (co)citations. While co-citation techniques have a natural advantage in clustering older papers, they do not perform well on recent papers that have not (yet) received frequent citations (Boyack & Klavans, 2010). In contrast, bibliographic coupling techniques have a natural advantage in clustering recent papers but underperform on old papers whose references the current discourse no longer uses (Boyack & Klavans, 2010).

With regard to IS DSR, few papers have applied co-citation analyses to map the intellectual foundation[20]. These studies have primarily focused on conducting co-citation analyses to determine papers that design science researchers have frequently cited (Akoka, Comyn-Wattiau, & Prat, 2016; Fischer, 2011; Piirainen, Gonzalez, & Kolfschoten, 2010). In summary, these works list most prominent design science papers (such as Gregor & Jones, 2007; Hevner, March, & Park, 2004; March & Smith, 1995; Simon, 1969; Walls, Widmeyer, & El Sawy, 1992). At the same time, however, they reveal that methodological papers

[18] Culnan's (1987), Culnan and Swanson's (1986), and Taylor et al.'s (2010) papers illustrate prominent co-citation analyses even though they focus on authors.

[19] One cannot easily evaluate the co-citation and bibliographic coupling technique's accuracy because the "ground truth" rarely exists (Boyack & Klavans, 2010). A common way to evaluate scientometric maps involves comparing them (or underlying similarities between individual papers) to expert judgments.

[20] We focus on scientometric, thematic analyses and, therefore, do not consider qualitative content analyses (e.g., Iivari, Hirschheim, & Klein, 2004; Indulska & Recker, 2010) or analyses on research output types (e.g., Dwivedi, Purao, & Straub, 2014).

dominate these lists and that the lists contain astonishingly few IS DSR papers (i.e., papers that focus on developing artifacts). Fischer (2011) acknowledges as much in stating that that "the common foundation of ISDSR is mainly composed of ISDSR conceptual papers rather than of ISDSR application papers" (p. 9). Complementing these intellectual base maps, we focus on bibliographic coupling to identify recent and impactful IS DSR papers. To the best of our knowledge, few papers have applied the bibliographic coupling technique to the IS literature (e.g., Hassan & Becker, 2007; Li, Chen, Zhang, Li, & Nunamaker, 2009), and none have explored IS DSR in particular. Table C1 summarizes how the co-citation technique compares to the bibliographic coupling technique and, thereby, clarifies our focus in exploring the IS DSR landscape.

Table C1. Scientometric Techniques for Developing Exploratory IS DSR Maps

Characteristics	Scientometric technique	
	Co-citation similarity	**Bibliographic coupling**
Similarity measure	Papers are co-cited (i.e., forward citations)	Papers share the same references (i.e., backward citations)
Result	Map of the intellectual base	Map of recent papers
Existing research on IS DS(R)	Akoka et al. (2016) Fischer (2011) Piirainen et al. (2010)	Present work

C2 Methodological Procedures

We outline the methodological procedure we followed to develop a scientometric map of impactful IS DSR papers and its clusters in Figure C1. Preliminary analyses confirmed that the alternative co-citation technique could not construct a valid scientometric map[21]. Bearing in mind that co-citation analyses perform better on older papers, we can ascribe this failure to IS DSR papers' relatively young age, which meant they had not yet accumulated a sufficient number of co-citations (e.g., see Jarneving, 2007a; Raghuram et al., 2010). Isolated papers in the co-citation map evidenced the primary fragmentation issue, although they were obviously related in content. In contrast, the bibliographic coupling technique derives papers' similarity from their reference sections, which meant we could use it to identify more appropriate thematic clusters of IS DSR papers.

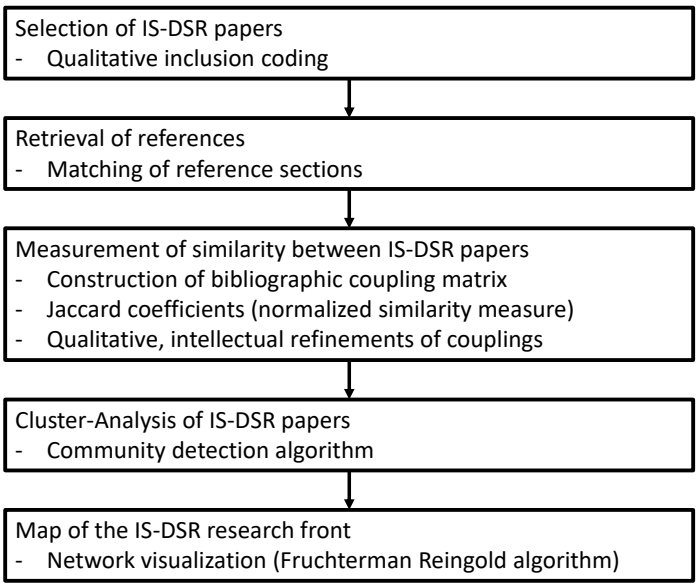

Figure C1. Procedure for Constructing a Map of Impactful IS DSR Papers

[21] As comparatively few authors have published multiple IS DSR papers, author-centric co-citation analyses did not produce substantially more coherent research clusters.

We extracted reference data from the Web of Science for all 115 IS DSR papers that we selected in Section 4. To ensure adequate data quality, we extracted the full reference tables and, as the Web of Science does not provide unique identifiers (accession numbers) for each cited reference, we applied semi-automated procedures to match the remaining references, an approach that scientometricians recommend (e.g., Persson, 1994; Smith, 1981)[22]. In total, we reduced 6,522 references (mean: 57 references per IS DSR paper, min: 14, max: 122) in 115 IS DSR papers to 5,734 unique reference IDs.

To determine papers' similarity, we calculated the bibliographic coupling matrix. Based on the resulting set of edges (IS DSR paper → reference), we derived the adjacency matrix C. We define the symmetric bibliographic coupling matrix B, which indicates the similarity between papers, as follows (Samatova, Hendrix, Jenkins, Padmanabhan, & Chakraborty, 2013, p. 148):

$$B = CC^T, \tag{2}$$

which means that each element indicates the number of references shared between the papers indexed in the row and column. We used the bibliographic coupling matrix for further refinements and analyses. Since reference lists vary in length (min: 14, max: 122), normalized measures of shared references ensure better comparability (Jarneving 2005; Persson 1994; Vladutz & Cook, 1984). Therefore, we applied the Jaccard coefficient, which provides a normalized similarity measure and bibliographic coupling analyses frequently use (Jarneving, 2005). We define the Jaccard coefficient S as the number of references that paper A and paper B share divided by the number of references that either paper shares:

$$S_{A,B} = \frac{|A \cap B|}{|A \cup B|}. \tag{3}$$

Random associations through shared references that do not relate to a shared topic can also produce bias (Jarneving 2007a). For example, two IS DSR papers with only loosely related topics (e.g., one paper on requirements elicitation and another paper on auction theory) may cite the same reference outlining the IS DSR research methodology (e.g., Hevner et al., 2004). These less significant associations, which frequently relate to papers that describe how one should do IS DSR, conceal the actual thematic structure of the map of impactful IS DSR papers. These associations resemble the strong connective role that methodology papers play; researchers have found that these papers conceal the thematic structure in both co-citation (Small & Griffith, 1974) and bibliographic coupling analyses (Boyack & Klavans, 2010). While researchers can eliminate influential methodology papers individually (Boyack & Klavans, 2010; Small & Griffith, 1974), they typically filter out random associations by setting thresholds on the normalized coupling strength (Jarneving, 2005, 2007a). Since the papers in our sample shared relatively few references (19.3 percent on average) and varied strongly in references to papers that describe how one should do IS DSR (from between 0 percent and 100 percent of IS DSR papers' shared references, mean: 15 percent), setting a fixed threshold did not fully uncover the delicate structure of impactful IS DSR papers. In fact, in most cases, typical coupling thresholds of 10 couplings (e.g., Jarneving, 2007a) eliminated all thematic associations of a paper. Therefore, we combined a low threshold with intellectual refinements (Smith 1981)[23]; that is, we qualitatively analyzed the thematic association between the IS DSR papers and their shared references. By scrutinizing the "fine structure of citation practice" (Smith, 1981, p. 91), we excluded references that referred to overly general papers (such as Benbasat & Zmud, 1999; Eisenhard, 1989; Yin, 2003), which represented the general discourse on rigor and relevance in IS, theory building, and case study research, respectively). Persson (1994) also recommends this approach and suggests fine-tuning each step in developing a scientometric map. Of the 6,522 references, we analyzed 1,260 references that at least two IS DSR papers shared and dropped 336 (27 percent) references in total. Specifically, we dropped 192 references that described how one should do IS DSR and 144 references that represented random associations. Figure C2 shows the percentage of references an IS DSR paper shared with other IS DSR papers before and after removing random associations.

[22] For one paper (Rossi, Ramesh, Lyytinen, & Tolvanen, 2004), which—like all papers that the *Journal of the Association for Information Systems* published between 2000 and 2005—the Web of Science did not index, we reconstructed the references based on the full-text paper.

[23] Note that our approach of excluding random associations (bibliographic couplings referring to methodological papers) does not apply to IS DSR co-citation analyses in a similar way. Due to IS DSR papers' comparatively low impact, correcting random associations in a co-citation analysis tends to cause more general papers, such as Benbasat and Zmud (1999), Davis, Bagozzi, and Warshaw (1989), Eisenhardt (1989), and Yin (2003), to emerge.

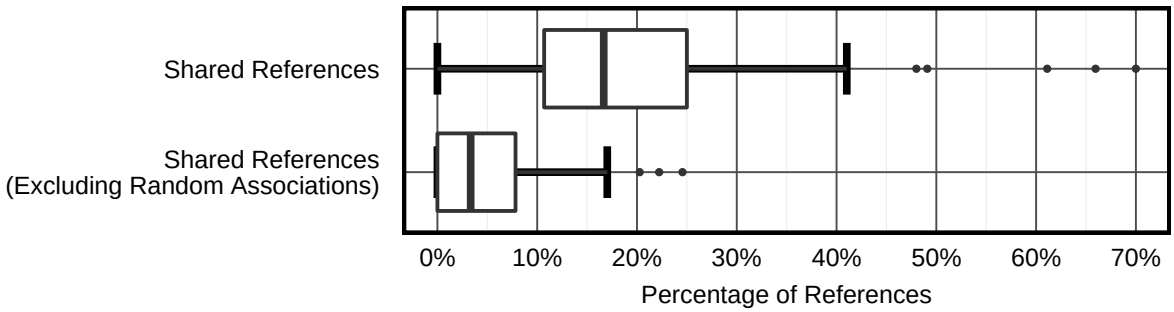

Figure C2. Shared References Before and After Excluding Random Associations (Edges)

Next, we applied state-of-the-art clustering and community detection algorithms to explore the structure of impactful IS DSR papers and to identify the main research topics that characterize IS DSR. While the hierarchical clustering algorithms and the hierarchical complete link clustering method in particular (Jarneving 2007a, 2007b) did not yield clusters that strongly related to one another in content, state-of-the-art community-detection algorithms turned out to produce the best results. To determine the content structure of the IS DSR papers, we finally applied the algorithm that Raghavan, Albert, and Kumara (2007) [24] developed. This algorithm identifies densely connected node communities by simulating a label-propagation process. Initially, each node receives a random, unique label and, in every iteration, adopts the label that most of its neighbors share (ties are broken randomly). The algorithm terminates when each node has a label that the maximum number of their neighbors have (Raghavan et al., 2007, p. 5). In contrast to many other clustering and community detection algorithms, the algorithm that Raghavan et al. (2007) developed derives communities from the network structure exclusively. It does not require defined ex ante parameters, such as the target numbers of clusters. Researchers have empirically shown the algorithm to perform well on scientific networks (Harenberg et al., 2014). In the clustering or community detection literature, it represents a relatively new alternative to algorithms such as traditional methods (e.g., graph and hierarchical clustering), divisive algorithms, modularity-based methods, and spectral algorithms (Fortunato, 2010). Based on content analyses, we mark four papers that are not strongly related to their assigned clusters. We also reassign 16 papers that were isolated to clusters[25].

To visualize the thematic structure of impactful IS DSR papers, we applied the Fruchterman-Reingold algorithm (Fruchterman & Reingold, 1991) to the matrix of distances, which we calculated by subtracting the Jaccard coefficients from 1. Figure 3 shows the impactful IS DSR papers (for each cluster, we show the two most highly cited papers). The nodes' size is proportional to the citations each IS DSR paper received, and the edges' thickness represents adjacent nodes' similarity based on normalized bibliographic couplings (Jaccard coefficient). Table C2 shows all clusters and the assigned papers, and Appendix B lists all 115 IS DSR papers and their clusters. After filtering isolated papers, we identified 13 clusters that represented 67 percent of impactful IS DSR papers. As the community-detection algorithm introduces a certain degree of randomness, we assessed the cluster solutions' reliability by checking whether repeated runs consistently yielded the same clusters (Balijepally, Mangalaraj, & Iyengar, 2011). While the algorithm consistently returned the solution that we display in Figure 3, we found some exceptions when we joined the business process management and the data quality clusters, which reflects the fact that papers contained in the latter cluster focused on data quality in workflow systems. Overall, qualitatively analyzing the papers in each cluster showed high face validity[26]. Table C2 shows the cluster groups, the IS DSR clusters, and the assigned papers. It also includes the papers that we did not automatically assign to clusters due to low bibliographic coupling. We highlight these papers by adding an asterisk to their references.

[24] We use the extended version provided in the R igraph package (which we implemented with the cluster_label_prop() function), which accounts for different edge weights (in our case, the Jaccard coefficient).
[25] Beyond authors not knowing about appropriate references (Smith, 1981), missing connections may also be an artifact of the bibliographic coupling methodology, which performs best on shorter time scopes (Jarneving, 2007a).
[26] Since we did not intend our sampling strategy to support inferences about a broader IS DSR paper population or to predict certain outcomes, we did not assess the degree to which the clusters represented the broader population or criterion-related validity as Balijepally et al. (2011) suggest.

Table C2. Clusters and Papers

Cluster group	IS DSR cluster and papers
Data analytics clusters	**Web information retrieval and classification (n = 17)** Adipat et al. (2011), Chau & Xu (2012), Cheng et al. (2011), Dang et al. (2012), Fan et al. (2005), Fang et al. (2012), García-Crespo et al. (2010), Lau et al. (2012)*, Müller-Wienbergen et al. (2011), Pant & Srinivasan (2013), Roussinov & Chau (2008), Storey et al. (2008), Wei et al. (2006), Wei et al. (2009), Wei et al. (2007), Zheng et al. (2012)*
	Fraud detection (n = 6) Abbasi et al. (2012), Abbasi & Chen (2008), Abbasi et al. (2008), Abbasi et al. (2010), Jiang et al. (2005)*, Wong et al. (2012)*
	Customer data mining (n = 7) Bansal et al. (2008), Chou et al. (2010), Churilov et al. (2005)*, Cui et al. (2012), Reinecke & Bernstein (2013)*, Saar-Tsechansky & Provost (2007), Sinha & May (2004), Xu et al. (2007)
	Data privacy (n = 5) Li & Sarkar (2006, 2011), Melville & McQuaid (2012), Menon et al. (2005), Oetzel & Spiekermann (2014)*
General systems development clusters	**Systems and architecture engineering (n = 17)** Aaen (2008), Choi et al. (2010)*, Ghosh & Li (2013)*, Kartseva et al. (2010), Keith et al. (2013), Krebs et al. (2004), J. Lee et al. (2008), Leimeister et al. (2005), Levermore et al. (2010), Montero et al. (2007), Närman et al. (2013) *, Puschmann & Alt (2005), Umapathy et al. (2008) *, Vergara et al. (2007), Vlas & Robinson (2012), Wagelaar & Van Der Straeten (2007)*, Zhang et al. (2011)
	Business process management (n = 4) Bai et al. (2013), Dreiling et al. (2006), Koschmider et al. (2010) and Sun et al. (2006)
	Data quality (n = 3) Bai et al. (2012), Krishnan et al. (2005), Parssian et al. (2009)
	Conceptual modeling (n = 4) Currim & Ram (2012), Fernández-Medina et al. (2007), Parsons & Wand (2008), Xiao & Greer (2007)
	Software development (n = 9) Dietz & Juhrisch (2012), D'Aubeterre et al. (2008a, 2008b), Hickey & Davis (2004)*, Pries-Heje & Baskerville (2008), Rossi et al. (2004), Siponen et al. (2006), Williams et al. (2008)*, Zappavigna & Patrick (2010)*
Specific purpose system clusters	**Collaboration support systems (n = 4)** Briggs et al. (2013), Chatterjee et al. (2009), Druckenmiller & Acar (2009), Kolfschoten & Vreede (2009)
	Negotiation support systems (n = 3) Lau et al. (2008), Lee & Kwon (2006), Yang et al. (2012)
	Agent-based systems (n = 5) Adomavicius et al. (2008), Adomavicius & Gupta (205)*, Bapna et al. (2008), Collins et al. (2010), Ketter et al. (2012)
	Recommender systems (n = 3) Adomavicius et al. (2011), Arazy et al. (2010), Sahoo et al. (2012)

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About the Authors

Gerit Wagner is a postdoc at HEC Montréal. His research focuses on literature reviews, the impact of research methods, and digital platforms for knowledge work. His research has been published in international journals, including *Decision Support Systems*, *Computers & Security*, *Communications of the AIS* and conferences such as the *International Conference on Information Systems*. He is a member of the *Association for Information Systems* and he regularly serves as a reviewer for Information Systems journals and conferences.

Julian Prester is a third-year PhD student at the UNSW Business School at the University of New South Wales, Sydney. He is doing research at the intersection of technology, work and organizations, focusing on various forms of Digital Work. Additionally, Julian is interested in literature reviews, process theorizing, natural language processing, and deep learning approaches. His research has been published in the *Computers & Security* journal and the proceedings of leading IS conferences such as the *European Conference on Information Systems* and the *International Conference on Information Systems*.

Guido Schryen holds the Chair of Management Information Systems and Operations Research at Paderborn University, Germany. His research interests cover quantitative decision support and operations research, benefits of information systems and services, literature reviews, and IT security. He has published both quantitative and qualitative research in international journals, including *European Journal of Information Systems*, *European Journal of Operational Research*, *OR Spectrum*, *Communications of the AIS*, *Communications of the ACM*, *Computers & Security* and others.