Enterprise systems complexity and its antecedents: a grounded-theory approach

Tobias Schoenherr
Department of Supply Chain Management, The Eli Broad Graduate School of Management, Michigan State University, East Lansing, Michigan, USA
Ditmar Hilpert
ESB Business School, Reutlingen University, Reutlingen, Germany
Ashok K. Soni
Operations and Decision Technologies Department, Kelley School of Business, Indiana University, Bloomington, Indiana, USA
M.A. Venkataramanan
Kelley School of Business, Indiana University, Bloomington, Indiana, USA, and
Vincent A. Mabert
Operations and Decision Technologies Department, Kelley School of Business, Indiana University, Bloomington, Indiana, USA

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Abstract

Purpose – The purpose of this paper is to develop a better understanding about drivers of enterprise systems complexity (ESC), as well as its multi-faceted conceptualization.

Design/methodology/approach – Case studies were conducted among German Mittelstand companies by an international research team. A grounded theory approach was followed, with the first phase of the case studies being exploratory, and the second phase being more focused.

Findings – Case study findings suggest that ESC is a multi-dimensional construct consisting of the following dimensions: seamlessness, adoption date, number of integrated subsystems, system type/composition, number of functional areas linked, and number of users. Drivers of ESC identified via the case studies include the multi-dimensional constructs of competition, complexity of processes, complexity of products, global operations, and the firm's customer base. Grounded theory development is used to conceptualize the measures of these drivers. Founded in these exploratory observations propositions for future research are developed.

Originality/value – The research reports on the experiences of companies with enterprise systems (ES), and explores organizational factors determining system complexity; as a sampling frame Mittelstand companies in Southwest Germany are chosen, making this study one of the few exploring ES within this context. The paper also places ESC within theoretical domains, especially the STS theory. The conceptualization of ESC and its antecedents presented provides a starting point for future academic research into this area.

Keywords Business enterprise, Complexity theory, Management strategy, Germany

Paper type Research paper

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1. Introduction

Enterprise systems (ES) are complex and their implementation can be a challenging, time consuming and expensive undertaking for any company (Davenport, 1998; Mabert *et al.*, 2001). Additionally, there is no guarantee of a successful outcome, even with significant investments in time and resources. Therefore, it is crucial that the chosen ES, the modules implemented, the modifications and customizations undertaken, and the link to existing legacy systems, if applicable, be carefully considered. The final implemented design of the ES should then be able to effectively support the company's goals, reflecting its requirements, constraints, and peculiarities.

Many aspects must be considered when implementing and designing an ES. For example, whether the system is adapted to the firm's processes, or whether the processes are modified to fit the system, is an important decision that can have long-term ramifications. Similarly, whether to maintain legacy systems whose processes cannot be replicated in the new ES, as well as their potential interlink with the package ES, is a choice that needs to be made. Furthermore, the selection of the system provider, and the implementation of a single system or the practice of a best-of-breed approach needs to be well thought-through. Above decisions should result in an ES that is ideally suited for the company, fitting its unique needs and objectives. However, depending on the firm's situation, the structure of the system can become quite complex; for instance, when legacy systems have to be interlinked with new components. As ES evolve and grow over time, this complexity can increase exponentially. Therefore, decisions regarding ES design, infrastructure and resulting complexity must be carefully evaluated.

In this paper, we explore enterprise systems complexity (ESC) and factors that contributed to it. We do not postulate complexity as either good or bad, but inherent in and demanded by a firm's context. Based on case study insights we explicate the degree of ESC present, and propose a conceptualization of ESC. We also provide theoretical underpinnings of ESC management, which are scarce in current academic literature. Therefore, an investigation into the environmental and organizational factors influencing ESC is needed, in addition to the analysis of the evolution of ESC. These insights are necessary to provide a foundation for an explanatory theory (Closs *et al.*, 2008). We provide such a framework and develop propositions grounded in socio-technical systems (STS) theory.

The case study method is used to collect data and obtain insights into ESC and its potential determinants. Owing to the exploratory nature of this research, case studies were deemed as the most appropriate methodology. We explore these issues within the context of the German Mittelstand. These companies possess some unique characteristics, adding a distinctive perspective to this research.

This paper makes several contributions to a growing body of knowledge. First, it explicates the concept of ESC based on influential determinants and develops propositions for future research. Second, the research puts ESC into theoretical perspective, using a STS theory lens, and is one of the few studies that focuses on the post-implementation effects of ES implementation, following the notable examples of McAfee (2002), Bendoly and Schoenherr (2005), and Gattiker and Goodhue (2005). Third, the paper studies these issues within the context of the German Mittelstand environment, which has seldom been the subject of ES research, providing some unique insights into this sector. And fourth, for each of the constructs explored we suggest measurement items with which these factors can be assessed.

This investigation is valuable for both academics and practitioners. For academic research, the present study provides the first comprehensive conceptualization and definition of ES complexity, as well as an explication of its antecedents. The paper places ESC within theoretical domains, and establishes a sound foundation for future exploration. For practice, the paper offers propositions for the effective management of ESC. This framework can aid information technology (IT) managers in the assessment of their current ES structure, and of what demands placed on the system may lead to greater complexity.

The paper is organized as follows. Section 2 provides a review of relevant past literature, putting this study in context, with Section 3 describing the methodology, as well as company characteristics of our sample. Section 4 discusses and analyzes the case study findings using within-case and cross-case analyses, and explicates the concept of ESC and its environmental and organizational antecedents. STS theory is applied to the findings in Section 5, with Section 6 suggesting a set of propositions based on our findings; here we also summarize, conclude, and provide suggestions for future research.

2. Enterprise systems and complexity

ES research, especially as it relates to enterprise resource planning (ERP) systems, has proliferated over the last decade. The roots of today's ERP systems can be traced back to the early materials requirements planning (MRP) and manufacturing resource planning (MRP II) systems. Mabert (2007) and Jacobs and Weston (2007) provided a comprehensive chronology of the historical development and evolution of these systems. The majority of published research concerning ERP systems has dealt with large organizations, which were the first to implement the new technology. While initial explorations focused on implementation (Ng *et al.*, 1999), evaluation frameworks (Teltumbde, 2000), and motivations and experiences of companies (Mabert *et al.*, 2000, 2003), subsequent studies investigated the impact of ERP systems on firm performance (Shin, 2006) and on the entire supply chain (De Búrca *et al.*, 2005; Hendricks *et al.*, 2007). With the proliferation of ERP research, attention shifted to small- and medium-sized companies and their unique requirements (Taylor, 1999). For example, a recent study by Snider *et al.* (2009) explored critical success factors of ERP implementations among five Canadian SMEs. The *International Journal of Operations & Production Management* played a key role in disseminating this valuable insight on ES research (Bendoly *et al.*, 2006; Bendoly and Jacobs, 2004; Bendoly and Schoenherr, 2005; Bozarth, 2006; Cagliano *et al.*, 2006; Ettlie *et al.*, 2005). The present study continues this research stream published in the journal.

The need for ES to be aligned and fitting with overall company strategy and characteristics has been reported as an important determinant for success. For example, Berry and Hill (1992) stressed the need for manufacturing planning and control systems to be aligned with business strategy, while Gattiker and Goodhue (2005) presented a model of the organizational impacts of ES once the system has gone live. Similarly, Bendoly and Jacobs (2004) found that the alignment of ERP solutions with operational needs is crucial to the perceived ability to deliver orders on time, as well as to the general satisfaction with the ERP solution. Therefore, the implementation of such systems has been characterized as a complex process (Poba-Nzaou *et al.*, 2008; Soja, 2006). Against this background, the goal of this paper is to explicate ES infrastructure by exploring environmental and organizational determinants of ESC.

The concept of complexity has been studied in various contexts (Xie and Lee, 2005). Motivation for this stream of research provides the notion that ES development must deal with both technological and organizational issues, the latter of which are mostly outside of the IT department's control (Kirsch, 1996; Xie and Lee, 2005). Examples include work by Tait and Vessey (1988, p. 98) who associated high system complexity with less successful systems. The authors defined system complexity as "the perceived complexity associated with the analysis and design of a system." Meyer and Curley (1991) focused on the complexity of expert systems, which they conceptualized as consisting of knowledge and technological complexity. Our research deals with the latter, which was defined by Meyer and Curley (1991) as the depth and scope of the programming effort, the user environment, and related technical efforts. Literature on function point analysis offers additional discourse on system complexity (Garmus and Herron, 2001). Nevertheless, no specific research was found that addresses the comprehensive management of ESC based on environmental and organizational conditions, as well as the grounding of this issue in theory.

Building on prior conceptualizations noted above, we define system complexity on a broad level as the degree of how multifarious, sophisticated, refined and intricate the infrastructure for an ES is. A complex ES consists of interrelated parts whose relationships are multifaceted and difficult for an outsider to comprehend (Merriam-Webster Online Dictionary, 2008). This definition is developed further in subsequent sections based on case study insight. For this investigation, ES infrastructure encompasses the totality of information systems in place, their linkages, interconnections and dependencies. These ES often comprise an ERP system, but can also include other interconnected systems not being part of an ERP package. Our study focuses on the post-implementation experiences of companies, i.e. the resulting ESC, which has seen little inquiry and is thus in need for research (Gattiker and Goodhue, 2005). Within this context we do not conceptualize ESC as either good or bad, but inherent in the system and demanded by certain environmental and organizational antecedents.

3. Methodology

While ES research is proliferating, no published studies were found that examined the resulting ES complexity after implementation, as well as drivers that may have contributed to the infrastructure being more or less complex. For such areas, where the knowledge base is still small, the utilization of case study methodology is suggested, enabling the collection of detailed information (Yin, 1994). This approach for collecting data, deriving insights and conclusions, and even develop theory has become quite popular (Eisenhardt and Graebner, 2007), with several researchers discussing the rigor and benefits of case study research (Eisenhardt, 1989; Ellram, 1996; Meredith, 1998; Voss *et al.*, 2002). Case study methodology has frequently found application in the operations management literature (Closs *et al.*, 2008; McCutcheon and Meredith, 1993; Wacker, 1998), and more specifically also in research studying ERP implementations (Snider *et al.*, 2009), deeming the approach as the most suitable for exploring dimensions of ESC and its drivers.

Prior to active data collection we developed a detailed case study research protocol, formalizing our objectives and research questions, study purpose, unit of analysis, case study design, and data analysis. This protocol provided guidance and structure throughout the various research stages, and ensured the validity and reliability of our findings. The basic questions we wanted to find insight for included the following:

Q1. How can ESC be defined and conceptualized?

Q2. What environmental and organizational factors drive ESC?

Q3. What theories describe how firms manage ESC?

3.1 Case context

The case studies were conducted in Germany at the enterprise-level, which serves as our unit of analysis. A unique characteristic of the German business landscape are companies frequently referred to as the Mittelstand, which are said to form the backbone of the German economy (von Keudell, 2007). While there is no legal definition of the term Mittelstand, its companies are frequently limited in size, typically not exceeding 1,000 employees. Mittelstand companies are often labelled as small- and medium-sized enterprises (SMEs), but do not necessarily adhere to SME definitions. For example, the European Union defines SMEs as companies with fewer than 250 employees (European Commission, 2008). However, it has been argued that such a quantitative dimension does not do the Mittelstand justice, but a more qualitative definition should be relied on, which assesses companies in terms of attitude and behaviour (Linnemann, 2007). This definition should focus on the character of the entrepreneur, "who is so deeply involved with the company that, at times, the business and businessperson can be described as one and the same" (Linnemann, 2007, p. 4). Leadership at Mittelstand companies for example means taking personal responsibility for one's actions, having a close relationship with one's employees, and being heavily involved in the community.

The Mittelstand numbers over a million companies, employs over 20 million people, is responsible for almost 40 percent of total German gross investments, and accounts for 30 percent of the exports (Hauser, 2000). The enterprises are often highly innovative and entrepreneurial, and are frequently very competitive international market leaders. The primary focus of German Mittelstand companies is on highly customized and specialized products and services, making information systems a key competitive weapon (Taylor, 1999; Voigt, 2001). Usually, the companies rely on highly skilled and flexible employees, which are supplied by Germany's exceptional vocational training system. This leads to a very loyal and stable workforce, with a low labour turnover rate of 2.7 percent (Simon, 2007). Overall, German Mittelstand companies provide a unique setting to study the design and complexity of ES.

3.2 Case selection

For the selection of our case studies we employed theoretical sampling (Eisenhardt, 1989; Meredith, 1998). Our goal was to select true Mittelstand companies that are known to be especially innovative, proactive and successful, to ensure that the propositions developed will have practical value for other firms (Wu and Choi, 2005). Ideal candidates included polar types, in which extremes can be observed, both in terms of ESC and its various influencing environmental drivers (Eisenhardt, 1989). Following the grounded theory approach postulated by Glaser and Strauss (1967), the individual case studies were conducted in two phases. In the first phase of our case research, the director at a regional chamber of commerce was contacted and asked to suggest a set of ten Mittelstand companies that would fulfil our requirements. We elected a regional focus to avoid any confounding effects. All ten firms agreed to participate in our study. Interviews during this phase were rather exploratory as we investigated and identified the concept of ESC as well as its determinants. Once the concept of ESC had been defined and its drivers identified, findings were compared to related literature. With this foundation of both empirical insight and related studies, the constructs could be operationalized for further investigation during the second phase of data collection.

For the second phase, the German co-author of the study, who is significantly involved in the business community of the investigated region, brainstormed an additional set of ten companies that would be able to refine the insight obtained in the first phase. Using the preliminary findings of phase one, we were able to select a more targeted and focused set of companies. These firms were again exceptional representatives of the Mittelstand, and were at different stages in the sophistication of their ES developments. This provided us with a range of ESC environments. While the additional ten companies participated in the research, we excluded two firms due to their industry, which was logistics and retail, respectively. These two case studies were conducted to obtain contrast, and to validate our findings collected from the set of 18 manufacturing firms. This second phase refined our thoughts, constructs and relationships derived in the earlier phase. With these two phases complete, it was determined that the cases had reached a point of theoretical saturation, thus no additional case studies were conducted (Glaser and Strauss, 1967).

3.3 Data collection and sample characteristics

A total of 18 Mittelstand companies in manufacturing were studied. For data collection a case study interview guide was developed, which included both specific and open-ended questions. This guide was used during the interviews to provide structure for the discussion. However, deviations were encouraged to facilitate the discovery of new concepts and issues (Closs *et al.*, 2008). Interviews were conducted with multiple interviewees per company, which ensured the capture of a variety of perspectives about ESC that may be present. Two or more members of the research team visited each company on site. To minimize bias, the combination of interviewers differed. Interviews were held in both English and German, depending on the preference of the interviewees, tape-recorded, and detailed transcripts in English were prepared. The duration of the interviews ranged from one to three hours. Interviewees were primarily key business managers and IT professionals, although we also obtained information from senior management, plus operations, logistics and marketing executives, enabling triangulation. Interviewees had various backgrounds, with all having significant tenure within the company, providing an excellent perspective of the past, present, and future of the firm's ES. Company visits sometimes included formal presentations by executive management and IT executives, as well as a formal demonstration of their ES.

During all visits members of the research team were given a tour of the production floor, highlighting the integration with ES. Valuable observations were made, including the type and sophistication of production processes, systems used directly on the shop floor, and the reach and proliferation of ES throughout the firm. These tours ensured the internal consistency of the data, provided contextual information, and enabled a triangulation of the interview data (Wu and Choi, 2005). Triangulation, a crucial component of rigorous case study research, offers heightened confidence in results (Eisenhardt, 1989; Lewis, 1998; Patton, 1990; Yin, 1994). Information obtained prior can be corroborated by other data sources to ensure its validity. Additional means for triangulation included the collection of quantitative data and printed material at each company visited, such as brochures, handouts, CDs, charts, and presentations. As a further means to validate the data, follow-up phone calls were conducted several months after the visits to corroborate the information, to obtain clarification to ambiguous conclusions, and to further ensure the accuracy of our data.

The sample was designed so a broad and diverse spectrum of German Mittelstand enterprises was represented. Products manufactured included parts for the automobile industry, sophisticated medical equipment, textiles, elevators, heat exchange systems, scales, industrial knitting machines, network systems and products, furniture, complete workstations, home appliances, heavy-duty processing machinery, machine controls, and specialty metal pipes. Annual revenues ranged from approximately €24 to 380 million, and almost all of the firms had a global presence. The manufacturing environment of the companies in the sample was predominantly make-to-order (MTO), with only two companies entirely producing to stock (make-to-stock, MTS). One third provided a mix of MTO and MTS products. The heavy emphasis on MTO production processes emphasizes the entrepreneurial and innovative nature of the Mittelstand, one of the unique characteristics of our sample frame chosen. Specific information about industry type, number of employees, and annual revenue for each of the companies is provided in Table I.

At the time of the interviews, only one company had not yet implemented an ERP system. While operating on a legacy system, the firm had plans for an ES implementation. The remaining 17 firms had already implemented an integrated ES or were in the process. Implementation was at various stages across the sample, providing a range of experiences. Being the largest world wide vendor of ES software and having German roots, SAP was the most frequently installed system. Other system vendors included Baan, PeopleSoft, Oxion, Rohna, and Ratioplan. A niche solution provider was sometimes preferred over one

Company	Industry type	Size (# employees)	Revenues (million €)
A	Scales and food processing equipment	1,000	378
B	Industrial mixers and grinders	600	120
C	Textiles	900	64
D	Food technology and home appliances	770	90
E	Material handling (forklifts)	593	100
F	Furniture	1,200	140
G	Machines for woodworking, tooling, and grinding	1,100	320
H	Elevators, medical technology, and gear technology	700 +	80-85
I	Heat and cooling technology	2,000	100
J	Waste management	220	Not available
K	Springs	208	25
L	Parts for automobile industry	100	24
M	Industrial precision scales	235	60
N	Industrial knitting machines	600	200
O	Gaskets for the automobile industry	3,000	380
P	Medical surgery equipment	480	70
Q	Parts for the automobile industry	500	275
R	Communications test and management solutions	350	100

Table I.
Industry type, number of employees, and annual revenue

of the major system package providers. The primary drivers to implement the system were to gain competitive advantage and to improve interactions with customers and suppliers.

An interesting observation was that most of the firms had the package ERP system combined with other internal legacy systems, which contributed to system complexity due to the interfaces that needed to be present. In addition, most companies in our sample implemented the system with a phased-in approach, as opposed to a "big-bang," and modification was kept to a minimum. We should note that within the context of ES implementations, customization involves setting system parameters to model the ES after the firm's processes and features, whereas modification means altering ES code to perform non-standard business processes (Brehm *et al.*, 2001). In this paper, we are primarily concerned with the latter.

3.4 Data coding and analysis

For data coding and analysis the grounded theory approach by Glaser and Strauss (1967) was employed. Instead of creating codes prior to collecting data, measurement dimensions, and codes were gradually developed during the first phase of the case studies, with their validation occurring during the second phase (Carter *et al.*, 2004). Applying suggestions by Miles and Huberman (1994), we first developed a case write-up for each of the companies visited. In this "within-case analysis" we identified the various drivers of ESC, as well as its conceptualization. All authors of the study participated in finalizing the measurement values for each of the case study companies. This assignment of values was first done independently based on our recollection, transcripts, interview notes, and company documentation. Results were then examined jointly, and discrepancies were discussed until a consensus among the team members was found (cf. the approach followed by Closs *et al.*, 2008). In a second step we conducted "cross-case analysis," in which we compared and contrasted the individual cases, in order to recognize similarities and differences (Walker and Harland, 2008).

4. Analysis and discussion

4.1 Conceptualization of enterprise systems complexity

One of the key findings in the first phase of our case study research was that the sample companies tried to match the functionalities of their systems as closely as possible with their organizational needs. Based on their environmental and organizational determinants the ES could then potentially evolve into a rather complex system; information collected in this first phase of our research also suggested that ESC is a multi-dimensional construct that can manifest itself differently in different companies. The insight obtained in this first phase provided guidance for the concurrent literature review in ES research and related domains. Applying this grounded theory approach, our goal was to develop a sound definition and conceptualization of ESC, backed by both our empirical findings and published literature. A set of six dimensions of ESC were derived which built a preliminary framework. This was further refined via more in-depth and focused case studies in the second phase. In addition, case study firms from the first phase were contacted again to ask specific follow-up questions in relation to these six dimensions. The following paragraphs summarize the result of this process, which led us to conceptualize ESC as consisting of six aspects: seamlessness, adoption date, number of different integrated systems, system type/composition, number of functional areas linked, and number of ES users. Values of our 18 case studies along those dimensions are provided in Table II, using a three or four point metric scale to capture complexity. There are some interesting firm differences on their degree of complexity, which was the result of organizational and environmental conditions. While these determinants will be discussed in a later section, we will now focus on the derivation of the ESC concept based on our case studies and related literature. Looking back at our case studies, we feel that the measurement proposed is a good representation of the firm's overall ESC.

4.1.1 Seamlessness. The first dimension we use to conceptualize ESC is that of Bendoly *et al.* (2004) who introduce the concept of "value chain resource planning," with which seamlessness among interrelated and interdependent systems can be achieved. Companies strive for seamlessness to provide more effective and efficient information, material and service flows, both between and within value chain partners. These relationships can be quite complex (Bendoly *et al.*, 2004), which in turn can mean that a fully integrated system shows a high level of complexity. This is due to the established linkages and seamless interrelationships between sub-systems or applications. Insights from our case studies suggested this seamlessness to be a major descriptor of ESC. Therefore, we put forward that system complexity can be measured by the degree of seamlessness inherent in the systems infrastructure, with a greater degree of seamlessness representing a greater degree of ESC. For seamlessness we assessed our case studies on a three-point scale ranging from basic to moderate and advanced levels of seamlessness. Firms exhibiting high levels of seamlessness were characterized by an

Company	Seamlessness	Adoption date	Number of subsystems	System type	Number of functions	Number of users	Average
A	2	2	3	4	3	3	2.83
B	2	2	2	2	3	2	2.17
C	1	2	2	2	1	1	1.50
D	3	3	3	3	3	2	2.83
E	3	3	3	4	2	2	2.83
F	2	2	2	2	1	2	1.83
G	2	2	3	3	3	3	2.67
H	3	3	3	3	2	2	2.67
I	3	2	1	1	3	3	2.17
J	1	2	2	1	2	1	1.50
K	3	2	2	1	2	2	2.00
L	2	3	1	1	2	1	1.67
M	1	1	1	4	1	1	1.50
N	3	1	3	1	2	3	2.17
O	2	2	2	1	2	3	2.00
P	2	2	2	1	2	2	1.83
Q	2	1	3	1	2	2	1.83
R	3	2	3	3	2	2	2.50

Notes: Measurement (higher ranking → greater complexity); *seamlessness*: basic (1), moderate (2), advanced (3); *adoption date*: 2002 or later (1), 1997-2001 (2), 1996 or before (3); *number of different integrated subsystems*: 1 (1), 2-4 (2), > 4 (3); *system type/composition*: package solution (1), best-of-breed standard modules (2), in-house systems combined with standard modules (3), unique in-house developed system (4); *number of functional areas linked*: 0-5 (1), 6-10 (2), > 11 (3); *number of ES users*: 0-100 (1), 101-300 (2), > 300 (3)

Table II. Cross company comparisons on ESC advanced integration of ES, both within the company and with external suppliers and customers.

High seamlessness was exhibited by Company H, who attributed their advanced ES to the exceptional expertise and knowledge of the IT staff. The highly developed and integrated system enables 99 percent of on-time delivery performance, and supports the innovative stance of the firm. For Company E an enthusiastic and motivated workforce was a key, plus possessing a sophisticated and deliberate IT infrastructure consisting of several best-of-breed applications. All different subsystems are seamlessly integrated with each other, enabling for example high automation on the logistics side; ESC was judged to be high by our interviewees at Company E. Company C serves as an example of low seamlessness; many of its IT systems are internally developed, with system documentation sometimes even missing. Modifications and upgrades are therefore virtually impossible. Owing to the capacity of the system and the inability of the firm to manage it, the company decided to completely restructure its ES infrastructure with an entirely new and integrated system to enable seamlessness. Company M was just beginning to approach seamlessness, with only a few system modules, like quality management, being implemented; ESC was assessed to be lower in this instance.

4.1.2 Adoption date. As a second dimension of system complexity we propose the length of time that a company has been operating with an integrated ES (Gattiker and Goodhue, 2005). It is reasonable to expect that the longer a firm has had the system, the more complex it has grown. This can be the case because more subsystems have been added and linked, more functional areas have been integrated, and/or connections to value chain partners have occurred successfully; early adopters of integrated systems have had more opportunity to develop and refine their systems over time. Findings from our first phase of case studies confirmed this link. In addition, Jennings (2001) suggested that hierarchic, i.e. complex, systems evolve more quickly than non-hierarchic ones of comparable size. This would mean that the systems of those firms that have had the ES in place for longer, evolve more quickly and become even more complex, perpetuating the impact to an exponential growth in complexity. Therefore, the adoption date of an integrated system forms our second dimension of system complexity. Based on our sample we quantify this dimension into three categories by implementation date: 1996 or before, between 1997 and 2001, and 2002 or later.

When comparing the ES implementation date with how case study firms described their system infrastructure, there was a clear connection between the two concepts; systems implemented earlier in time exhibited greater overall complexity. For example, Company H, which implemented its first integrated system in 1996, had significant experience and learned a lot over the years, for example how to best structure and integrate different ES. This expertise and knowledge, gained over time, enabled the development of a complex and sophisticated system. Company D also followed a very structured and deliberate approach of gradual implementation of modules. As such, while the firm started with its finance module in 1995, it did not implement the quality management module until 2000. Several additional systems have been added over the years, all being interlinked with each other, contributing to the firm's ESC. In contrast, while Company Q is using several ES, most of them have not been integrated with each other yet, decreasing overall complexity. An additional complicating factor is change management that is still in progress at Company Q;

employees continue to resist the change to a new integrated system. This illustrates the influence of time on ESC: the longer an integrated system has been implemented, the more sophisticated, refined and complex it has grown.

4.1.3 Number of different integrated subsystems. The number of different integrated subsystems within the enterprise forms a third dimension of system complexity derived from our case study observations. Simon (1996), who described a complex software system as one with a large number of interacting parts, provides support for our use of this dimension. Thus, we suggest that when the ES is composed of many different subsystems, it can be categorized as complex (Tait and Vessey, 1988). Based on the characteristics of our sample, we created three groups for this dimension: companies that possess only one major sub-system, two to four major sub-systems, and five or more major sub-systems.

Company M serves as an example for having a single integrated ES within the firm. This is in line with the firm's organizational structure and processes, which are designed to be fairly lean and not overly complex; ESC was judged to be low. Also, Company L wanted to keep its ESC as low as possible and purposefully modified its internal processes to fit the ES. When the firm implemented the system, all data were entered completely from scratch, to enable a start with a solid and simple ES. In contrast, Company D relies on a multitude of subsystems, having 13 different platforms with stand-alone applications, partly developed in-house and partly bought from outside vendors. These different subsystems are integrated with a company data warehouse, ensuring visibility and accountability; overall, this system seemed to be very high in complexity. Certain challenges still exist, such as the compatibility of data across systems; the firm needs to expend significant resources to clean the data in order to make them transferable between different applications. Company D serves as an example of high ESC, as measured by the number of different integrated subsystems in place.

4.1.4 System type/composition. Different enterprises require various systems due to internal or external requirements, such as activities to support, functionalities to link to, capabilities to offer, stakeholders to satisfy or reporting obligations to perform. These factors place different demands on the system. For some firms this set of demands is easily fulfilled by a standard packaged ES. If a more complex approach is needed to satisfy their requirements it can be achieved either by a combination of best-of-breed modules from several different systems, or by extensive modifications or customization of standard modules. In the present research we are concerned with modification, since it can add much more complexity to a firm's ES than regular customization; regular updates from the ES vendor may not be able to be implemented on top of this modified version and support by the vendor may be limited due to this alteration. When regular off-the-shelf applications are not able to satisfy the firm's needs, in-house developed systems will prevail, sometimes combined with standard modules. Therefore, the system type and composition, as well as the extent of modifications of standard modules, serves as our fourth measurement dimension derived via the grounded theory approach from our case study observations (Gattiker and Goodhue, 2005). Findings suggested that complexity increases as one moves from packaged solutions, to best-of-breed standard modules, to in-house systems combined with standard modules, to unique in-house developed systems. We therefore differentiate between these four characteristics.

Companies A and M had the most complex systems in this regard, since they consisted of an intricate interlinked infrastructure of in-house developed components. Specifically, Company A did not want to lose the unique capabilities of its own systems, which were not readily available in commercial packages. The firm had to design a sophisticated IT infrastructure to accommodate the information exchange between all these diverse systems. Supporting this approach was the philosophy of the head of data processing, who cautioned not to be lured away by apparent functionality of package solutions, since their disadvantages may only show in the long run. Similarly, the decision of Company M to stick with their own systems was based on packaged ES providers not being able to offer the unique solutions it required. Company R is an example of having in-house systems combined with standard modules. The firm first wanted to go with an overall package solution, but soon realized that the scope was too big and not feasibly manageable in an integrated fashion. Expectations were scaled back, and only a few key modules were implemented; these were subsequently linked to existing in-house systems. In contrast, Company B uses an array of best-of-breed applications since it requires specialized programs for several functions. In addition, politics and power struggles between departments resulted in each wanting their own preferred system. All these are instances where high ESC was judged to be present. An example of a firm using a single package solution is Company I, who implemented most modules available in the SAP suite. The goal of this approach was standardization across the firm's world wide subsidiaries and plants; a single standard system enabled this objective. A similar motivation was in place for Company O, exhibiting low ESC.

4.1.5 Number of functional areas linked. Our fifth assessment of ESC uses the number of functional areas linked with the system. We rely on arguments by Jennings (2001), who assessed system complexity by the interrelationships that subsystems possess; the overall system is more complex if it exhibits a large number of interdependencies. The degree of system integration and interdependence is thus measured by the number of functional areas linked in the enterprise, which became apparent with our case studies. Based on the sample, we differentiate between up-to-five, six-to-ten, and over-11 functional areas linked.

Few systems are interlinked in Company C, since the firm relies on a rather old IT infrastructure consisting of several stand-along legacy systems. Future plans of the company include the implementation of a more integrated and interlinked system. Currently, the sophistication of the ES at Company C is fairly low. On the other extreme, almost all functions at Company A are linked via the ES. To do so, a sophisticated IT infrastructure had to be created, linking systems residing on different platforms. Numerous functional areas, plants, and subsidiaries are also interconnected in the ES at Company G. The rationale for this move was faster information sharing, which the firm noted as one of their competitive advantages. The resulting ESC was subsequently very high.

4.1.6 Number of ES users. The sixth and final dimension identified in our case studies draws on Brooks (1995), who noted that complexity is an innate property of large systems. We posit that larger systems show signs of a more complex structure. The size of an ES is assessed by the number of system users. Three categories were derived based on the characteristics of our sample (0-100 users, 101-300 users, and over 301 users).

Companies with the highest number of users included Companies N and O. The former had several internal functions integrated into the system, in addition to having external connections to customers and suppliers. While the latter did not institute an integrated system until 2001, early ES applications linking functional users date back to the late 1980s. Both instances serve as an example of high ESC. In contrast, very few users were reported in Companies C and J, which can be explained by the focus on design and production in Company C, and the relative low complexity of the business in Company J. This was reflected in an ES low in complexity.

Having scored all companies in our sample on these six dimensions, averages can be built. As seen in Table II, six firms have an average ESC value of above 2.5. These firms are primarily characterized by a seamless integration of their ES, an early ES adoption date, a large number of interconnected subsystems, and a system that has been configured to their needs. Furthermore, these firms have many functional areas interlinked in the ES and have a large number of system users. On the other extreme, three firms received a value of 1.5, indicating low ESC. The results suggest that there is a wide spread of ESC present in our sample. The overall average was 2.14 with a standard deviation of 0.48.

4.2 Determinants of enterprise systems complexity

Next, we derive determinants of ESC based on our sample. Similar as above, initial determinants, as well as their measurement, were developed in our first phase of the case studies, which were then grounded into existing literature. The second phase validated our choices. Once confirmed, we went back to the firms in the first sample to ask them specific questions about the now refined determinants and their measures to further validate the results. Using grounded theory development, we targeted the identification of determinants that had a clear impact on ESC as conceptualized above. The derived determinants of ESC include process and product complexity, competition, international orientation, and customer base, which will be discussed in the remainder of this section. Based on the interview transcripts and insight of the authors, each firm was ranked along these dimensions. We especially focus our attention in explicating the first two dimensions, since case studies suggested these to be especially influential.

4.2.1 Process complexity. Our initial case studies revealed that the complexity of a firm's processes can be a key factor influencing ESC; more demanding processes may require special or more advanced modelling of the ES infrastructure. Process complexity can also lead to increased modification of a standard ES software package (change of system code), a more sophisticated interlink with numerous functions, and a larger number of users across the enterprise (Corso *et al.*, 2001). Since predominantly manufacturing companies were in the sample, we concentrated on the process of manufacturing output to determine process complexity. Our case studies suggested that process complexity can be primarily described by five aspects, all of which relate to ESC (Table III).

We started quantifying process complexity with the number of different sub-processes involved in producing output. Observations suggested that when there were several different sub-processes involved, the overall process of managing them tended to be more complex. This increased complexity was reflected in heightened ESC. We differentiated companies by whether they require few (up to ten), some (11-29) or many (above 30) sub-processes/functions to transform raw materials into final

Company	Sub-processes	Difficulty	Material flow	Standardization vs customization	MTO or MTS	Average
A	2	3	2	1	2	2
B	2	3	3	2	2	2.4
C	1	1	1	3	3	1.8
D	3	2	2	1	1	1.8
E	3	3	3	3	3	3
F	1	1	1	3	1	1.4
G	2	2	3	1	2	2
H	3	3	3	3	3	3
I	2	2	1	1	2	1.6
J	1	1	2	1	2	1.4
K	1	2	1	2	2	1.6
L	1	1	1	2	2	1.4
M	1	1	3	1	2	1.6
N	3	2	3	3	2	2.6
O	1	1	3	2	2	1.8
P	2	3	3	3	3	2.8
Q	1	1	3	1	3	1.8
R	1	1	3	1	3	1.8

Notes: Measurement (higher ranking → greater complexity); *number of different sub-processes involved in production*: few (1), some (2), many (3); *average difficulty of sub-processes*: low (1), medium (2), high (3); *flow of material*: flow shop (1), mixture (2), job shop (3); *standardization vs customization*: standardization (1), customization (2), standardization and customization (3); *MTS or MTO*: MTS (1), MTO (2), MTS and MTO (3)

Table III.
Cross-company comparisons on process complexity

products, forming the first component of process complexity. On the high end, Company N had numerous sub-processes, with each of their manufactured machines being different from each other due to customer requirements. Of 2,000 machines the company produces per year, only 50 rely on the same set of processes, requiring a more complex ES due to this environment. On the low end, Company K, manufacturing springs, relied on only two lines producing four different items; this setting was satisfied with a lower ESC.

Case study insight also suggested that the individual difficulty of sub-processes can influence overall process complexity, which again was reflected in heightened ESC. In our context we classified a sub-process as difficult if sophisticated equipment or highly trained employees are required to perform the task. For evaluating our companies along this second measurement dimension of process complexity we performed a relative comparison of the average difficulty of the sub-processes between the firms. Processes at Company C, a producer of basic textiles, were judged to be simpler, with many of them still being performed manually. Similarly, Company F's focus on furniture for schools required straightforward processes. In these instances, less complicated systems were able to meet the requirements of the firm. Sophisticated medical surgery equipment was the industry of Company P, which required complex manufacturing processes. Similarly, Company H, specializing in medical technology, needed customized processes for which modifications had to be made in their ES (change of system code).

High complexity of manufacturing processes may also be characterized by a jumbled material flow (job shop) or a disconnected line flow (batch processing), whereas low complexity may exist in a continuous flow or connected line flow (assembly line) environment (Hayes and Wheelwright 1979a, b). We observed that the former usually demanded more sophisticated ES, whereas the latter was accommodated with a system of lower complexity. We use this distinction as our third measurement dimension for process complexity. Company B exhibited true job shop characteristics, with most mixers and grinders manufactured being one of a kind, possessing a throughput time of between three and four weeks; consequently, their ES was rather intricate and detailed. The typical flow shop was present in Company C, with 75 percent of their items being described as “bread and butter” products that are constantly produced; a standard mapping of their processes in the ES was possible.

Another measure of process complexity proposed by Hayes and Wheelwright, and supported by our cases studies, is that standard or off-the-shelf products tend to require less complex processes; in contrast, customized products tend to demand more complex processes. Related to this measurement element is the ensuing orientation of the firm towards MTS or MTO approaches. The degree of product customization or specialization, as well as whether the company focuses on MTS or MTO, form our fourth and fifth measurement dimension of process complexity. Firms in our sample suggested that a high degree of product customization, as well as an MTO setting, demanded more complex ES. The MTO environment was exhibited at Company O, which characterized its process design as customized; mapping these characteristics in their ES resulted in it increasing in complexity, as assessed by our dimensions of ESC introduced above. Typical MTS production was present at Company F, and at the home appliance manufacturer D, which was reflected in lower demands on system complexity.

We evaluated our case study companies along these five dimensions of process complexity. The scores were determined after our site visits and through follow-up conversations. These evaluations resulted in a mean score of 1.99 with a standard deviation of 0.54 across the sample. Table III summarizes the process complexity construct. A few firms display very high process complexity, with the majority possessing values of 2.0 or smaller.

4.2.2 Product complexity. Interviews with case study firms also suggested a relationship between product complexity and ESC. A product is the output of a process, and is often the final item offered to customers. The term product is used here to denote not only physical products but can also entail services. Our case study observations indicated that the management of more complex products requires more complex systems, and possibly an earlier adoption timeframe as well. This section summarizes measures for product complexity derived from our case studies via grounded theory and related literature (Table IV).

We again refer to Hayes and Wheelwright (1979a, b), who distinguish firms based on the importance they place on flexibility and quality, vs dependability and cost. In the latter case, the focus is on high volume and high standardization, whereas in the former importance is placed on low volume and low standardization. Applying this framework to our case studies we observe that a focus on flexibility and quality is an indication of high product complexity, and a focus on dependability and cost an indication of low product complexity. This constitutes our first measurement

Company	Focus	Interrelated elements	Element integration	Threat of substitute products	Switching costs	Average
A	3	2	2	2	3	2.6
B	2	2	2	2	3	2.4
C	3	1	1	2	2	2
D	3	2	2	2	3	2.6
E	3	3	3	2	3	3
F	3	1	1	1	3	2.4
G	3	3	2	2	3	2.8
H	2	3	3	2.5	2.5	2.6
I	3	2	1	2	3	2.4
J	1	1	1	3	1	1.2
K	2	1	1	2	3	2
L	1	1	1	2	3	1.8
M	2	1	1	3	2	1.6
N	2	3	3	2	2	2.6
O	3	1	1	2	3	2.2
P	3	3	3	3	3	2.8
Q	2	1	1	2	3	2
R	2.5	3	2	2.5	2.5	2.5

Notes: Measurement (higher ranking → greater complexity); *focus*: dependability and cost (1), mixture (2), flexibility and quality (3); *number of interrelated elements in the final product*: few (1), some (2), many (3); *degree of element integration in final product*: low (1), medium (2), high (3); *threat of substitute products*: very high (1), high (2), low (3), very low (4); *switching costs*: very low (1), low (2), high (3), very high (4)

Table IV. Cross-company comparison on product complexity

dimension for product complexity derived from our case studies. Company L, which produces parts for the automobile industry, such as fasteners, had a clear focus on dependability and cost. Systems were able to be structured very efficiently, and were often streamlined and simple. In contrast, Company I, specializing in heating and cooling technology, focused on flexibility and quality, as did Company O, which was subject to an annual quality survey by its customers. We observed that this required higher flexibility resulted in an increase in system complexity, in order to accommodate the more involved environment. A few firms, such as Company H, strove for both a cost and a quality advantage.

The number of interrelated elements in the product forms our second measure. The more items there are, the bigger the demands and requirements on the system (Brooks, 1995). Based on insights obtained in the case studies we consider the number of interrelated elements in the final product as an indication of the product's complexity. When there are many interrelated elements in the final product it is judged to be more complex than a comparable one with fewer interrelated elements. This is also consistent with Simon's (1996) observations. Products at Company L were fairly straightforward without inherent complexity, as illustrated by an average of only one or two parts per bill of material (BOM). This was reflected in their ES, which we assessed to be not very complex. Products at Company I, which produces for example water coolers, had an average of 30 parts per BOM, with the products usually being protected by patents. An extreme case was Company N, which uses an average of

220,000 single parts for a final end product. Their ES was characterized as very complex, mainly in order to accommodate the variety inherent on the product side.

Earlier we suggested that the level of integration and interdependence between functional areas via ES is an assessment of system complexity, and had substantiated this with the models presented in Bendoly *et al.* (2004) and Jennings (2001). Along the same lines we argue, based on our exploratory case study insight, that the degree of element integration in the final product is an indication of the product's complexity. Thus, for our third product complexity aspect, we classify a product as complex if its degree of element integration is high. This is especially the case if these elements possess critical characteristics that are absolutely essential for the proper functioning of the final product. Element integration was for example very high at Company P, which produces high frequency generators for medical surgeries, and at Company N, which produces sophisticated industrial knitting machines. Complex products, as illustrated by item integration, were also produced by Company E, who only produces an average of eight to fourteen forklifts per day. Interviewees at these firms evaluated their ES as fairly complex, based on the complexity of the products. Element integration was low at Company C producing textiles, primarily undergarments, and at Company F manufacturing basic chairs and tables for schools. Consistent with our observation above, this characteristic influenced their ES to not be as involved.

The fourth component of product complexity is the threat of substitute products, as part of Porter's (1980) five forces competitive market model. As such, the threat is low when a product is not easily imitable. This is the case when the product is complex, is protected by patents, requires proprietary knowledge, or when sophisticated equipment is needed to make it, as suggested by our case study firms. The threat of substitute products was characterized as very high by Company F, illustrating the low degree of product complexity of basic chairs and tables. The threat was low for companies possessing patents, such as Company P, which exhibited a more complex ES. Most firms fell in the "high" category.

Our fifth measure of product complexity is switching costs that customers may incur when they change products. If these costs are high, customers may be reluctant to switch. Based on our case studies and related literature (Burnham *et al.*, 2003), we suggest that this cost is higher for more complex products. Company J, providing waste management services, noted their customers having very low switching costs, since it is very easy to change from one provider to the other, due to the comparability of offerings. Most other firms suggested their customers to have high switching costs, attributing this fact to the often significant investments they have been making in, for example, machines for woodworking, tooling, and grinding (Company G). Our sample firms associated this higher switching cost with more demands on the system, since a variety of different customers had to be accommodated on a frequently changing basis.

Each of our case study companies was evaluated along these five product complexity dimensions, summarized in Table IV. The mean across the firms was 2.31 with a standard deviation of 0.46. Most firms achieved values between 2.0 and 3.0, with only three companies scoring below 2.0.

4.2.3 Competition. A third factor that may influence ESC is the competitive environment of a company, frequently also characterized by Porter's (1980) five forces. Past studies have shown that the more competitive the environment, the more innovative IT solutions are likely to be (Farrell, 2003). As such, innovative IT solutions enable the development of both new products and efficient processes. This occurs because IT facilitates the fast diffusion of innovation, and exhibits strong economies of scale (Farrell, 2003; Rogers, 2003). This is especially true for SMEs and Mittelstand companies, who frequently regard investments in IT as a way to secure and improve their competitive position (Voigt, 2001). It seems even more relevant for companies that are experiencing growth and are faced with fiercer competition. Insight from our case study companies also suggested that firms in a more competitive environment possess more sophisticated, developed and integrated ES, to be able to weather the competitive environment. In addition, these companies may have been early adopters, driven by a more competitive situation. Table V summarizes how we assessed the degree of competition, which was indeed associated with ESC.

We measure the competitiveness of a firm's environment based on five dimensions, all of which can be related back to and substantiated with Porter's (1980) competitive market model. First, the number of competitors seems to be a suitable indicator of the competitive environment a company finds itself in: the higher the number of competitors, the more intense the competition. This was also often reflected in a higher overall ESC. The relationship was especially noted by Company L, the producer of parts for the automobile industry, as well as by Company K, the manufacturer of springs. Firms producing very specialized products had few competitors, such as Company P, offering medical surgery equipment, and Company F, focusing on school furniture.

Second, to account for the possibility that a small competitor may be influential, we also consider the degree of pressure competitors can exert on the enterprise. Company

Company	Immediate competitors	Influence of competitors	Intensity of competition	Threat of new entrants	Size of average competitor	Average
A	3	2	2	1	2	2
B	2	2	2	2	1	1.8
C	2	1	2	2	3	2
D	3	2	3	3	2	2.6
E	2	2	3	1	2	2
F	1	1	1	2	1	1.2
G	2	3	2	1	1	1.8
H	3	2	3	2	2.5	2.5
I	3	2	3	1	3	2.4
J	1	1	1	2	1	1.2
K	3	1	3	2	3	2.4
L	3	1	3	2	3	2.4
M	1	1	1	1	1	1
N	2	1	3	1	1	1.6
O	1	1	1	1	1	1
P	1	1	3	1	3	1.8
Q	1	3	3	1	2	2
R	2	3	2	3	2	2.4

Notes: Measurement (higher ranking → greater competition); *number of immediate competitors*: few (1), some (2), many (3); *degree of influence/pressure competitors can exert*: low (1), medium (2), high (3); *intensity of competition*: low (1), medium (2), high (3); *threat of new entrants*: low (1), medium (2), high (3); *size of average competitor*: smaller (1), same (2), larger (3)

Table V.
Cross-company comparison on competition

R serves as an example: the firm is exploring the transfer of data via the internet, as well as its web presence, based on the competition contemplating similar actions. In contrast, Company M has never perceived its competitors exerting any pressure. We observed overall high ESC at Company R and overall low ESC at Company M, which interviewees partly also attribute to competitive pressures.

The intensity of competition forms our third measurement dimension. Especially, firms in high-technology industries, such as Companies H, I, and P, were faced with high competitive intensity levels. In contrast, firms in niche markets, such as Companies F and M, producing some very specialized equipment, characterized their competitive environment as having a low level of intensity. Overall, our interviewees suggested their ES to be more complex with higher competition intensity; ES were utilized to serve as a means for differentiation and the attainment of competitive advantage.

Fourth, we suggest that when the threat of new entrants is high, the environment is likely to be more competitive. This threat was especially given for Company D producing home appliances, and Company R, offering communication and management solutions. This was reflected in increased demands on the ES, as judged by the firms. For most other companies this threat was low, since significant start-up costs were often associated with their business. And fifth, we use the size of an average competitor as a proxy for competitiveness: the larger the average competitor, the more intense the competition. Most firms in our sample were competing against smaller or same-sized companies, not significantly increasing ESC.

From our site visits and follow-up conversations each of the case study companies was evaluated on these dimensions, which are summarized in Table V. The case study companies exhibited a mean of 1.89 and a standard deviation of 0.52 for competition, with most firms having values between 1.5 and 2.0.

4.2.4 International orientation. Companies engaged globally are more likely to operate in a more competitive environment, requiring more sophisticated IT solutions. Competing globally can create increased pressure by the larger international playing field and the more complex and involved transactions. Different requirements such as currencies, regulations, laws, and customs can also have an impact. In addition, the need for a more sophisticated ES infrastructure is emphasized by companies growing from small locally or nationally oriented firms to medium-sized players in the international marketplace. This is especially true for our Mittelstand sample which exhibited some of these traits. The shift towards increasing internationalization was noted as one influencing factor determining ESC. Case study firms primarily mentioned three aspects indicative of their international commitment: the number of international subsidiaries, percentage of exports, and the desire to be global (Table VI).

The first element we use to assess a firm's degree of internationalization is the number of international subsidiaries it possesses. Connecting these international units in an integrated ES is likely to result in increased ESC due to country-specific requirements, such as reporting obligations or the accommodation of different currencies. Second, the percentage of the company's business conducted internationally, as measured by its exports, is used as an indicator of a firm's international orientation. Similar as above, the added complexity and increased information requirements when dealing with multiple countries is likely to increase the ES' complexity. And third, a company's desire to have a global presence. Even if the company has not gone global yet,

Company	International subsidiaries	Percentage of export	Desire to be global	Average
A	2	2	4	2.7
B	2	3	4	3
C	1	1	2	1.3
D	3	1	2	2
E	3	1	3	2.3
F	1	1	2	1.3
G	2	3	4	3
H	3	3	3	3
I	3	3	4	3.3
J	1	1	1	1
K	3	2	3	2.7
L	2	1	3	2
M	1	1	1	1
N	3	3	4	3.3
O	3	2	4	3
P	3	2	3	2.7
Q	1	1	1	1
R	3	2	4	3

Notes: Measurement (higher ranking → greater international orientation); *Number of international subsidiaries*: 0 or 1 (1), 2-5 (2), > 5 (3); *Percentage of exports*: 0-30 (1), 31-60 (2), > 60 (3); *Desire to be global*: Very low (1), low (2), high (3), very high (4)

Table VI.
Cross-company comparison on international orientation

provisions for such could have already been considered in the ES. Examples include the accommodation of various currencies, customs regulations, laws, and terms and conditions. Overall, it is reasonable to expect that subsidiaries overseas, a high percentage of exports and a strong desire to be present globally are properties of an international orientation.

One of the most international firms in our sample is Company I with five European subsidiaries, four international sales and service centres, and 80 percent of its business being produced for export. Internationalization was also illustrated by 200 of the firm's suppliers being from countries other than Germany. An extreme case was also Company N, who noted that almost 99 percent of its business is for export, primarily to Turkey, China, and the Far East. Several sister companies and sales organizations exist in South America and Asia. IT systems were seen as a key enabler for this internationalization, which in turn were however judged to be more complex. On the other side, Company M had no international connections, and produced solely for the domestic market, leading to its low ESC.

Each company was evaluated along these three dimensions based on our interviews. Table VI provides a summary of these measurement components and their levels. The mean value across the sample was 2.31 with a standard deviation of 0.85. The majority of the firms have scores of above 2.5, indicating a strong international orientation, which was reflected in a more complex ES. There are three companies with a score of 1.0, suggesting no international orientation at all, exhibiting overall lower ESC due to this fact.

4.2.5 Customer base. A second-related issue to competitiveness is a firm's customer base, and whether it is broad or more focused. A broad customer base can be defined as having a wide variety of different customers, whereas a focused customer base has a limited number of customers. Based on our case study insight we suggest that organizations with a broad base have more complex transactions due to the information that need to be processed. We also observed that a broader base can be the result of either a firm growing larger, the firm expanding its offerings, or both. This, in turn, has to be supported by an appropriate ES infrastructure which most likely becomes more complex. We characterize a firm's customer base with four features introduced below (Table VII).

First, we consider the relative number of each firm's customers in our sample. Fewer customers are associated with lower demands on the ES, which was for example the case for Company L. This firm had primarily big automobile manufacturers as customers. Many more customers were present for Company C, which sells its textiles to various department stores. Second, our sample suggested bargaining power of customers as a measure for pressure that may be exerted from this side. Illustrative is Company L, a supplier to major car manufacturers, which are known to have high bargaining power due to the volume they request. On the other hand, Company P characterized their customer base as having very little influence, except for a few opinion leaders. Third, we characterize the customer base according to whether it has similar or dissimilar demands on the firms. Companies I and P noted its homogeneous customer demands as an advantage, whereas Companies O and Q mentioned the heterogeneity of its customers to be creating added complexities. And fourth, we operationalize customer base according to how influential these customers are. Low influence of the customer base was mentioned by Companies J and M, while influential customers were present for Companies K and L. The ESC was reflective of that.

Company	Number of customers	Bargaining power	Demands	Influence	Average
A	3	2	3	3	2.8
B	1	1	2	3	1.8
C	3	1	1	3	2
D	3	2	2	3	2.5
E	3	2	2	2	2.3
F	2	1	1	4	2
G	2	1	2	3	2
H	3	2	2	3	2.5
I	1	3	1	4	2.3
J	2	2	1	1	1.5
K	2	3	3	4	3
L	1	3	1	4	2.3
M	1	1	2	1	1.3
N	2	2	2	2	2
O	2	3	3	2	2.5
P	1	1	1	2	1.3
Q	3	3	3	3	3
R	1	2	1	3	1.8

Notes: Measurement (higher ranking → greater customer base); *relative number of customers*: few (1), some (2), many (3); *bargaining power of customers*: low (1), medium (2), high (3); *demands of customers*: similar, homogeneous (1), mixture (2), different, heterogeneous (3); *customer influence*: very low (1), low (2), high (3), very high (4)

Table VII. Cross-company comparison on customer base

We evaluated each company along these four dimensions, which are summarized in Table VII. Individual values ranged from 1.3 to 3.0, and the mean score was 2.16 with a standard deviation of 0.52.

5. A socio-technical systems theory perspective of ESC

In this section, we utilize the findings from above to develop a STS theory perspective of ESC. After having explored ESC with a grounded theory approach above, we felt that STS theory would serve as a sound theoretical anchor to explicate ESC. Motivation provided also Closs *et al.* (2008, p. 607), who suggested that STS theory "should be used as a basis for design of future research studies which evaluate key competencies for the management of complexity." We start this section with an introduction into STS theory, followed by its application to our research context, as well as how STS can be used to determine ESC.

STS theory is concerned with the design and operations of organizational elements recognizing the interaction between the social system (people, believes, and values) and the technology (systems, procedures, and approaches) (Avgerou *et al.*, 2004; Cherns, 1976, 1987; Clegg, 2000; Trist and Bamforth, 1951). The theory states that "the design and performance of new systems can be improved [. . .] if the 'social' and 'technical' are brought together and treated as interdependent aspects of the work system" (Clegg, 2000, p. 464). In addition, STS views an organization as an "open system," meaning that the "socio-technical work design should meet the demands of the external environment" (Closs *et al.*, 2008, p. 602); or in other words, synergy needs to be present. This theoretical lens seems to be perfectly suited to our context, in which we explore the complexity of ES and explicate their structure based on external determinants. To facilitate and drive the desired synergy, Cherns (1976, 1987) developed a set of ten work-system design principles that should be applied. Being guided by the structure in Closs *et al.* (2008) we apply in the following the ten design principles to our context of ESC and its antecedents.

First, Cherns (1976, 1987) notes compatibility, which emphasises that the design of a work system should be compatible with the design objectives. For our context it means that ES should be compatible with the overall business strategy of the firm, supporting its goals and ambitions. The complexity of an ES should be reflective of the firm's product and process complexity, its customer base and competition, as well as its international orientation. The ES should enable and facilitate these strategies, i.e. it should be congruent and aligned with them. We observed in our case studies that a heightened degree of ESC was driven by more complex products and processes, fiercer competition, a heterogeneous customer base, as well as a desire to be global. STS now provided the theoretical grounding for these observations.

The second design principle relates to minimal criteria specification, meaning that no more should be specified than absolutely necessary. Applied to our situation, essential characteristics and capabilities of the ES must be defined and specified. Guidance for this specification provide the five ESC determinants derived in our case studies. For example, if the production process of a firm is very complex, more requirements are placed on the ES, and thus more specifications are necessary. On the other hand, if a company is only operating domestically, fewer specifications are necessary, leading to a less complex system. Overall, the ES should be as simple as possible, and only be as complex as necessary.

The third principle concerns variance control, suggesting that variances should not be exported. In our context this principle is espoused by the practice of most case study firms attempting to keep the complexity of their ES at a minimum. For example, when transforming from legacy to integrated ES, most firms in our sample made a clean cut and most often went to a completely new integrated solution, rather than attempting to patch different legacy systems together to an integrated system. The aim was to reduce overall ESC. However, when demanded by the five determinants, ESC was increased for the operational benefit of the firm. ESC should however only be increased when warranted, and otherwise be kept as small as possible.

Boundary location is the fourth design principle of STS, which suggests that social and technical boundaries should not be drawn to impede information sharing, knowledge or learning. This is the central premise of most ES, namely to integrate and share knowledge between functions. As for the design of the system, feedback should be sought from various stakeholders in the company, with the goal to enable their requirements without increasing ESC. There is a fine line to be drawn, especially considering the five antecedents derived in our study. These dimensions should be accommodated by the system, however with the least complexity possible.

Information flow, the fifth principle, should be provided to those who require it when needed. This is again a premise of moving to more complex ES, to enable the flow of information necessary and to facilitate decision making. With a more challenging environment, characterized by the five determinants in our study, more complex ES may be needed.

The sixth design principle, power and authority, stresses that those making decisions should be equipped with the necessary authority to implement them. In our context, the complexity of the ES should be determined by a cross-functional team consisting of the various parties that will be using the system. At the same time, however, compromise needs to be found so that no one function dominates or dictates the ES structure. The smallest common denominator should be determined, so as to not unnecessarily put strain on the system's complexity.

Seventh, the multifunctional principle emphasises a holistic view of the system. Those responsible for its design and implementation should thus obtain a thorough understanding of the needs in each functional department that will be utilizing the system. A fine line needs to again be drawn between accommodating function-specific requirements and the inherent increase in ESC.

Support congruence is the eighth design principle, which states that supporting systems and sub-systems need to be congruent. This means that sub-systems within individual functions should be aligned with and contribute to the overall goal of the company. ESC should thus not be rewarded if it is not beneficial to the firm. However, if this is what is needed, as determined by the five dimensions identified in this research, then ESC is warranted.

As the ninth dimension, transitional organization is mentioned, which refers to companies being in constant change and transition. ES must thus be designed flexibly enough to accommodate such change, for example by the addition of further modules or functionalities. Transitions also need to be approached proactively, anticipating the change, rather than reacting to it.

The tenth design principle of incompletion means that no state of equilibrium exists. Similar to the ninth principle, the ES needs to be constantly re-assessed to determine whether its complexity can be reduced or whether it should be increased, depending on the five determinants identified in our study. ES should aim to be at all times a perfect fit with the requirements of the firm.

6. Conclusion

Integrated ES have been implemented in thousands of companies over the past decade. During this time, researchers have looked at a variety of issues regarding adoption, implementation and usage. Much of this research has concentrated on the implementation experiences by large companies, leaving a knowledge void for smaller enterprises. Additionally, very little work has been done on the organizational factors that determine the need for such complex ES, or how companies determine the system design and complexity level required. These aspects are even more critical for our sample of Mittelstand companies who are frequently constrained in terms of resources, such as human and monetary capital. This paper addressed these topics.

We developed the concept of ESC, and proposed a set of determining factors based on 18 case studies conducted in the German manufacturing industry. Measurements for each construct were developed and applied to case study firms. Assessing our case studies along these dimensions revealed that different antecedents place diverse demands on ESC. This is in line with prior research stressing the need to align manufacturing planning and control systems with business strategy (Berry and Hill, 1992). Our contribution lies in the empirical derivation of measures for ESC, as well as the exploration of determinants of ESC. Furthermore, we applied the theoretical perspective of STS and viewed our results with this lens.

Based on our findings and their theoretical grounding, a set of propositions can be developed for future testing, summarizing the main thrusts of the paper. These propositions, derived empirically and grounded theoretically, can be summarized as follows:

P1. Complex products require a heightened degree of ESC for optimal firm performance.

P2. Complex processes require a heightened degree of ESC for optimal firm performance.

P3. A more competitive environment requires a heightened degree of ESC for optimal firm performance.

P4. A greater international orientation of the firm requires a heightened degree of ESC for optimal firm performance.

P5. A heterogeneous customer base requires a heightened degree of ESC for optimal firm performance.

These propositions are meant to motivate researchers to further explore this fascinating area. The construct measurements, empirically derived above using a grounded theory approach, should be validated and the propositions should be tested with a large-scale survey.

The present research made several contributions. First, it explored the concept of ESC as a result of influential determinants, and grounded these relationships in the theoretical domain of STS. No published research has been found that investigated the impact of organizational factors on ES complexity. In addition, it is one of the few studies that focused on the post-implementation effects of ES implementation (Gattiker and Goodhue, 2005). Our framework and suggested measurements can help IT managers in the assessment of their current system; it can provide them with potential explanations for the complexity inherent in their ES. At the same time, they can use the ten design principles of STS to assess their system along those dimensions; ideally in an attempt to reduce unnecessary complexity. Second, the paper studies these issues within the context of the German Mittelstand environment, which has seldom been the subject in ES research; this study provided some unique insights into this sector. Third, for each of the constructs explored, the paper suggests measurement items with which these factors can be assessed in future studies. These measures were derived via a grounded theory approach from our case studies, and future research is encouraged for their validation. And fourth, we viewed our results from a STS theory perspective, providing a theoretical anchor for our findings.

This research is valuable for both practitioners and academics. For practicing managers, the paper provides a framework for the assessment and measurement of ESC. The framework can provide validation of why some firms have a more complex system than others. The framework can be applied to companies who are in the early stages of ES implementation, plus companies that are in the growth phase of their lifecycles. Based on their factor measurements, firms can predict whether they are likely to have a complex ES, i.e. whether factors such as their process and product complexity, the competitive environment they operate in, their international orientation, and their customer base demand a more complex ES. For academics, this research provides a first comprehensive conceptualization and definition of ES complexity, as well as an exploration of its antecedents. The paper places ES complexity within theoretical domains, most notably within the STS perspective, and establishes a sound foundation for future exploration.

Some final notes of caution and exciting areas for future research. Although we have been able to draw some preliminary conclusions and suggest propositions from our findings, it is difficult to develop generalizations for the whole population, to statistically test hypotheses, or to base statements on hard quantitative assessments, due to the small sample size. Similarly, we derived the conceptualization of ESC and its antecedents based on our case study firms and prior literature. While we feel that these descriptors and their assessment fit well and provide a valid evaluation of our firms, other companies in different contexts may be presented with additional forms of complexity. Our study focused on Mittelstand companies in Southwest Germany, most of which operated in an MTO environment, inherently characterized by higher complexity. Future research is needed to generalize our findings or replicate this study in other context-specific settings, such as different countries, operating foci and firm sizes. In addition, while we used an aggregate formative measure to assess complexity in our exploratory study, dimensions of ES complexity could be singled out and their specific antecedents could be identified in more confirmatory research. This extension represents an exciting area for future research.

In the present study we have demonstrated that certain antecedents require more or less complex systems, suggesting that there is a right level of complexity depending on a firm's context and environment. Building on our work, future studies should incorporate some type of performance measurement. The propositions developed above are a first attempt toward this goal – the issue of fit between complexity and company environment/characteristics is crucial. Arguments could be based on contingency theory, which for example would then suggest that if ES complexity is below the level required by the firm based on its business complexity, suboptimal performance is likely. Vice versa, a system more complex than needed by the firm would also result in poorer performance, due to unnecessary sophistication. While we certainly expect this link between the right level of ES complexity and subsequent company performance, we did not explore this relationship in the present research. Prospective studies are therefore encouraged to incorporate this worthwhile link.

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About the authors

Tobias Schoenherr is an Assistant Professor of Supply Chain Management at the Eli Broad College of Business, Michigan State University. Schoenherr holds a PhD in Operations Management and Decision Sciences from Indiana University, Bloomington, from where he also obtained his BSc and MB. He also holds a Diplom-Betriebswirt (FH) from the European School of Business, Reutlingen University, Germany, and is an APICS Certified Supply Chain Professional. Schoenherr's research focuses on strategic supply chain management, including strategic sourcing (global) operations strategy, use of technology in SCM, and outsourcing. His work has appeared or is forthcoming in the *International Journal of Operations & Production Management*, *Management Science*, the *Journal of Operations Management*, *Production and Operations Management*, the *Journal of Business Logistics*, the *Journal of Supply Chain Management*, *OMEGA – The International Journal of Management Science*, *Business Horizons*, the *Journal of Purchasing & Supply Management*, the *International Journal of Procurement Management*, the *International Journal of Integrated Supply Management*, and *PRACTIX*, among others. Schoenherr has been active in several professional associations, including Decision Sciences Institute (DSI), Institute for Supply Management and APICS. Currently, he serves as President of the Midwest DSI. Tobias Schoenherr is the corresponding author and can be contacted at: Schoenherr@bus.msu.edu

Ditmar Hilpert is a Professor at the ESB Business School at Reutlingen University, Germany. He has earned a Master's degree both in biotechnology and economics and holds a PhD in pharmacology and toxicology. After more than ten years in the pharmaceutical industry, he has held the chair in strategic management at ESB for the last 11 years. His current research interest is in the comparison of strategic approaches of SME on an international background. Hilpert also serves the European Commission, DG XII, as an advisor and is the head of the ESB Executive Institute.

Ashok K. Soni is a Chairperson and Professor of Operations and Decision Technologies and the ArcelorMittal Faculty Fellow at the Kelley School of Business at Indiana University. He received a BS in aeronautical engineering from Manchester University, an MS in operations research from Strathclyde University, and an MBA and DBA from Indiana University. Professor Soni's teaching and research interests are in the areas of enterprise applications, emerging technologies, quantitative modeling, and decision support systems. His research interests are in enterprise technologies and decision support systems. His research has appeared in *Management Science*, *Naval Logistics Research*, *Computers and Mathematical Modeling*, *Omega*, *IIE Transactions*, and *European Journal of Operational Research (EJOR)*.

M.A. Venkataramanan is an Associate Dean of Academic Programs at the Kelley School of Business at Indiana University, Bloomington. Prior administrative appointments have included Chairperson of the Operations and Decision Technologies Department, as well as Glaubinger Professor of Operations and Decision Technologies and Chair of the Undergraduate Program of. Venkataramanan received his PhD in Business Analysis and Research from the Texas A&M University. His research interests include ERP, radio frequency identification (RFID), network modeling, artificial intelligence, high-speed computing and supply chain models. His teaching interests are in the area of RFID, decision support systems, computer programming, ERP, optimization techniques, and project management. He is one of the principle investigators in the ERP research and teaching initiative at Indiana University. He has more than 25 research articles published in a variety of journals including *Operations Research*, *Decision Sciences*, *Annals of Operations Research*, *Naval Research Logistics*, *Computers and OR*, *EJOR*, and *Mathematical Modeling*.

Vincent A. Mabert is an Editor-in-Chief of the *Production and Inventory Management Journal* and Professor Emeritus of Operations Management in the Operations and Decision Technologies department at the Kelley School of Business, Indiana University. Mabert's research and teaching have focused on operations and supply chain management. He is widely recognized as a leading contributor to the field and has published more than 85 articles in the areas of workforce planning, order scheduling, ERP systems, new product development, and manufacturing system design. His publications include articles in *Management Science*, *Decision Sciences*, *IIE Transactions*, *Journal of Operations Management*, *The Accounting Review*, and the *Academy of Management Journal*. While at Indiana University, Mabert has been department chairperson, associate dean, and leader of the Indiana Manufacturing Excellence Roundtable. He has been active and held officer positions in a number of professional societies including Industrial Engineering, INFORMS, APICS, and Decision Sciences. He is a Fellow of the DSI.