DEVELOPMENT OF A MEASURE TO ASSESS THE COMPLEXITY OF INFORMATION SYSTEMS DEVELOPMENT PROJECTS

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Abstract

Information systems development (ISD) projects are becoming increasingly complex. ISD project complexity makes it difficult for project managers to deliver effective systems within time and budget constraints. As a result, the success of ISD projects is increasingly dependent on an organization's ability to effectively assess and manage complexity. The purpose of this paper is to develop a measure for assessing ISD project complexity. A two-dimensional conceptual framework is proposed to define four distinct types of software project complexity: structural organizational complexity, structural IT complexity, dynamic organizational complexity, and dynamic IT complexity. Based on field interviews, focus group discussions, and a large-scale survey of ISD project managers, a measure of ISD project complexity with 17 indicators was developed. The results of an exploratory data analysis provide strong evidence that the final measure has satisfactory measurement properties. The contributions of this research to both theory development and practice are discussed.

Keywords: Information system development projects, complexity, measurement development, conceptual framework

1 INTRODUCTION

Although organizations invest heavily in information systems (IS) with the hope of improving their operational and strategic positions, many organizations fail to achieve their objectives because of a high failure rate of information systems development (ISD) projects. The Standish Group reported in 1994 that U.S. companies spent more than $250 billion each year in the early 1990s on IS application development projects with a success rate of only 16.2 percent. The 2001 Standish Group report showed that, although the investment amount increased by almost four times, compared to the early 1990s, only 28 percent of the IS projects were successful. To enhance the return on investment in information technology (IT), organizations must first improve their ability to successfully deliver ISD projects.

In this research, ISD refers to the analysis, design, and implementation of IS applications to support business in an organizational context, including major enhancement of existing systems and work on new systems yet to be installed (Swanson and Beath 1989). Typical ISD projects exhibit Campbell's (1988) four basic task characteristics that increase task complexity. ISD projects include *multiple paths*, which are often characterized by *conflicting interdependence*, to arrive at *multiple desired outcomes* under a significant level of *uncertainty*. More specifically, ISD projects are complex tasks because they involve not only technologies but also business processes. There exist in most organizations installed IT infrastructure and application bases. New ISD projects must take advantage of the fast advancement and convergence of new IT and, at the same time, must be seamlessly integrated with the existing legacy systems. In addition, the business environment becomes hyper-competitive and organizations constantly change their strategies, structures, and business processes, which makes it difficult for the ISD projects to define business requirements and to produce a viable technological solution.

Researchers and practitioners have attributed poor ISD project performance to the complexity of such projects (Murray 2000). Complexity is widely acknowledged by practitioners as an important factor that makes a difference to the management of projects (Bennett 1991). ISD project complexity affects project scope, time, cost and quality objectives (Murray 2000). Furthermore, project complexity influences the management of project resources such as personnel, project process capabilities, user involvement, and top management support. While there exist a number of risk factors that might jeopardize project success (Schmidt et al. 2001), complexity is a specific type of risks that focuses on project environmental conditions, as opposed to other risk factors related to lack of efficiency or maturity of project processes and capabilities. We argue that complexity deserves further investigation as a separate construct as its importance has dramatically increased.

Understanding and effectively managing ISD project complexity to enhance project success rate has become a strategic issue for contemporary organizations. IS activities in most organizations are organized on the basis of ISD projects. Despite the practical importance of ISD project complexity, there has been little theoretical and operational understanding of the construct. Although various measures of *software complexity* have been proposed, these measures are not adequate to assess complexity of ISD *projects*. Software is a core part of a software project; however, there are many other important organizational or environmental factors that contribute to overall complexity of the ISD project. These additional factors need to be taken into account to accurately assess the degree of ISD project complexity.

The purpose of this research is to develop a valid and reliable measure of ISD project complexity. This measure is intended to incorporate the unique context of ISD projects while covering a wide range of project components beyond a software product. The paper is organized as follows. The next section reviews the relevant literature. A two-dimensional conceptual framework of ISD project complexity is then proposed as the basis for empirically developing the measure. In the following section, the methods used for developing the measure and the results of measurement testing are reported. The paper concludes with discussions of the contributions and limitations of the research as well as directions for future research.

2 LITERATURE BACKGROUND

2.1 Task and Project Complexity

The concept of task complexity can be used as the basis for conceptualizing project complexity. Wood (1986), in his seminal work, defined three types of task complexity: component, coordinative, and dynamic. Component complexity of a task is a function of the number of distinct acts that need to be executed in the performance of the task and the number of distinct information cues that must be processed in the performance of those acts. Coordinative complexity refers to the nature of relationships between task inputs and task products. The form and strength of the relationships between information cues, acts, and products are aspects of coordinative complexity. Both component and coordinative complexity reflect the structural aspects of the complexity of the acts and information cues. On the other hand, dynamic complexity is caused by changes in the states of the world which have an effect on the relationships between tasks and products (Wood 1986).

Based on the concept of task complexity, the project management literature has defined project complexity in terms of (1) many varied interrelated parts and (2) uncertainty (Baccarini 1996; Turner and Cochrane 1993; Williams 1999). For example, Williams proposed two distinct dimensions of project complexity: *structural complexity* and *uncertainty*. Structural complexity refers to the differentiation and interdependency of project components. It encompasses both the component and the coordinative complexity as defined by Wood. Uncertainty, which brings a futuristic aspect to the construct of complexity, implies changes in goals and methods for achieving those goals (Turner and Cochrane 1993).

2.2 ISD Project Complexity

To the best of our knowledge, there is no reported research that focuses on the conceptualization and operationalization of the ISD project complexity construct. However, a number of related research areas provide useful reference bases for defining ISD project complexity. For example, Tait and Vessey (1988) measured system complexity in terms of the difficulty of determining the information requirements of the system, the complexity of the processing, and the overall complexity of the system design.

Meyer and Curley (1991) defined the technology complexity in the context of expert system applications as a composite measure of diversity of technologies, database intensity, and systems integration effort.

Function point analysis literature proposes 14 general systems characteristics that rate the general functionality of the application software (Garmus and Herron 2001). Most of the 14 general systems characteristics capture various aspects of software complexity that determine the value adjustment factor (VAF) to obtain total adjusted function points (TAFP). These characteristics include distributed data processing, data communication, complex processing, multiple sites, and installation ease.

Another body of knowledge that can inform ISD project complexity is the software project risk management literature. This literature contends that we should identify and analyze project risk factors in order to reduce the chance of software project failure (Boehm 1991). Since a large portion of the causes for software project failure are suggested to be managerial factors, risk factors identified in this literature tend to include more management-related factors than technological ones. Some of the important risk factors related to complexity are unstable corporate environment, lack of top management commitment, managing multiple stakeholders, stability of technical architecture, multi-vendor projects, complicated dependencies, etc. (Schmidt et al. 2001).

3 A CONCEPTUAL FRAMEWORK FOR ISD PROJECT COMPLEXITY

3.1 Dimensions of ISD Project Complexity

Given the complex nature of the ISD project complexity construct, it is unlikely that it can be measured using a single indicator. Based on the previous literature review, we propose a framework for ISD project complexity, which is shown in Figure 1. This framework consists of two dimensions: *nature* and *locus* of complexity. Each dimension, in turn, includes two distinct categories, resulting in four types of ISD project complexity.

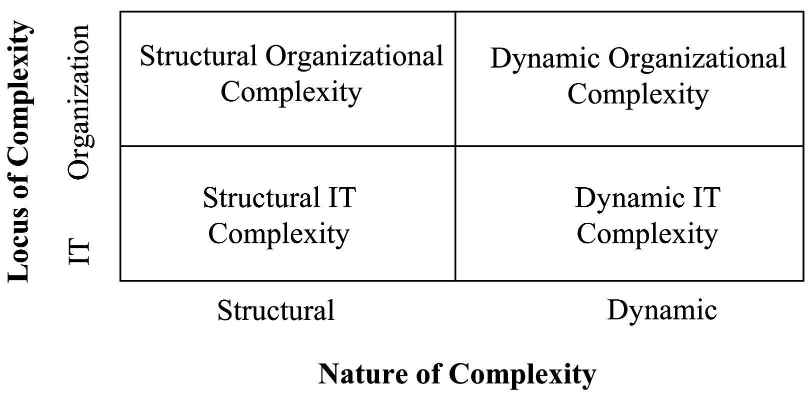

Figure 1. A Conceptual Framework for ISD Project Complexity

3.2 Nature of Complexity: Structural Versus Dynamic

The *nature* of ISD project complexity is divided into *structural* versus *dynamic* aspects. This distinction between structural and dynamic complexity is consistent with the literature of task and project complexity (Baccarini 1996; Campbell 1988; Wood 1986). The structural aspects of ISD project complexity are consistent with Campbell's notion of conflicting interdependence and with Wood's categorization of component and coordinative complexity. *Structural complexity* is a function of the number of project components and the form and strength of the relationships between the components. Typical ISD projects involve a number of technological components, user units, stakeholders, IS personnel, vendors, and external service providers. As the number of components increases, the number of interdependencies among components also increases.

Similarly, the dynamic aspects of ISD project complexity are consistent with Campbell's notion of uncertainty and with Wood's definition of dynamic complexity. *Dynamic complexity* refers to complexity due to changes in business and technological environments. Most ISD projects need to deal with various changes during the project life cycle. Dynamic complexity adds the time dimension to the concept of ISD project complexity. Changes may result from either the stochastic nature of the environment or a lack of information and knowledge (i.e., uncertainty).

3.3 Locus of Complexity: Organization Versus IT

The *locus* of ISD project complexity refers to whether it is associated with organizational factors or IT factors. This distinction between *organizational complexity* and *information technological complexity* is important and has been proposed in the project management literature (Baccarini 1996). The organizational factors of ISD project complexity include organizational structure, business processes, organizational information needs, user involvement, top management support, and project personnel capabilities.

The IT components include not only hard technology elements such as hardware, software, and network, but also soft technology elements such as knowledge, skills, and experiences. The distinction between different loci of complexity is important because different project capabilities are required to deal with *organizational complexity* as opposed to *IT complexity*.

This two-dimensional framework thus results in four components of ISD project complexity: s*tructural organizational complexity*, *structural IT complexity*, *dynamic organizational complexity*, and *dynamic IT complexity*. The elements of structural organizational complexity are mostly associated with the nature and the strength of the relationships between the project and the organizational entities that surround the project, e.g., project resources, users, top management, and project personnel. The elements of structural IT complexity reflect a multitude of IT elements, including both the hard and the soft technologies. The elements of dynamic organizational complexity capture the pattern and rate of changes in the ISD project's organizational environments. The elements of dynamic IT complexity measure the pattern and rate of changes in the IT environment of the ISD project.

4 INSTRUMENT DEVELOPMENT PROCESS

4.1 Initial Item Creation

An initial pool of items was generated from two sources. First, relevant measures in the reviewed literature were adapted to reflect the four types of ISD project complexity. Second, a one-hour focus group discussion with 50 IS practitioners was conducted to generate a list of items that can be used to measure ISD project complexity. Combining items from these two sources resulted in an initial pool of 33 items for measuring ISD project complexity. For the specific items in the initial pool, please see Appendix A. Items retained in the final measure are labeled and highlighted in Appendix A.

4.2 Sorting Procedure

We implemented a sorting procedure in order to qualitatively assess the face validity and construct validity of the measure. Four IS researchers participated in the sorting procedure as judges. They had on average 8 years IS work experience. Each item in the initial pool was printed on a 3 ×5-inch index card. In the sorting procedure, each judge was asked to carefully read the card and place it in one of the four types of ISD project complexity. One additional category, "too ambiguous/unclear," was also included.

Prior to sorting the cards, the judges read a standard set of instructions. To make sure the judges understood the sorting procedure, they did a sorting exercise of the 12 items of the well-known ease of use and usefulness instrument (Davis 1989). All of the judges completed this trial sorting successfully, indicating they had a clear understanding of the sorting procedure and were able to use it appropriately.

Each judge then sorted the ISD project complexity items on index cards into the categories independently from the other judges. After completing the sorting task, they provided the reason why they sorted cards into the "too ambiguous/unclear" category. Five items were dropped because the judges identified them as being too ambiguous or too broad to fit into any of the four categories. As a result, 28 items remained after the sorting procedure.

4.3 Pilot Test

In order to further validate the relevance, coverage, and clarity of initial items, we conducted a pilot test with four IS project managers and three IS researchers. These IS project managers had at least 5 years work experience in project management and the IS researchers had at least 4 years work experience in IS. Each subject participated in a one-hour individual interview. In the interview, each participant first filled out the questionnaire that contained questions regarding the importance and relevance of the 28 items with regard to ISD project complexity. Before they started to answer the questionnaire, the researchers left the meeting room to ensure that the participants did not have any social pressure. After completing the questionnaire, the participants were asked to identify items that appeared inappropriate or irrelevant to ISD project complexity. Participants also made suggestions for improving the relevance, coverage, understandability, and clarity of the measurement items. Based on the interview meetings, five items were dropped. Furthermore, two items were combined into a single item because of their similarity.

4.4 Survey Sample

A Web-based survey of IS project managers was used to collect the data for testing the measure of ISD project complexity. The source of the survey respondents was the Information Systems Specific Interest Group of the Project Management Institute (PMI-ISSIG). A PMI-ISSIG-sponsored e-mail letter with a hyperlink to the Web-based survey was sent to the target group. Seven-point Likert-type scales were used for items measuring ISD project complexity. The ISD project complexity items were randomized in order. Individualized user IDs and passwords were given to the e-mail recipients. A follow-up reminder e-mail was sent two weeks from the first notice e-mail.

In total, 218 valid responses were obtained. Table 1 presents the characteristics of the study sample. Most of the respondents were project managers either from internal IS departments or from external consulting firms. The organizations in which the projects were being implemented represented a variety of industries. The projects evenly represented three types of ISD projects including new development, packaged software implementation, and enhancement of existing software. About 80 percent of the projects had more than $100,000 budget and 74 percent of the projects lasted six months or longer, with 76 percent of the projects having 10 or more project team members.

Table 1. Characteristics of the Study Sample

Characteristics of respondents		***Characteristics of projects***	
Project manager from		Type of project	
Internal IS department	67.9%	In-house new development	30.7%
Business unit	9.3%	Packaged software implementation	29.3%
External consulting service	22.8%	Enhancement of existing software	25.6%
		Other	14.4%
Characteristics of organizations			
Industry		Number of project members	
Manufacturing	13.3%	Less than 10	24.5%
Consulting/software	15.9%	10 – 50	57.3%
Financial service	20.0%	Over 50	18.2%
Other services	28.6%		
Other	22.2%	Project budget	
		Less than $100,000	21.1%
Number of employees		$100,000 – 1 Million	40.6%
Less than 1,000	29.1%	Over $1 Million	38.3%
1,000 – 10,000	33.9%		
Over 10,000	37.0%	Project duration	
		Less than 6 Months	26.1%
Sales		6 – 12 Months	33.7%
Less than $100 Million	30.7%	Over 12 Months	40.2%
$100 Million – 1 Billion	27.2%		
Over $1 Billion	42.1%		

5 MEASUREMENT PROPERTIES

5.1 Test Procedure

An exploratory factor analysis (EFA) method was used for validating the measures. Although a confirmatory factor analysis (CFA) method is equally useful, an EFA was chosen mainly because the present research is in the early stages of the research life cycle. A CFA needs to be done with an additional data set in future research.

5.2 Convergent and Discriminant Validity

In this study, convergent validity of the measure was first tested using corrected-item total correlation. One item was dropped because it had a very low (less than 0.01) corrected-item total correlation with the rest of the items. In addition, an exploratory factor analysis (EFA) of the items using principal component extraction with Varimax rotation was employed to further test the convergent and discriminant validity. Four additional items were dropped after the EFA procedure because they were cross-loaded onto more than one factor.

As shown in Table 2, an EFA of the remaining 17 items demonstrated a clear factor structure as proposed by the two-dimensional framework of ISD complexity. Four factors with *eigen* values greater than one emerged from the analysis, which can be interpreted as corresponding to the four types of ISD project complexity. These four factors collectively explained 62.7 percent of the variance. Each factor included three to five items and there were no cross-loaded items. Overall, these results suggest that the 17-item measure of ISD project complexity had adequate convergent and discriminant validity. The items retained in the final measure are labeled in Table 2 and presented in Appendix A.

Table 2. Factor Analysis Results of Scale Items

Item	Dynamic IT Complexity	Dynamic Organizational Complexity	Structural IT Complexity	Structural Organizational Complexity
ISDPC17	**0.929**	0.127	0.095	0.041
ISDPC8	**0.892**	0.121	0.146	0.113
ISDPC4	**0.891**	0.128	0.157	0.138
ISDPC10	**0.758**	0.151	0.209	-0.073
ISDPC15	0.113	**0.843**	0.071	0.086
ISDPC2	0.099	**0.824**	0.046	-0.030
ISDPC6	0.139	**0.782**	0.085	0.048
ISDPC13	0.143	**0.745**	0.070	0.250
ISDPC11	0.043	**0.623**	0.164	-0.056
ISDPC12	0.065	0.126	**0.835**	-0.023
ISDPC7	0.045	0.049	**0.816**	-0.109
ISDPC16	0.14	0.050	**0.709**	0.076
ISDPC1	0.13	0.054	**0.573**	0.103
ISDPC5	0.159	0.138	**0.458**	0.102
ISDPC14	0.021	0.023	0.170	**0.761**
ISDPC9	0.083	0.119	-0.182	**0.76**
ISDPC3	0.046	0.029	0.125	**0.699**
Eigen value	3.170	3.072	2.625	1.800
% of variance	18.645	18.071	15.444	10.589

5.3 Reliability

Reliability refers to the internal consistency of measurement items within each construct. Table 3 reports the item means, standard deviations, corrected item-total correlations, Cronbach's alpha, and Guttman's Lower Bound (GLB). The first two factors, dynamic IT complexity and dynamic organizational complexity, had Cronbach's alphas of 0.92 and 0.84, respectively, indicating high levels of reliability. The third factor, structural IT complexity, also exhibits a satisfactory level of reliability (alpha = 0.74). However, the fourth factor, structural organizational complexity, had a relatively lower reliability (alpha = 0.62), although it may be considered adequate for an exploratory research like this study. In general, the results suggest that each of the four factors displayed adequate internal consistency.

Table 3. Reliability of Measures

Item	Mean	Standard Deviation	Item-to-Total Correlation	Cronbach's alpha	GLB
ISDPC17	3.023	1.672	0.881	0.92	0.92
ISDPC8	3.128	1.776	0.838		
ISDPC4	3.023	1.756	0.851		
ISDPC10	2.766	1.686	0.669		
ISDPC15	3.762	1.824	0.722	0.84	0.85
ISDPC2	3	1.699	0.703		
ISDPC6	3.807	1.834	0.645		
ISDPC13	3.959	1.784	0.647		
ISDPC11	3.463	2.158	0.475		
ISDPC12	5.009	1.972	0.637	0.74	0.76
ISDPC7	5.294	1.868	0.592		
ISDPC16	4.931	1.783	0.544		
ISDPC1	3.674	2.227	0.401		
ISDPC5	5.211	2.064	0.346		
ISDPC14	3.193	1.747	0.432	0.62	0.61
ISDPC9	3.014	1.897	0.436		
ISDPC3	4.22	2.208	0.406		

5.4 Nomological Validity

Nomological validity assesses if the measure is associated with other constructs, as the theory would predict. Previous research suggests that, in general, project complexity is positively associated with project duration because complexity imposes more workload, all else being equal (Clark 1989; Griffin 1997; Meyer and Utterback 1995). In order to test this predicted relationship, a composite score was calculated for each of the four factors based on their corresponding items. An overall ISD project complexity score was obtained by averaging the four factor scores. Project duration was calculated by subtracting the project's start date from the project's actual completion date. There were 29 missing values for the project duration data. A total of 26 duration responses were considered outliers because they were outside the three standard deviation range. As a result, a total of 163 data cases were used for testing the nomological validity of the measure. Table 4 shows the results of regression analyses of project duration on (1) overall ISD project complexity and (2) four factors of ISD project flexibility. The results indicate that all four factors of ISD project complexity significantly affected project duration. Therefore, the prediction was supported by the data. In particular, among the four types of ISD project complexity, structural IT complexity exhibited the strongest association with project duration. We concluded that the measure of ISD project complexity had adequate nomological validity.

Table 4. Regression Analysis Results

Relationship	Adjusted R^2	Beta	t-value
Model I	0.290		
Project duration =			
Overall ISD project complexity		0.543	8.205**
Model II	0.303		
Project duration =			
Structural IT complexity		0.345	4.931**
Structural organizational complexity		0.132	1.990*
Dynamic IT complexity		0.215	3.004**
Dynamic organizational complexity		0.172	2.506*

*p<.05 ** p <.01

6 DISCUSSION AND CONCLUSIONS

Overall, the measure of ISD project complexity developed in this research exhibited adequate levels of measurement properties. An EFA produced a factor structure as we hypothesized, providing empirical support to our conceptualization of ISD project complexity as a two-dimensional/four-type construct. The results suggest ISD project complexity can be further divided into four distinct types of complexity: structural organizational complexity, structural IT complexity, dynamic organizational complexity, and dynamic IT complexity. In addition, the 17-item measure developed in this research can be used as a validated instrument for assessing ISD project complexity.

Some caution should be taken when interpreting and applying the measure developed in this research. The structural organizational complexity factor exhibited a relatively low reliability. The three items under this factor seem to be indirect indicators of the construct rather than direct indicators. For example, the item ISDPC3, "The project manager did not have direct control over project resources," indirectly contributes to structural complexity because a lack of direct control over the project makes it difficult to coordinate project resources. However, seemingly more direct indicators (e.g., "The project involved coordinating multiple user units") were dropped during the measurement development and analysis process because they were either (1) cross-loaded to multiple factors, and/or (2) not correlated with other indicators. Further investigation is required before we draw any definitive conclusion about the reliability of the measure.

This research makes significant contributions to both theoretical development and practice. Existing project complexity measures are too general to tap the unique context of ISD projects whereas existing software complexity measures capture only ISD *product* complexity. The new measure developed in this research overcomes these limitations and covers a wide range of the domains of the ISD project complexity construct with enhanced specificity. In addition, by defining four distinct types of ISD project complexity, this research enables researchers to theorize the construct more precisely. As shown in Table 4, the four types of ISD project complexity had different impacts on the duration of the project. As Baccarini (1996) argued, when referring to project complexity, it is important to state clearly the type of complexity being dealt with because complexity is multidimensional. The conceptualization and measure of ISD project complexity will enable researchers to test theories that better explain the organizational determinants and impacts of ISD project complexity.

The results also have important practical implications. The four types of ISD project complexity provide a framework for managers to understand their project context. In order to enhance project success rate, project managers must first understand the relative weights of the four different types of ISD project complexity under their unique context, and take specific measures to manage them accordingly. In addition, the measurement developed in this research provides managers with a practical tool to make meaningful assessments of the complexity level of their ISD projects. With the measurement, it becomes possible for managers to effectively plan and deploy various organizational resources to discriminatingly manage ISD development projects with varying levels of complexity.

This research employed exploratory data analysis methods in developing and testing the measure. Future research using confirmatory data analysis methods is needed to confirm our conceptual framework and measurement. Such a research life-cycle consisting of both exploratory and confirmatory methods will ensure both the relevance and the rigor of the instrument development process, which will in turn enhance the validity of the measurement. In addition, future research may investigate the patterns through which the four types of ISD project complexity affect the various dependant variables. Our hope is that this research serves as the starting point for developing theories for understanding and managing ISD project complexity, and ultimately enhancing ISD project success.

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Appendix A
Initial Items of ISD Project Complexity
(Final Items are in Bold)

Code of final item	Item description
ISDPC1	**The project involved multiple external contractors and vendors**[f]
ISDPC2	**The end-users' organizational structure changed rapidly**
	The system involved data processing from multiple sites[b]
	The project involved new technologies[b]
	The project team was cross-functional[e]
	The system involved high transaction rate[b]
ISDPC3	**The project manager did not have direct control over project resources**
ISDPC4	**IT architecture that the project depended on changed rapidly**
	The project was given a fixed deadline[a]
	Business users provided sufficient support and involvement[d]
	The project was a major capital investment by company[b]
ISDPC5	**The system involved real-time data processing**
ISDPC6	**The end-users' business processes changed rapidly**
	It was a new project that we had never done before[a]
	Implementing the project caused changes in the users' business processes[e]
	There were conflicts between user units involved in the project[b]
ISDPC7	**The project involved multiple software environments**
ISDPC8	**IT infrastructure that the project depended on changed rapidly**
	The project required many person-hours[a]
	Overall, the project was complex[a]
	The project involved multiple vendors[c]
ISDPC9	**There was no sufficient commitment/support from the top management**
ISDPC10	**Software development tools that the project depended on changed rapidly**
	The project involved coordinating multiple user units[e]
ISDPC11	**Implementing the project caused changes in the users' organizational structure**
ISDPC12	**The project involved multiple technology platforms**
ISDPC13	**The end-users' information needs changed rapidly**
ISDPC14	**There was no sufficient/appropriate staffing for the project**
ISDPC15	**The business environment of the end-users changed rapidly**
	The project personnel did not have required knowledge/skills[e]
ISDPC16	**The project involved a lot of integration with other systems**
	There would have been a significant impact on the business if this project had failed[a]
ISDPC17	**Overall, information technologies that the project depended on changed rapidly**
	The project involved multiple contractors[c]

Notes: [a]Items that were dropped after a sorting procedure due to lack of fit with constructs
[b]Items that were dropped after the pilot test
[c]Items that were combined into a new item (ISDPC1)
[d]The item that was dropped due to extremely low correlations with other items
[e]Items that were dropped due to significant cross-loadings on more than one factor
[f]The item that was created by combining two related items after the pilot test