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IT Application Maturity in China: How Do You Manage It?

Jianping Peng, School of Business, Sun Yat-Sen University, Guangzhou, China & School of Management, Xinhua College of Sun Yat-Sen University, Guangzhou, China

Peiwen Guo, School of Management, Xinhua College of Sun Yat-Sen University, Guangzhou, China

Meiwen Guo, School of Management, Xinhua College of Sun Yat-Sen University, Guangzhou, China

Guoying Zhang, Dillard College of Business Administration, Midwestern State University, Wichita Falls, USA

ABSTRACT

In order to investigate the relationship between IT application maturity and management capabilities, the authors conducted a survey study to collect related company information for analysis. Data processing was conducted to obtain valid and reliable variables representing IT application maturity, management institutional capability, and process management capability. Then, they adopted a partial differential equation approach to capture the time dynamics of these variables. The equations were solved analytically, and further empirically estimated through our processed survey data. The validated model demonstrates that both management capabilities have direct enhancement effects on IT application maturity. In addition, process management capability has a greater influence on IT application maturity in comparison with management institutional capability. Furthermore, it is found that there exist local maximums for both enhancement effects, provided that the two management capabilities are well balanced. The findings not only offer practical implications, but also supplement the literature of factors for IS success in light of the dynamic relationship between IT application maturity and management capabilities.

KEYWORDS

IT Application Maturity, Management Institutional Capability, Process Management Capability, Partial Differential Equation

1. INTRODUCTION

Information Technology (IT) has been the leading field for innovations. In the past decades, innovations in technology have brought changes to various cultural and societal activities. More specifically, information technology also changes the business world. From an organization's perspective, the extensive use of IT applications can integrate disparate business processes, facilitate information flow, encourage employees' contextual performance, raise customers' satisfaction level, and generate new opportunities in a global business environment. Prior research in the information systems (IS) field propose models of examining technology's business value through utilization of IT applications (Melville et al., 2004). At the same time, it is also conceivable that effective utilization of IT

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applications has to be subject to an organization's resources and management capabilities (Sabherwal et al., 2006). Therefore, determining how to effectively utilize IT applications becomes an important task for both researchers and practitioners. In this study, we use the concept of IT application maturity to capture organizations' effective utilization of IT applications.

IT application maturity is a newly emerging concept for evaluating the effectiveness and sustainability of IT application adoption and utilization. IT application maturity stems from the concept of the software capability maturity model (CMM) (Humphrey, 1988). In fact, IT applications are often viewed as the utilization of hardware, software, data and networking technology. Consequently, IT application maturity is defined as the maturity level of this utilization (Peng et al., 2011). It is important to note that IT application maturity is not a static concept. Instead, it is an evolving status of how IT applications are utilized in organizations. Presumably, when new IT applications are deployed in an organization, the maturity level should be low and preliminary. Gradually, as more frequent and effective utilization of IT applications emerge, the maturity level will increase, provided an alignment process exists between IT applications and business strategy or process.

The IT application maturity level can be defined by a discrete number of levels. For example, the ITIL maturity model has defined five levels of maturity: Initial, Repeatable, Defined, Managed, and Optimized (Pereria and da Silva, 2011). Other popular IT related maturity models include: Capability Maturity Model Integration (Chrissis et al. 2011), Maturity Model for COBIT processes (IT Governance Institute, 2007), IT Balanced Scorecard Maturity Model (Van Grembergen and Saull, 2001), and IS/ICT Management Capability Maturity Framework (Renken, 2004). Achi et al. (2016) provide a review of sixteen innovation (IT related) maturity models and conduct a comparative analysis of these models. Poeppelbuss and Roegliner (2011) is also a comprehensive study to propose the framework of designing maturity models. Regardless of the variety of these maturity models, mature utilization of IT application enables organizations to ease information flow internally and externally, to reduce production costs, to streamline operation processes and, ultimately, to improve business performance (Xiao and Xie, 2007; Peng et al., 2011).

It is important, therefore, for organizations to identify critical factors to improve IT application maturity. Sabherwal et al. (2006) propose a comprehensive model for identifying Information Systems (IS) success and highlight two constructs as Organizational Determinants – top management support and facilitating conditions. Petter et al. (2013) also identify 43 determinants that have been posited to affect IS success and categorize them as: tasks, people, and structure. More specifically, Dwivedi et al. (2015) conduct a panel study to reflect on the new research directions within this domain. As a literature review, their study specifically calls for future research in "…a broader view of the dynamics of organizational change in a complex business environment…" and to "enable a better integration of institutional forces into the discussion of why IS fail or succeed as well as stressing the need for IS research to focus more on the alignment of IS with organizational processes." In order to answer this research call, in this study, we focus on the investigation of institutional management and process management capabilities.

1.1. Research Motivation

To answer research call from Dwivedi et al. (2015), we specifically study the above two highlighted organizational capabilities: management institutional capability and process management capability.

Organization's institutional capability or capital has always been recognized as one of the core management capabilities (Love and Irani, 2004; Leidner and Kayworth, 2006; Ke and Wei, 2008). Strong management institutional capability of establishing and enforcing rules, policies, and regulations is the capstones of competitive organizations. This capability has also been widely studied in economics field in the form of institutional theory (Scott, 1987), which plays an important role in business strategy and management research. The other highlighted management capability is based on Porter's value chain model (Porter, 1985). According to Porter, business processes are the sources for generating values for organizations. The capability for process management is the enabler to gain competitive advantage (Powell, 1995). Benner and Tushman (2003) further point out that, although process management has been a prevailing practice to improve organizational efficiency, it needs to be investigated under organizational institutional context.

These two management capabilities are recognized as core organizational competencies, however, there is no prior research in investigating their influences toward IT application maturity. Intuitively, management institutional practices enforce the adoption and acceptance of IT applications, and the process management capabilities determines the effectiveness of IT application utilization. We are intrigued to further this direction validate the influence of these management capabilities toward IT application maturity. It is also interesting to note that these variables are not static in organizations, and the dynamics with respect to the change of capabilities and maturity level are also important for examination.

In order to fulfill this research motivation, we designed a survey instrument to collect data from professional managers from various companies in China. The instrument consists of items related to measurement constructs of IT application maturity (ITAM), management institutional capability (MIC), and process management capability (PMC). We distributed 143 formal questionnaires and received 123 effective responses. A Confirmatory Factory Analysis was conducted to process data with reliability and validity tests. To avoid the random selection of model specification, we further adopted the approach of partial differential equations to formulate time dynamics of ITAM, MIC, and PMC. The partial differential equations were solved analytically, and validated through our processed survey data. Parameters estimations were also generated from this empirical model.

Our validated non-linear model shows that both management capabilities have direct enhancement effects on IT application maturity. In addition, it is interesting to note that process management capability has a stronger influence toward IT application maturity in comparison with management institutional capability. Furthermore, it is found that there exist local maximums for both enhancement effects. In fact, the local maximums can only be achieved with an appropriate combination of two management capabilities. These results provide practical implications for an organization to improve IT application maturity more effectively through balancing and improving two management capabilities.

1.2. Contributions

Our findings not only offer practical and managerial insights for organizations during the life cycle of utilizing IT applications, but also supplement the literature of factors for IS success in light of the dynamic relationship between IT application maturity and management capabilities. We believe our IT application maturity is a novel angle to enrich the traditional literature of IS success, because maturity represents the continuous improvement of IT application utilization. Our research has also addressed the literature calls of analyzing the influences from two distinct management capabilities (Benner and Tushman, 2003; Dwivedi et al., 2015).

Furthermore, our survey data empirically validate a non-linear model to depict the relationship between IT application maturity and management capabilities. The significant parameter estimations further allow us to claim greater positive influence from process management capability (toward IT application maturity) in comparison with management institutional capability. It is also interesting to note, there exists a combination condition of two management capabilities, such that their enhancement effects (toward IT application maturity) reaches a local maximum.

The paper is organized as follows. A literature review is presented in Section 2. In Section 3, research design, data collection, and data analysis are elaborated. Section 3 also provides an analytical solution toward our partial differential equation modelling. The model is then empirically validated through the processed survey data. Section 4 further interprets the model and provides discussions toward the parameter estimations. Section 5 highlights the practical implications for organizations. We conclude and provide future research directions in Section 5.

2. LITERATURE REVIEW

The relationship between Information Technology and business performance has received a great abundant research attention in the past decades (Wu et al., 2015; Melville et al., 2004). Among them, there are studies on identifying what construct information systems success (Delone and Mclean, 2003; Sabherwal et al., 2006). There are also studies on competitive advantages from IT (Powell and Dent-Micallef, 1997), return on investment from IT (Weill and Aral, 2006), and strategy implementation based on IT (Chari et al., 2008). Nonetheless, IT is an important enabler for better business performance, and it is necessary to investigate how to improve IT utilization.

In the literature, there exist studies on identification of critical success factors for specific IT applications, such as Enterprise Resource Planning (ERP) application (Somers and Nelson, 2001; Umble et al., 2003; Zhong et al., 2004). Furthermore, in accordance with the technology adoption theory, Chatterjee et al. (2002) study the influence of organizational factors on the successful adoption of Web technology. Tang (2000) also captures critical factors affecting the success of Intranet adoption. However, most of them are targeted toward a specific IT application, and the success is often defined by the initial implementation or adoption. In this study, we use the IT application maturity concept to capture a continuous, dynamic status of IT application utilization. We intend to identify how organizational management capabilities can influence IT application maturity on an on-going base.

Yu (2004) summarizes critical success factors for IT applications, and which include management capabilities, production capabilities, institutional capabilities, and service capabilities. Petter et al. (2013) also identify about 43 determinants that have been posited to affect IS success and categorize them as: tasks, people, and structure. More recently, Dwivedi et al. (2015) conduct a panel study to highlight the factors enabling IS success and avoiding IS failure. As a literature review with panel experts, their study calls for future research with an integration of institutional forces with organizational processes.

Hence, this current study addresses the gap in the research with two organizational capabilities, management institutional capability and process management capability. We intend to identify their influences on IT application maturity. In addition, instead of simply defining initial adoption or implementation as a success, we contribute to the literature in terms of adopting the IT application maturity concept to capture a continuous, dynamic process of IT application utilization. Furthermore, the research sheds practical insight on how to manage the evolving of IT application maturity from influence of management capabilities.

Other related research includes IT-business "Strategic Alignment Maturity" (SAM) model (a comprehensive review from Luftman et al., 2008) and how to design maturity model. The Luftman's SAM model (2000) consists of forty-one factors and can be aggregated into six components of: communications, value measurement, technology scope, partnership, governance, and skills. In essence, SAM focuses on the strategic elements driving strategic alignment between business and IT. Poeppelbuss and Roegliner (2011) is comprehensive study to propose the framework of designing maturity models. However, their study mainly focuses on how to define different stages for maturity evaluation. Our research intends to investigate the relationship between IT application maturity and management capabilities at an operational level. We provide the theoretical background for these research objects as follows.

2.1. Theoretical Background

2.1.1. IT Application Maturity

In 1987, under a commission from the U.S. Department of Defense, Carnegie Mellon University Software Institute (SEI) established a software process maturity model called Capability Maturity Model (CMM). This model categorizes software process maturity into five levels: ad hoc, repeatable, defined, managed, and optimized (Chrissis et al, 2011). Harmon (2004) proposes a process maturity model or Business Process Maturity Model (BPMM) to categorize business process maturity into a similar five levels, namely, initial, repeatable, defined, managed, and optimized. Hammer (2007) further proposes a process and enterprise maturity model or Process and Enterprise Maturity Model (PEMM). More recently, ITIL maturity model was proposed with five defined levels of maturity: Initial, Repeatable, Defined, Managed, and Optimized (Pereria and da Silva, 2011). Other popular IT related maturity models include: Capability Maturity Model Integration (Chrissis et al., 2011); maturity models for COBIT processes (IT Governance Institute, 2007); IT Balanced Scorecard Maturity Model (Van Grembergen and Saull, 2001); and IS/ICT Management Capability Maturity Framework (Renken, 2004). Xiao and Xie (2007) also propose a model with five defined levels of IT application maturity: basic, partial integration, complete integration, enhanced coordination, and strategic driving level. Achi et al. (2016) provide a review of sixteen IT related innovation maturity models and conduct a comparative analysis of these models. Regardless of the variety of these maturity models, the purpose of these model is mainly for assessment and evaluation of IT utilizations.

Prior research confirms the importance of successful IT application utilization toward business performance. A mature IT application systems is often at the core of realizing business competitive advantage. At the same time, IT application is not an isolated component for organizations, it has to be subject to an organization's resources, culture, and management capabilities (Sabherwal et al., 2006). Our focus of the study is to investigate how management capabilities can influence IT application maturity.

2.1.2. Management Institutional Capability

In the line of research of organizational behavior, organizational institutionalism has been identified as one of the core theories of the past forty years (a comprehensive review of this stream of research is provided by Greenwood et al., 2008). A strong organizational capability of generating and enforcing management policies and regulations represents the capstone of enterprises with an orderly and competitive operational environment. Furthermore, North (1992) proposes institutions and economic theory. Oliver (1997) states that institutional context often refers to organizational culture and politics, organizational rules and norms, as well as other organizational acceptable behavior.

More relevant to our research interest, Love and Irani (2004) provide an exploratory study on IT benefits in small and medium-sized enterprises (SMEs) of construction industry. The study suggests that organization types significantly differ in IT investment instead of organizational size. Ke and Wei (2008) discuss organizational culture and leadership in ERP implementation. "Learning and development, participative decision making, power sharing, support and collaboration, and tolerance for risk and conflicts" are dimensions identified to be important for successful ERP implementation. Liu et al. (2010) draw up the institutional theory to investigate how institutional pressures can motivate the adoption on an online supply chain systems. Leidner and Kayworth (2006) provide a comprehensive review of the culture research in IT, and summarize six themes in the field: culture and information system development; culture and IT adoption and diffusion; culture and IT use and outcomes; culture and IT Management and strategy; the impact of IT on culture; and IT culture. To summarize these research outcomes, our study intends to combine all these institutional components such as organization type, culture, leadership style, policy executive, and so on into a multi-facet term, management institutional capability. In general, an organization with strong management institutional capability are often considered to have comprehensive policy planning ability, effective execution ability of decisions, adaptive workforce training process, continuous improvement culture, among others.

In fact, aligning with these literature's findings, strong management institutional capability not only enables the successful initial adoption or acceptance of IT applications, but also critical to improve the maturity and ongoing utilization of IT applications. Liang et al. (2007) validate that institutional pressures (coercive, mimetic, and normative) do contribute to post-implementation of the ERP system. Therefore, we would like to propose:

H1: Management institutional capability has positive influence toward IT application maturity.

2.1.3. Process Management Capability

Process management capability is another core organizational capability, which is related to business process-based practices contrasting to traditional function based operations (Zairi, 1997). Mithas et al. (2011) define it as "a firm's ability to attain flexibility, speed, and cost economy through the design and management of three major types of (business) processes." In fact, there exists a specific literature stream mainly dedicating toward how to implement business process (re-engineering) (a comprehensive literature review from van der Aalst, 2013). For example, Gregoriades and Sutcliffe (2008) use a socio-technical approach to describe the business process redesign. Moreover, although there are differences among various business process management approaches or models, process management capability is regarded as a core competency leading to better business performance (Mithas et al., 2011, Hammer & Stanton, 1999; Harry & Schroeder, 2000).

More specific to IS research, a substantial amount of literature has identified process management capability as an essential component of implementing IT systems (Cotteleer and Bendoly, 2006; Love and Irani, 2004; Ming, 2005; Zairi 2000; Davenport, 1993). Benner and Tushman (2002) further investigate the influence of process management activities on technological innovation. Holland and Skarke (2008) recommend that an organization can explore its potential for technology utilization and can achieve better performance by synchronizing process management capability with IT applications. Nonetheless, process management capability is an indispensable factor for IT application development, design, deploy and post-implementation. Therefore, we would like to propose:

H2: Process management capability has positive influence toward IT application maturity.

Last but not the least, we understand in general both organizational capabilities are indicators of the organizational characteristics. Not only are they established before the development and adoption of IT applications, these capabilities are also key enablers for effective IT application utilization after the initial implementation. Management practices and policies need to be designed and deployed to encourage the use of IT applications, promote the data standards associated with IT applications, and most importantly, align IT applications toward business strategic goals (Turban et al., 2015).

3. RESEARCH DESIGN

3.1. Variable Descriptions

We begin the elaboration of our research design by providing formal definitions of these variables.

IT application maturity (ITAM): it refers to how IT applications are effectively deployed, utilized, and maintained in organizations. It is important to note that IT application maturity is an evolving concept for organizations. In other words, organization's IT application maturity can improve over time. In order to capture such dynamics, we don't want to fixate a certain number of levels for maturity as indicated in majority of literature. Therefore, we adopt the composite dimensions in Peng et al. (2011), which includes a comprehensive set of components to evaluate IT application maturity, namely: Technology, Data, Operation, Functional management, Strategic support, and Man – machine synergy. This model allows us to capture the dynamics of IT application maturity without the restriction of discrete stage labeling.

Management institutional capability (MIC): Institution is a term often referring to structures and mechanisms of orders and cooperation, which govern the behavior of a set of individuals. Institutional components are existing procedures, standards of processes, organizational culture, and other organizational policies (Oliver 1997). Therefore, management institutional capability refers to the organization's capability for establishing institutional structures, executing policies and rules, and improving institution mechanisms on a continuous basis. Peng and Xie (2010) establish a framework to capture this institutional context, while from the management perspective. Their framework thus defines "management institutional capability" with three variables: planning capability, which refers to organization's awareness and capability for planning institutional infrastructure; execution capability, which refers to effectiveness for management policy execution; and improvement capability, which refers to organization's institutional self-improvement capability. These capabilities are defined at the operational level and it captures an on-going dynamics of organization's management institutional capability (Peng and Zhang, 2012; Peng et al., 2019).

Process management capability (PMC): it often refers to the organization's capability of continuously improving business processes to achieve better business performance and customer satisfaction. Peng and Zhang (2012) summarize the literature and proposes a framework with three dimensions: implementation capability, which refers to the effectiveness of implementation of process involving multi-functional coordination; quality control capability, which refers to organization's capability for process optimization and problem solving; and customer satisfaction orientation, which places customer-oriented emphasis in process management activities.

These constructs are comprehensive concepts and unobservable directly, which requires good measurement models to be established. In order to design an effective survey to collect data, a project group in the author's university first conducted several rounds of face-to-face interviews with managers and IT personnel from a number of companies in China. The average interview time is about 2 hours to discuss the appropriateness and completeness of pilot survey items. Comments and suggestions from these interviews were incorporated to refine the measurement models in the literature. Table 1 provides the summary of these variables and constructs' descriptions.

Table 1. Variables descriptions

Variable	Construct	Description
IT application maturity (ITAM)	Technology	Information technology, including mainly hardware infrastructure and software systems
	Data	Includes basic data, operational data, and decision data. Basic data refers to internal static data; operational data refers to dynamic data generated in business processes; decision data is the data supporting decision making processes.
	Operation	How effectively IT application supports business operations
	Functional management	How effectively IT application supports functional department management
	Strategic support	How effectively IT application supports business strategies
	Man – machine synergy	Whether IT application provides user-friendly interface, interactive visualization and intelligence
Management institutional capability (MIC)	Planning capability	Organization's awareness and capability for planning institutional infrastructure
	Execution capability	Effectiveness and capability for institutional execution
	Improvement capability	Organization's institutional self-improvement capability
Process management capability (PMC)	Quality control capability	Organization's capability for process optimization and problem solving
	Implementation capability	Effectiveness of implementation of process involving multi-functional coordination
	Customer satisfaction	Emphasis of customer-oriented philosophy in process management

3.2. Data Collection

After the pilot survey was finalized with experts' opinions, a formal questionnaire was established. Our sample frame is the registered companies located in Guangzhou China at the time of this research. Since the authors' university has the top-ranking Executive MBA program in this region, we used the convenient sampling approach to distribute the questionnaire to Executive MBA alumnus. 143 formal questionnaires were distributed to these alumni who are also professional managers from various companies in this region. Among the job title of these respondents, 27 are senior managers (19%), 36 are mid-level managers in IT departments (25%), 44 are mid-level managers in non-IT departments (31%), and 36 are low-level managers (25%).

Each of these respondents represents one company. In order to control the potential bias for this "one representative one company," all the items were phrased in a way seeking for fact-based information related with the company. There are in total 21 items related with IT application maturity, 15 items related with management institutional capability, and 7 items related with process management capability. Later on, during the factor analysis, the reliability tests on Cronbach's alpha show strong internal consistency of all items. Third, we understand that some of the junior managers might not have sufficient knowledge toward three or four items related with strategic decision making. Hence, all the items were designed with a "Don't Know" option. This option was later treated as a missing value for our data processing. We imputed the average value to treat less than 10 of these of missing data points, among a total of around 5200 data points.

123 eligible responses were collected and each of them represents one distinct company. The type of industry splits between manufacturing and service by 48% and 52%, which is approximately the same as the type of company industry split of companies in this region according to its local chamber of commerce report. The type of company ownership varies from state-owned, private, and joint-venture with percentages of 46%, 15%, and 39%. The distribution of company size ranging from less than 100 employees to over 10000 employees is relatively normal, where about 69% have 100-5000 employees. Furthermore, the distribution of company's annual revenue is also relatively normal, with about 66% of the companies have a mid-range yearly revenue. Table 2 lists all the detailed distributions. These distributions of the sampling company features are in line with the data from Guangzhou Chamber of Commerce report at the time of data collection. Therefore, our sample is reasonable enough to represent the companies in the region of Guangzhou China.

During this data collection stage, it is also important to assure that there should be less chance of having "common method variance" bias since measurement data were collected from single respondent of each company. According to the literature, we have both *ex ante* and *ex post* remedies (Chang et al., 2010). First, the survey targets were assured of confidentiality of this study. All the items were also double checked through a pilot study of face-to-face interview with a different group of professional managers. The questionnaire items are more fact-based to relate to the current status of a business aspect (Podsakoff et al., 2003). Second, there are randomization of the order of the questionnaire items. Last but not the least, our *ex post* remedy includes avoiding overly simple linear regression model between dependent and independent variables. We elaborate our models in Section 3.4, which is entirely a non-linear model to avoid possible cognitive miser principle (Harrison et al., 1996). In addition, according to Podsakoff et al. (2003), we conduct additional statistical tests to ensure common method bias is not present in our model.

3.3. Data Processing

LISREL 8 is the statistical tool to conduct the Confirmatory Factor Analysis (CFA) using our survey data. Tables 3-5 list the details of factor loading results for ITAM, MIC, and PMC.

There are numerous goodness-of-fit indexes to assess measurement models. In general, if most of indexes indicate a good fit, we can claim the goodness-of-fit for our measurement models. According to Table 6, all three constructs have Chi-square/df less than 2.00; root mean square of error

Table 2. Effective responses

Type of Industries	Number of Companies (Percentage)
Manufacturing	59 (48%)
Service	64 (52%)
Total	123
Type of Ownership	**Number of Companies (Percentage)**
State-owned	56 (46%)
Private	19 (15%)
Joint ventures and listing companies	48 (39%)
Total	123
Number of Total Employees	**Number of Companies (Percentage)**
≥10000	15 (12%)
5000-10000	10 (8%)
2000-5000	22 (18%)
1000-2000	19 (16%)
100-1000	43 (35%)
<100	11 (9%)
No data	3 (2%)
Total	123
Annual Revenue (100 Million RMB)	**Number of Companies (Percentage)**
≥500	9 (7%)
100-500	13 (11%)
10-100	30 (24%)
1-10	38 (31%)
<1	13 (11%)
No data	20 (16%)
Total	123

of approximation (RMSEA) less than 0.08; Non-Normed Fit Index (NNFI, also known as TLI) more than 0.95; and Comparative Fit Index (CFI) more than 0.90 (Hu and Bentler, 1999).

It is also important to double check the reliability of our CFA models. SPSS 15.0 is the statistical tool for this analysis. Table 7 indicates strong internal consistency of all items for measurement constructs, where all of them have a Cronbach's alpha greater than 0.8 (George and Mallery, 2003).

These tests of reliability and validity indicate that our measurement models are suitable, and the computed factor scores were further utilized. In addition, we complete the *ex post* test for common method bias.

3.3.1. Common Method Bias

Beyond the procedural approach to address common method bias during the research design and data collection stages, we further adopted several statistical approaches to test common method bias.

First, Harman's single factor test is conducted to load all items into an exploratory factor analysis to identify whether one single factor accounts for the majority of the covariance between

Table 3. Factor loadings for ITAM

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Variable Name
Advancement	.816	-	-	-	-	-	Technology
Comprehensiveness	.748	-	-	-	-	-	
Scalability	.775	-	-	-	-	-	
Compatibility	.774	-	-	-	-	-	
Security	.565	-	-	-	-	-	
Standardization	-	.760	-	-	-	-	Data
Accuracy	-	.745	-	-	-	-	
Integrity	-	.810	-	-	-	-	
Timeliness	-	.817	-	-	-	-	
Quality Control	-	-	.770	-	-	-	Operations
Supervision	-	-	.800	-	-	-	
Intelligence assistance	-	-	.714	-	-	-	
Optimization	-	-	-	-	.504	-	Functional management
Supervision	-	-	-	-	.764	-	
Intelligence assistance	-	-	-	-	.892	-	
Importance	-	-	-	-	-	.792	Strategic support
Support	-	-	-	-	-	.582	
Integration	-	-	-	-	-	.508	
Ease of Use	-	-	-	.881	-	-	Man-machine synergy
Usefulness	-	-	-	.831	-	-	
Flexibility	-	-		.568	-	-	
Eigenvalue after Rotation	3.976	3.574	2.644	2.618	2.326	1.399	Total variance explained
Cumulative after Rotation	18.9%	36%	48.5%	61%	72%	78.7%	

all the items. We found the test results in a single factor with an explained variance lower than the threshold of 50% for all the three measurement models. This approach is necessary, but it is often considered as insufficient.

Second, unmeasured common latent factor analysis is conducted to introduce a new latent variable to the model (Podsakoff et al., 2003, Figure 3A in Table 5). This latent factor is introduced to our measurement model and related to all observed variables. We reran all the three measurement models with this common latent factor. Then, we compared the standardized regression weights of all items between models with and without the common latent factor. The differences were found to be smaller than the 0.2 threshold, which confirmed that common method bias should not an issue for our data (Gaski, 2017).

Finally, a zero-constraint model of unmeasured common later factor is compared with an unconstrained model as described in the above approach (Gaski and Lim, 2017). The Chi-square difference test between two types of models is not significant, indicating two types of models are invariant. In other words, with or without the unmeasured common later factor, our measurement models are essentially the same. Therefore, common method bias is not a significant concern for this data set.

Table 4. Factor loadings for MIC

	Factor 1	Factor 2	Factor 3	Variable Name
User friendly	-	-	.784	Planning capability
Culture	-	-	.684	
Forward-looking	-	-	.703	
Continuity	-	-	.688	
Timeliness	-	-	.581	
Systematic	-	-	.517	
Authorization	-	.675	-	Execution capability
Independence	-	.758	-	
Command	-	.774	-	
Equality	-	.747	-	
Monitoring	.636	-	-	Improvement capability
Evaluation	.744	-	-	
Adjustment	.814	-	-	
Adaptability	.746	-	-	
Innovation	.774	-	-	
Eigenvalue after Rotation	3.9	3.5	3.37	Total variance explained
Cumulative after Rotation	26%	49%	71.9%	

Table 5. Factor loadings for PMC

	Factor 1	Factor 2	Factor 3	Variable Name
Cross-function	.714	-	-	Quality control capability
Processes re-engineering	.871	-	-	
Systematic approach	.734	-	-	
Flexibility	.731	-	-	
Exception handling	-	.888	-	Customer satisfaction
Customer Satisfaction	-	.746	-	
Assurance of coordination	-	-	.976	Implementation capability
Eigenvalues after Rotation	2.607	1.69	1.08	Total variance explained
Cumulative after Rotation	37%	61.4%	76.8%	

3.3.2. Variables of ITAM, MIC, and PMC

We can now proceed with computing our key variables for this study: ITAM, MIC, and PMC. According the variable descriptions in Section 3.1. ITAM, MIC and PMC are indeed composite variables containing reflective first-order constructs derived from the above factor analysis. ITAM is composed of six first-order latent constructs: Technology, Data, Operation, Functional management, Strategic support, and Man – machine synergy. MIC is composed of three first-order latent constructs:

Table 6. CFA model fit indexes

Variable	χ^2	df	χ^2/df	RMSEA	NNFI	CFI
ITAM	234	155	1.51	0.072	0.96	0.91
MIC	140	87	1.61	0.061	0.98	0.99
PMC	21	11	1.90	0.075	0.96	0.98
Common Threshold value			≤ 2.00	≤ 0.080	≥ 0.95	≥ 0.90

Table 7. Reliability analysis

<table>
<tr><th colspan="2">ITAM</th><th colspan="2">MIC</th><th colspan="2">PMC</th></tr>
<tr><th>α_{total}=0.931</th><th>Dimension α</th><th>α_{total}=0.948</th><th>Dimension α</th><th>α_{total}=0.847</th><th>Dimension α</th></tr>
<tr><td>Technology</td><td>0.913</td><td rowspan="2">Planning capability</td><td rowspan="2">0.884</td><td rowspan="2">Implementation capability</td><td rowspan="2">0.761</td></tr>
<tr><td>Data</td><td>0.922</td></tr>
<tr><td>Operation</td><td>0.893</td><td rowspan="2">Execution capability</td><td rowspan="2">0.890</td><td rowspan="2">Quality control capability</td><td rowspan="2">0.843</td></tr>
<tr><td>Functional management</td><td>0.871</td></tr>
<tr><td>Strategic support</td><td>0.822</td><td rowspan="2">Improvement capability</td><td rowspan="2">0.908</td><td rowspan="2">Customer satisfaction</td><td rowspan="2">0.770</td></tr>
<tr><td>Man – machine synergy</td><td>0.828</td></tr>
</table>

Planning capability, Execution capability, and Improvement capability. Finally, PMC is also composed of three first-order latent constructs: Implementation capability, Quality control capability, and Customer satisfaction.

Composite variables are associated with the concept of simplified "formative" constructs rather than "reflective" constructs (Javis et al., 2003; Petter et al., 2007). A common way to differentiate these two types of constructs is to check the interchangeability of related first-order constructs. Our first-order constructs are *not* interchangeable. Furthermore, the second-order variables are composed of all first-order constructs (Diamantopoulos et al., 2008, Diamantopoulos and Winklhofer, 2001, Jarvis et al., 2003). Finally, without any specific prior weighting theory, the value of these variables can be calculated simply by using equal weightings of their first-order constructs (Petter et al., 2007, Cadogan and Lee 2013).

3.4. The Model

It is necessary to present an appropriate empirical model to investigate the influence of MIC and PMC toward ITAM. In general, it is often the researcher's choice of basic model specification. However, it is difficult to choose from a pool of different models: linear, non-linear, or other formats. In order to avoid a random choice among various models, as well as common method bias from our single respondent data collection, we begin by modeling the research targets with regard to their time dynamics.

As noted early, all of these constructs are not static in organizations. Maturity can grow and capability can expend or deprecate. It is usually quite challenging to collect the longitudinal data for each company; however, we can incorporate such time dynamics using partial differential equations (PDEs) modeling. PDE modelling has been adopted widely in science, engineering, and finance field and becomes popular in the last decade also in social-economics research domain (Burger et al., 2014). This approach allows us to make assumptions for target constructs in a very small time interval. Consequently, we can use these characteristics of target constructs to derive a basic model specification.

Let us denote y as IT application maturity (ITAM), x_1 as management institutional capability (MIC), and x_2 as process management capability (PMC). The assumptions of these constructs during an infinite small time interval are:

- The impacts of MIC and PMC on ITAM are investigated with an assumption that, during each infinite small time interval, all other organizational factors are constant;
- The time derivative of ITAM ($\partial y / \partial t$) is associated with its current value (y). The change rate of ITAM has to be determined by its current status. In other words, IT application maturity's change is state-dependent on its current value. For example, improvement of standardizing data in the organization is heavily dependent on the current level of data standardization. State-dependent is a common assumption for time dynamics modeling;
- The time derivative of MIC or PMC ($\partial x_1 / \partial t$, $\partial x_2 / \partial t$) is also associated with its current values (x_1, x_2), respectively. The change rate in either capability is influenced by its current status too. In other words, the change in an infinite small time interval is state-dependent on its current value. For example, improving the cross-functional integration with regard to a certain business process management, has to be associated with the process's current status of integration level;
- The time derivative of ITAM ($\partial y / \partial t$) is also associated with the current values of MIC and PMC (x_1 and x_2). While no assumption is made about either a positive or negative relationship, it is important to note that both MIC and PMC do have impacts on changes of ITAM (Peng and Zhang 2012). Intuitively, MIC and PMC influence and facilitate changes of IT application maturity. Given an infinitely small time interval, without referring to the current status of management capabilities, the change of IT application maturity might be out of context;
- A saturation factor $\left(1 - \frac{y}{100}\right)$ is applied to the time derivative of ITAM ($\partial y / \partial t$). This factor controls the growth of ITAM with an upper bound. In other words, IT application maturity has to be bound by a specified threshold. In literature, maturity models usually define a highest level to indicate a best possible utilization of IT applications.

With the above assumptions, differential equations are set up for target constructs with regard to time dynamics. Let us use β_1 and β_2 to represent the coefficients of MIC in the differential equations of ITAM and MIC, respectively; while β_3 and β_4 represent the coefficients of PMC in the differential equations of ITAM and PMC, respectively. Equation (1) represents the set of differential equations for capturing our assumptions listed above:

$$\begin{cases} \dfrac{\partial y}{\partial t} = \left(\beta_1 x_1 + \beta_3 x_2\right) y \left(1 - \dfrac{y}{100}\right), \\ \dfrac{\partial x_1}{\partial t} = \beta_2 x_1, \\ \dfrac{\partial x_2}{\partial t} = \beta_4 x_2. \end{cases} \tag{1}$$

By integrating the first equation over t and utilizing the next two equations in (1), it can be derived that:

$$\ln\left(\frac{y}{100-y}\right)=\frac{\beta_1}{\beta_2}x_1+\frac{\beta_3}{\beta_4}x_2+c \quad (2)$$

Let $\beta_1 / \beta_2 = \lambda_1$, $\beta_3 / \beta_4 = \lambda_2$ Equation (2) can be rewritten as:

$$\ln\left(\frac{y}{100-y}\right)=\lambda_1 x_1+\lambda_2 x_2+c \quad (3)$$

Since the right hand side of Equation (3) is a linear function, linear regression analysis are used to estimate the parameters. We also noted that the correlation between MIC and PMC is 0.645, and hence VIF analysis was included when estimating the parameters. After model estimation, we obtained a VIF score of 1.698, which is lower than a common threshold of 5.00 (Studenmund, 2011). Therefore, it can be argued that collinearity between the two capabilities is not a significant issue for this model. Table 8 shows the results of parameter estimations in Equation (3).

Table 8. Results of regression analysis – Equation (3)

	Constant *c*	**x_1 Coefficient λ_1**	**x_2 Coefficient λ_2**
Estimated parameters	−0.851***	0.010***	0.012***
R^2	0.397		
F	37.244***		
N	123		

** $p < 0.05$; *** $p < 0.01$

Our model is essentially a linear regression model. However, the dependent variable is not ITAM. In fact, according to our initial model derivation, the dependent variable is in a transformed format of ITAM, i.e., $\ln\frac{y}{1-y}$. Our model is significant in explaining a transformed value of ITAM, using MIC and PMC ($F = 37.244$, $p < 0.01$). The model can significantly explain 39.7% of the variance of the transformed ITAM. Furthermore, MIC has a positive significant coefficient of 0.010 ($p < 0.01$), and PMC also has a positive significant coefficient of 0.012 ($p < 0.01$). In other words, both MIC and PMC have positive influences on the transformed value of ITAM. Please note also, the transformed value of ITAM is monotonically increasing with ITAM. Therefore, our model proves that both MIC and PMC have positive influences on ITAM too. Both hypotheses in Section 2 can now be accepted.

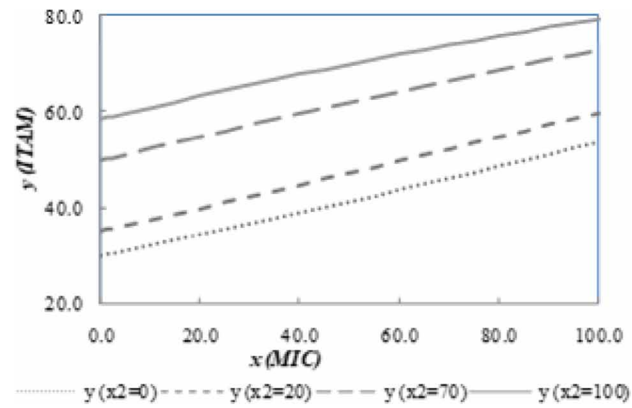
Given that all the estimated parameters are significant, it is appropriate to use them and expand Equation (3). After some algebraic manipulations, it can be obtained that the function form of ITAM with regards to MIC and PMC is indeed:

$$y=\frac{100e^{0.01x_1+0.012x_2-0.851}}{1+e^{0.01x_1+0.012x_2-0.851}} \quad (4)$$

In other words, each unit increase of MIC leads to an increase of ITMC of $\frac{y\left(1-0.01y\right)}{100+0.01y}$, where *y* represents the current value of ITMC, and we approximate $e^{0.01}=1.01$. Similarly, each unit increase of PMC leads to an increase of ITMC of $\frac{y\left(1.2-0.012y\right)}{100+0.012y}$, where *y* represents the current value of ITMC, and we approximate $e^{0.012}=1.012$.

To visualize these effects, we use Figure 1 to illustrate several numerical examples of ITAM versus MIC for a given value of PMC. It is clear to see that with the increase of MIC, ITAM increases accordingly. At the same time, a higher level of PMC leads to a higher ITAM.

Figure 1. ITAM vs. MIC



4. DISCUSSION

In this section, a detailed discussion is provided for the empirically validated model in Equation (4). The validated enhancement effects of MIC and PMC are further elaborated in the following propositions and corollaries. Without loss of generality, we carry out the following discussion for $x_1, x_2, y \in \left(0,100\right)$.

Proposition 1: The time derivative of ITAM ($\partial y / \partial t$) is positively correlated with the time derivative of MIC ($\partial x_1 / \partial t$) or PMC ($\partial x_2 / \partial t$).

Proof: Let us take partial differentiation of (4) with regard to time variable *t*. It can be obtained that:

$$\frac{\partial y}{\partial t}=\frac{e^{0.01x_1+0.012x_2-0.851}}{\left(1+e^{0.01x_1+0.012x_2-0.851}\right)^2}\left(\frac{\partial x_1}{\partial t}+1.2\frac{\partial x_2}{\partial t}\right) \tag{5}$$

Here, the coefficients $\partial x_1 / \partial t$ and $\partial x_2 / \partial t$ are both positive. Hence, the time derivative of ITAM is positively correlated with the change rates of two capabilities.

It can be concluded from Proposition 1 that, given an infinitely small time interval, change from either MIC or PMC can move ITAM in the same direction (negative or positive). In fact, during the parameter estimation stage of the empirical model, we have already assumed a relationship between the time derivative of ITAM and the current status of MIC and PMC. Proposition 1 further confirms a positive relationship between the time derivate of ITAM and the time derivatives of MIC and PMC.

Proposition 2: ITAM increases (decreases) with increases (decreases) of MIC or PMC. In this study, these are called the enhancement effects to ITAM. Further, local maximum enhancement effects exist for both MIC and PMC.

Proof: Let us take partial derivatives of Equation (4) with regard to x_1 and x_2, respectively. It can be obtained:

$$\frac{\partial y}{\partial x_1} = \frac{e^{0.01x_1+0.012x_2-0.851}}{\left(1+e^{0.01x_1+0.012x_2-0.851}\right)^2} \tag{6}$$

$$\frac{\partial y}{\partial x_2} = \frac{1.2e^{0.01x_1+0.012x_2-0.851}}{\left(1+e^{0.01x_1+0.012x_2-0.851}\right)^2} \tag{7}$$

It is obvious that both $\partial y / \partial x_1 > 0$ and $\partial y / \partial x_2 > 0$, that is, ITAM, increases (decreases) directly with the increases (decreases) of MIC or PMC. Equations (6) and (7) are hereafter called the enhancement effect of MIC to ITAM and the enhancement effect of PMC to ITAM, respectively. Let us denote them as E_{MIC} and E_{PMC}.

Both of these enhancement effects are further investigated by checking optimization conditions. By taking first order derivatives of E_{MIC} and E_{PMC}, it can be obtained:

$$\frac{\partial E_{MIC}}{\partial x_1} = \frac{0.01e^{0.01x_1+0.012x_2-0.851}\left(1-e^{0.01x_1+0.012x_2-0.851}\right)}{\left(1+e^{0.01x_1+0.012x_2-0.851}\right)^3} \tag{8}$$

$$\frac{\partial E_{PMC}}{\partial x_2} = \frac{0.0144e^{0.01x_1+0.012x_2-0.851}\left(1-e^{0.01x_1+0.012x_2-0.851}\right)}{\left(1+e^{0.01x_1+0.012x_2-0.851}\right)^3} \tag{9}$$

Solving for $\frac{\partial E_{MIC}}{\partial x_1} = 0$ and $\frac{\partial E_{PMC}}{\partial x_2} = 0$, consequently, we obtain the same condition of:

$$x_1 + 1.2x_2 = 85.1 \tag{10}$$

Plugging Equation (10) to check the second-order conditions of enhancement effects, we find that both of them are satisfied, that is:

$$\left.\frac{\partial^2 E_{MIC}}{\partial {x_1}^2}\right|_{x_1+1.2x_2=85.1} < 0 \text{, and } \left.\frac{\partial^2 E_{PMC}}{\partial {x_2}^2}\right|_{x_1+1.2x_2=85.1} < 0$$

Hence, local maximums exist when Equation (10) is satisfied.

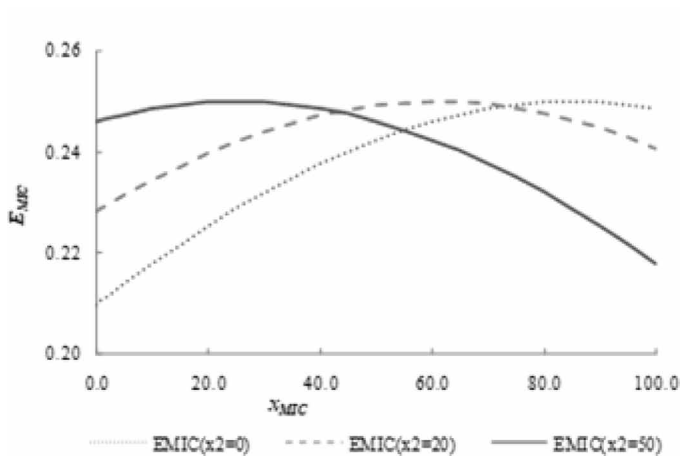
In other words, when MIC and PMC satisfy Equation (10), the enhancement effect of MIC, E_{MIC} reaches its local maximum with a value of 0.25. At the same time, the enhancement effect of PMC, E_{PMC} reaches its local maximum with a value of 0.30.

Proposition 2 illustrates that ITAM can be improved directly from the improvement of MIC and PMC.

Proposition 2 also shows that such enhancement effects have local maximums. In other words, the enhancement effects have upper bonds. In fact, only with a proper combination of MIC and PMC (Equation 10), enhancement effects to ITAM can be maximized. Perceivably, at the local maximum of the enhancing effect of MIC (E_{MIC}), optimal MIC decreases given a higher PMC; similarly, at the local maximum of the enhancing effect of PMC (E_{PMC}), optimal PMC decreases given a higher MIC. Consequently, we can argue MIC and PMC are substitute to each other in boosting the enhancement effects toward ITAM.

To visualize the results in Proposition 2, we use Figure 2 to provide a numerical example by plotting the enhancement effect of MIC. First, we can easily observe that there is a local maximum

Figure 2. Enhancement effect of MIC to ITAM



point for the enhancement effect of MIC. Second, it is demonstrated that when PMC (x_2) increases, for example, from $x_2 = 0$, to $x_2 = 20$, to $x_2 = 50$, the optimal MIC to reach the local maximum of E_{MIC} decreases.

Our empirical model validates the direct positive influence of MIC or PMC toward ITAM in organizations. In order to further elaborate the intriguing substitution between the enhancement effects of MIC and PMC, we derive the following corollaries for discussion.

Corollary 1: There exists a threshold value of MIC, such that the enhancement effect of PMC is always decreasing for any given MIC greater than the threshold. There also exists a threshold value of PMC, such that the enhancement effect of MIC is always decreasing for any given PMC greater than the threshold.

Proof: We first solve Equation (10) to get the threshold value: $x_1^* = 85.1$, if $x_2 = 0$. Then it can be shown that, for any given $x_1 > x_1^*$, we always have $\frac{\partial E_{PMC}}{\partial x_2} < 0$. In other words, the enhancement effect of PMC is always decreasing with the increase of PMC. Similarly, we can also solve Equation (10) to get $x_2^* = 70.9$, if $x_1 = 0$. Then, for any given $x_2 > x_2^*$, we always have $\frac{\partial E_{MIC}}{\partial x_1} < 0$. In other words, the enhancement effect of MIC is always decreasing with the increase of MIC.

We know from Proposition 2 that IT application maturity can be improved by enhancing either management institutional capability or process management capability. Corollary 1 further shows that such enhancement effect on IT application maturity from one of the two management capabilities will decrease when the given value of the other capability exceeds a threshold value. Therefore, if either of the two capabilities reaches its threshold value, it is important to note that although it is still possible to further improve management capability for increasing IT application maturity, the enhancement effect (or marginal effect) is diminishing.

Corollary 2: The ratio of the two enhancement effects E_{PMC} / E_{MIC} is a constant.
Proof: We can divide Equation (7) by Equation (6) to get:

$$E_{PMC} / E_{MIC} = \frac{\partial y}{\partial x_2} / \frac{\partial y}{\partial x_1} = 1.2$$

Hence, the ratio of the two enhancement effect is a constant.

Corollary 3: The ratio of the first order condition of two enhancement effects $\frac{\partial E_{PMC}}{\partial x_2} / \frac{\partial E_{MIC}}{\partial x_1}$ is also a constant.
Proof: We can divide Equation (9) by Equation (8) to get:

$$\frac{\partial E_{PMC}}{\partial x_2} / \frac{\partial E_{MIC}}{\partial x_1} = 1.44$$

Hence, the ratio is also a constant.

Corollaries 2 and 3 illustrate the differences of the enhancement effects of MIC and PMC on ITAM. The enhancement effect of PMC is always 1.2 times of that of MIC. If this constant ratio number is not too prescriptive to be generalized, we can at least argue that enhancement effect of PMC is stronger than that of MIC to ITAM. In other words, improvement on PMC can bring more improvement on ITAM in comparison with the same level of changes made toward MIC. Furthermore, the first order conditions of two enhancement effects, which can be perceived as acceleration rates, are also different. The accelerate rate of enhancement effect from PMC is also larger than that from MIC. In other words, the incremental improvement on PMC leads to stronger enhancement effect of PMC in comparison with that of MIC.

5. PRACTICAL IMPLICATIONS

Managerial insights can be gained from our propositions and corollaries to improve IT application maturity in organizations. The results provide a guidance on how to evaluate the influence from management institutional capabilities and process management capabilities.

First, both process management and management institutional capabilities are important to exert positive influence toward IT application maturity. With regard to management institutional capability, we recommend organizations to put an on-going emphasis on institutional planning capability, effective policy execution capability, and continuous improvement capability for institutional context. At the same time, an organization should also examine its process management capability, including quality-control mechanism, process implementation and optimization, and customer satisfaction centered process design.

Second, the enhancement effect from process management capability is stronger than that from management institutional capability. Therefore, if an organization needs to prioritize improvement plans, process management related projects should be the ones to start with in terms of improving IT application maturity. If there are budget or resource constraints, then process management related requests should be satisfied first in order to raise IT application maturity level.

Finally, it is interesting to note that management capabilities should be balanced to generate maximum enhancement effects on IT application maturity. If the process management capability is too high, the enhancement effect from management institutional capability decreases. Symmetrically, if an organization already has too strong management institutional capability, the enhancement effect from process management capability also decreases. Therefore, organizations need to identify a proper combination of management capabilities, while effectively allocating organizational resources between them. The proper balancing of management capabilities can in turn enhance IT application maturity to the greatest extent.

6. CONCLUSION AND FUTURE DIRECTIONS

There are lots of literature in studying IS success, including how to define IS success, critical factors for IS success. At the same time, there are various models to capture IT application maturity mainly for IT utilization evaluation and assessment (Poeppelbuss and Roegliner, 2011). However, to the best of our knowledge, there are limited amount of research dedicating to essential management capabilities' influence on IT application maturity. Our study intends to bridge this gap by studying the influence factors of two core competencies: management institutional capability and process management capability (Benner and Tushman, 2003; Dwivedi et al., 2015).

In order to empirically investigate the influence of management capabilities on IT application maturity, survey data were collected to construct measurements for our research objects. A Confirmatory Factor Analysis was conducted to process data with both reliability and validity testing. Then, we proposed a set of partial differential equations to capture the time dynamics of IT application maturity, management institutional capability, and process management capability. The model was solved analytically and all the parameters in the model were estimated using the processed survey data.

Our validated non-linear model shows that both management capabilities have a direct enhancement effect on IT application maturity, that is, the partial derivative of IT application maturity over either of the management capabilities is always positive. In addition, it is interesting to note that the enhancement effect from process management capability toward ITAM is always stronger than that from management institutional capability. In other words, process management capability has a greater influence toward IT application maturity in comparison with management institutional capability. Furthermore, it is found that there exists a local maximum for the enhancement effect from either MIC or PMC. In fact, this local maximum can only be achieved with an appropriate combination of the two management capabilities. If one of them is high enough (over a threshold value), the other capability will still enhance IT application maturity, but at a diminishing rate.

This study provides practical implications for organizations to improve IT application maturity through management practices. First, both process management and management institutional capabilities are important to exert positive influence toward IT application maturity. Second, the enhancement effect from process management capability is stronger than that from management institutional capability. Therefore, if an organization needs to prioritize process management related projects in order to improve IT application maturity. Finally, there is a delicate combination condition to balance both management capabilities. Only when this condition is satisfied, we can expect maximum enhancement effects from both MIC and PMC. Therefore, organizations need to identify this combination and effectively allocate resources between two management capabilities, which can in turn enhance IT application maturity to the greatest extent.

This study offers a number of possible directions for future research. First, our data samples are from a local region in China, which may pose a geographical limitation in interpreting the results. The possible generalization may stimulate a research stream on the similarities or differences among companies from different geographic regions. Second, our data samples are from one representative in each company, therefore, subjective bias might still exist regardless of the controls to validate the responses. A possible future direction can involve participation from different management levels to describe the company in a more comprehensive way. Third, we use the time dynamics for generating the relationship model between IT application maturity and management capabilities, and the assumptions of time dynamics only capture a general trend of the changes among these research objects. More elaborate variations of the model are needed to check for robustness. Finally, we assume all the companies in the data sample are the homogenous in regards to the influence of management capabilities on IT application maturity. However, it is highly possible that firm-level differences exist in such relationship. More controls at the firm level need to be incorporated to refine the model specification.

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Jianping Peng is an Associate Professor in School of Business, Sun Yat-Sen University. He hold a PhD from Sun Yat-Sen University. His research interests include enterprise management information systems, electronic commerce and process management, organizational behavior impact of employee social network. He has published in Information Systems Research, Decision Support Systems, Journal of Organizational and End User Computing, Information Resources Management Journal, International Journal of Information Management.

PeiWen Guo is the lecturer of Xin Hua College of Sun Yat-sen University. She got her master's degree from Sun Yat-sen University in 2013, majoring in education management.

Meiwen Guo currently works for the School of Management, Xinhua College of Sun Yat-sen University.

Guoying Zhang received her PhD degree in Information Systems from Foster School of Business at the University of Washington Seattle. Her research and teaching interests include information resource management, social networks, data mining, and economics of information systems. Currently, she holds the professor position of Management Information Systems in Dillard College of Business Administration at Midwestern State University. She has published in two of the top three MIS journals: MIS Quarterly and Journal of Management Information Systems. Her works also appear in recognized journals such as INFORMS Journal of Computing, Decision Support Systems, Management Decision, Information Systems and e-Business Management, International Journal of Virtual Communities and Social Networking, International Journal of Networking and Virtual Organisations, Journal of International Technology and Information Management, among others.