A Model of Data Warehousing Process Maturity

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Abstract—Even though data warehousing (DW) requires huge investments, the data warehouse market is experiencing incredible growth. However, a large number of DW initiatives end up as failures. In this paper, we argue that the maturity of a data warehousing process (DWP) could significantly mitigate such large-scale failures and ensure the delivery of consistent, high quality, "single-version of truth" data in a timely manner. However, unlike software development, the assessment of DWP maturity has not yet been tackled in a systematic way. In light of the critical importance of data as a corporate resource, we believe that the need for a maturity model for DWP could not be greater. In this paper, we describe the design and development of a five-level DWP maturity model (DWP-M) over a period of three years. A unique aspect of this model is that it covers processes in both data warehouse development and operations. Over 20 key DW executives from 13 different corporations were involved in the model development process. The final model was evaluated by a panel of experts; the results strongly validate the functionality, productivity, and usability of the model. We present the initial and final DWP-M model versions, along with illustrations of several key process areas at different levels of maturity.

Index Terms—Data warehousing process, design-science research, model validation, software maturity models.

1 Introduction

Data warehousing (DW) has experienced tremendous growth in the last decade. It has become so popular in industry that it was cited as the highest priority postmillennium project of more than half of IT executives [64]. A data warehouse is a subject-oriented, integrated, time-variant, and nonvolatile collection of data that supports managerial decision making [28]. The data in a data warehouse are typically extracted and loaded from multiple online transaction processing (OLTP) systems and other data sources using an extract, transform, and load (ETL) process.

Data warehouse projects tend to be costly [71]. Despite the fact that the projects require large investments, both in terms of money and effort [30], the data warehouse market is continuing to experience incredible growth, primarily because of the role of data warehouse as a powerful decision support tool [61]. If the growth trend continues, the real data in the data warehouse could easily reach 1,000 terabytes [73]. This growth is not only in sheer size, but also in the number of end users, query volumes, data complexity, and "right-time" information. Data warehouses are now getting incorporated into mission-critical systems that demand high availability, right-time "refresh" rates, and high data quality [4].

Despite this booming market, a large number of DW initiatives end up as failures. Friedman [14] expected that over 50 percent of data warehouse projects would experience limited acceptance, if not outright failure. It is therefore critical for the DW community to devote more thought to understanding what afflicts DW design, development, implementation, and management. DW initiatives often end up as failures because of factors such as slipped schedules, unacceptable performance, expandability problems, poor availability, complicated tools, poor data quality, and unhappy users [2], [31]. *Data quality* is a very important issue [74] because it caters to a variety of stakeholders, encompasses diverse aspects (e.g., coherency, freshness, accuracy, accessibility, availability, etc.), and requires complex assessment techniques [15], [67].

In response to similar types of problems in the software engineering domain, researchers advocated the need to study the software process and its management. Humphrey [21], [22] broadly defines a software process as a set of tools, methods, and practices used to produce a software product. The objectives of software process management are to generate products according to plan, while concurrently improving the capability to produce better products [21]. The Capability Maturity Model (CMM) [49] and ISO 9001 [48] were developed in an effort to promote and assess software process quality standards in organizations.

Although data warehousing has been around since the early 1990s, unlike software development, the assessment of its *process* maturity has not received much attention. A *data warehousing process* (DWP) can be viewed as a data production process that includes subprocesses such as business requirements analysis, data design, architecture design, data mapping, ETL design, end-user application design, data quality management, business continuity management, implementation, and deployment.

Just as CMM has been useful in reducing defects in a software development process [1], [19], we expect a mature DWP to address many issues surrounding the development and management of a data warehouse. While many DW development methodologies are currently available (see, for example, [58], [59]), they have not been extended to incorporate CMM-like maturity concepts. Most firms do not appear to follow a set of engineering practices and standards for data warehousing and, as a result, have not

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attained the high levels of maturity that software development has, resulting in failed DW implementations, poor data quality, and other associated problems.

Most companies embark on data quality initiatives to address concerns such as spiraling direct-mail costs, poor customer service, and faulty reports [54]. Poor data quality costs money in terms of lost productivity, faulty business decisions, and an inability to achieve results from expensive investments in enterprise applications. One of the major reasons for data quality problems is inconsistent data definition. A data warehouse, which reflects the "single version of the truth" [25] for an organization, is a prime touch point for addressing data quality problems. Subject matter experts who are knowledgeable about business as well as data are often employed to define data cleansing rules and data quality metrics, as well as recommend whether to fix the data at the source, the staging area, or the warehouse [10].

In addition to addressing data quality concerns, a mature DWP can be expected to provide several other benefits. A mature DWP would help the organization to define and deliver projects with predictable durations. It would force the organization to develop data quality and data governance strategies that enhance the trust of sponsors and users in the data. By building trust and providing the ability to perform sophisticated business analytics, a mature DWP would also keep the user base satisfied, thereby addressing one of the main causes of data warehouse failures.

The need for a CMM-like maturity model for DWP has been mooted in the literature [33], [34], [35], [60], [69]. But none of the prior studies has gone beyond presenting a sketchy or preliminary model. In this paper, we describe the design and development of a comprehensive, detailed, and robust DWP maturity model—based on *design-science research* guidelines—over a period of three years.

It is important to note that while there are many issues common to software development and data warehousing, there are a number of factors that render DWP unique. In particular, any discussion on DWP maturity revolves around data quality management, ETL design, metadata management, data change management, data warehouse governance, end-user cube design, etc.—activities that do not fall under the purview of traditional software development. The main contribution of our work is in designing a DWP maturity model by identifying, defining, and accommodating those aspects that pertain specifically to DW.

The paper is organized as follows: Section 2 provides the motivation for developing the DWP maturity (DWP-M) model. Section 3 reviews the extant literature on maturity models. Section 4 first presents the framework that has been recently proposed for conducting design-science research in IS, and then describes how we employed this framework to design, develop, and evaluate the DWP-M model. Section 5 discusses the contributions of our study and Section 6 concludes the paper and identifies the future research directions.

2 Motivation for a DWP Maturity Model

A *data warehousing process* is a set of activities that begins with the identification of a need and concludes with delivering a product that satisfies the need [60]. More specifically, it is a set of activities, methods, practices, and transformations that people use to develop, maintain, and operate data warehouse and its associated products.

Many DWP tasks can be categorized as *development tasks*, which revolve around the design, development, and implementation of the data warehouse. Development tasks in DWP include *business requirements analysis, data design, architecture design, data mapping, ETL design, end-user application design, end-user cube design, implementation*, and *deployment* [25], [28], [60]. Data warehouses are geared toward addressing the analytic questions of business managers and executives, as opposed to processing routine transactions in OLTP systems. Given the complexity inherent in such analytics, special attention has to be devoted to designing the right type of data marts, aggregates, and cubes in order to promote ease of access and support efficient processing of business queries. The firm also needs to be aware of end-user applications such as business intelligence (BI), data mining, and customer relationship management (CRM), which rely heavily on warehouse data.

As discussed later, it became clear from our interactions with industry experts that a DW process also needs to focus on the operations of the data warehouse. *Operations tasks* are generally responsible for making sure that the data warehouse keeps functioning as designed. Operations tasks in a DWP include *metadata management, recovery management, financial services management, data warehouse governance, data governance,* and *service level management.* Other operations tasks in a DWP provide customer service/support consistently in a timely manner to the end users by supplying high quality and valuable data. These tasks include *supporting business users, training business users, managing the technical infrastructure, information delivery management, tuning for database performance,* and *service level agreement* [28].

We believe that a DWP is quite complex because it includes many activities, a variety of tools (such as ETL, metadata management, and end-user tools), and resource coordination with these activities. Such activities are critical in any DW implementation. For instance, a successful DW venture entails having the right plan for managing *metadata*. Metadata in a DWP can be broadly classified into three types: operational metadata, extraction and transformation metadata, and end-user metadata [28]. *Operational metadata* describes the operational data sources, while *extraction and transformation metadata* contains information on the extraction of data from source systems and its subsequent transformation in the staging area. *End-user metadata* provides a navigational map for users to browse and find the information that they are interested in. The metadata in a warehouse, therefore, is not only used for building the warehouse, but also for using and administering the warehouse.

Data warehouses are time dependent, i.e., they can track history. That is one of the major differences with operational databases, which store transient data and do not typically maintain any history. From an operations standpoint, it is important to ensure that there are right procedures in place to effectively execute the change management strategies.

These complexities make us believe that the management of a data warehousing process should follow the tenets of

TABLE 1
Comparison of Maturity Models from Different Domains

Maturity Model type	Inherent maturity abstraction	Focus of maturity support (process or product)	Model benefits	Model scope	Related technologies	Stakeholders
CMM (Software Capability Maturity Model) [49]	Crosby's framework [8]	Software development and maintenance processes	Higher quality software, cost effectiveness, timely delivery, better software development productivity, etc.	From software project management to defect prevention	Software development, software maintenance	Software engineers, clients and partners
IT Service CMM [42],[43]	CMM	IT services (software maintenance, operations of information systems, etc.)	Enabling IT service providers to assess their capabilities with respect to the delivery of IT services, and to provide directions and steps for further improvement of their service capability	Main *focus* of the model is the complete service organization and its *scope* encompasses all service delivery activities	IT services	Service providers, customers
IQMM (Information Quality Maturity Model) [12]	CMM	Information quality management process	High quality information	Development of disciplined approach to information quality	Data warehouse, data bases	Developers, clients
NASCIO EAMM (Enterprise Architecture Maturity Model) [41]	CMM	Enterprise architecture development process	Reduced software and data redundancy, greater reliability, more accurate forecasting of development and support costs, etc.	Provides a path for architecture and procedural improvements within an organization	Architecture development, maintenance and planning	Managers, legislatures, government leaders, IT community
EDMMM (Enterprise Data Management Maturity Model) [9]	CMM	Data base administration process	Better management of the data base administration (DBA) process	From project planning, subcontract management to continuous process improvement	Database life cycle tasks	DBA, database end users
SOAM (Service Oriented Architecture Maturity Model) [63]	CMM	Reuse of business process components posed as "services"	IT cost reduction, business responsiveness, collaboration with partners, etc.	From R&D experiments to services available to its partners	Service-based technologies employing reuse, event-driven automation, business activity monitoring, etc.	SOA Developers, architecture groups, CIO, other business stakeholders
Project management Maturity Model [24]	Considered CMM but concluded not appropriate; used its own model	Project management process	Promotes improved project management practices	Provides managers with a procedure for measuring project management processes	Project management issues	Project manager
OSMM (Open source Maturity Model) [16]	Moore's Chasm model [38]	Open source product adoption process	Offering organizations the ability to assess the maturity level of open source products.	Determining how useful a product element will be to the organization	Open source evaluation	Developers
Data Warehouse Maturity Model [11]	CMM and Moore's Chasm model	Data warehouse product improvement	Distinguishing different stages of the product	From management reporting with spread sheets to BI services	Data warehousing, BI services, data marts, etc.	Executives, developers, etc.

management of a software process. "Good software processes help produce better, cheaper software faster. In fact, when either a defined process is not available or when such a process is defined but not used the chances are that a software project will fail" [32]. Software process improvement has become an important challenge to modern organizations. Maturity models such as CMM [49], *Capability Maturity Model Integration* (CMMI) [55], and ISO 9001 [48] play an extremely important role in helping software companies achieve higher levels of maturity, in terms of their development process and product quality. To be considered mature, an organization needs to not only define and use a software process, but to also evolve it continuously [21], [50]. Using this as a basic principle, we envision a continuously evolving data warehousing process in an organization as one that promotes quality and timely delivery of information.

3 Extant Literature on Maturity Models

Maturity models have their roots in the field of quality management [6], [8], [13]. The concept of maturity implies progress from some initial state to a more advanced state. The notion of evolution is implicit in the stages of growth, suggesting that the progress transitions through a number of intermediate states on the way to higher maturity levels. In his Quality Management Maturity Grid (QMMG), Crosby [8] describes the typical behavior exhibited by firms at five levels of maturity with respect to various aspects of quality management. The QMMG has a strong evolutionary theme, suggesting that firms typically evolve through five phases—*uncertainty*, *awakening*, *enlightenment*, *wisdom*, and *certainty*—in their ascent to quality management excellence.

Crosby's framework has been adopted by many disciplines, including software development, project management, open source systems, web services, data governance, service-oriented architectures, enterprise architectures, information quality management, database administration, and IT services. To determine the inherent characteristics of a maturity model, we analyze a representative sample of maturity models (see Table 1) based on a set of attributes, which include inherent maturity abstraction, focus of maturity support, model benefits, model scope, related technologies, and stakeholders. The *inherent maturity* *abstraction* attribute illustrates the intrinsic maturity paradigm that is used to develop the model. The model can focus on either process maturity or product maturity. Process maturity concentrates on how a process evolves toward maturity. Product maturity, on the other hand, explains the evolution to better products. The *model benefits* attribute describes the benefits obtained from a maturity model. The *model scope* attribute describes the focus of the maturity model. The *related technologies* attribute portrays the technologies that are covered by the maturity model. Finally, the *stakeholders* attribute describes the people or groups affected by the maturity exercise.

Our analysis of the extant models reveals that maturity models focus on process or product evolution. All models, directly or indirectly, use Crosby's framework to abstract their inherent processes even though the stages of evolution can differ. The process maturity models—such as IT Service CMM [42], [43], [57], IQ CMM [12], and NASCIO's EMM [41]—borrow heavily from CMM. Some, such as the project management maturity model [24], [39], have their own specific models since CMM is geared toward IS companies. Others, such as OSMM [16] and DW Maturity Model [11], follow the *Chasm Model* espoused by Moore [38]. Also, note that Eckerson's DW maturity model [10], [11] focuses on product (data warehouse) maturity, not on process maturity.

Even though many types of maturity models have been proposed for different contexts (see Table 1), they all share a set of common features. We find that a maturity model typically supports the three key features described below:

Feature-1: Maturity levels. The idea of levels originated from Crosby's work. The number of levels in a model typically ranges from three to six. Each level usually has a descriptor that serves as a name for the level. The Capability Maturity Model developed by the Software Engineering Institute (SEI) for software development process reflects the best practices in software development and emphasizes the need to conduct periodic software process assessments and introduce improvements. CMM advocates that continuous process improvement be based on small, evolutionary steps and provides a framework for organizing those steps into five maturity levels [50]. The five levels are *initial*, *repeatable*, *defined*, *managed,* and *optimizing*.

Many organizations provide IT services [51], [70] either internally or externally. These services include software maintenance, operating information systems/data centers, running networks, and providing technical support. Customers of these services at times may not be able to express their real service requirements and may not know the performance needs. Quite often, service providers also do not know how to assess their own capabilities with respect to the delivery of IT services. According to Niessink et al. [43, p. 12], "Regardless of the exact circumstances in which an IT service provider operates, sufficient emphasis should be on processes...to be able to deliver quality IT service." To address these problems, Niessink and van Vliet [42] and Niessink et al. [43] proposed the IT Service CMM model based on the CMM Version 1.1 framework. The scope of this model covers all of the service delivery activities and focuses on the maturity of the service organization. Like CMM, this model also has five levels and does not measure the maturity of individual services, but only that of the entire service organization.

With respect to IT services, the Information Technology Infrastructure Library (ITIL) provides a comprehensive framework that is built around a process model-based view of controlling and managing operations [7]. Its goal is to help an IT organization understand how to deliver value to its customers and for the parent/client organization to better realize value from IT services. The ITIL framework provides a set of best practices to help organizations achieve enhanced efficiency and effectiveness in their IT service management and realize the following objectives: 1) align IT services with both current and future needs of business, 2) improve the quality of IT services, and 3) reduce the cost of providing these IT services [65].

The primary focus of most organizations practicing ITIL has been on two process groups: 1) service support and 2) service delivery [44], [45]. *Service support* consists of six categories:

1. service request management,
2. incident management,
3. problem management,
4. change management,
5. release management, and
6. configuration management.

Service delivery consists of five categories:

1. service level management,
2. capacity management,
3. IT service continuity management,
4. availability management, and
5. financial management.

Feature-2: Key process areas. Each level in the maturity model indicates a level of process capability. A level is decomposed into a set of key process areas (KPAs) that an organization should focus on to improve its process. The levels and KPAs form a grid for a maturity model. All maturity models invoke this grid approach [8] and provide textual descriptions for the performance characteristics/traits at each level. Each KPA includes a cluster of related activities that, when performed, collectively achieve a set of goals considered important for enhancing process capability. Processes at each level provide the foundation for the higher level processes. In CMM and other maturity models, KPAs differ from level to level. For example, requirements management, software project planning, etc., form the KPAs for the *repeatable level* (or level 2) in CMM. For higher levels, organizational process definition, intergroup coordination, integrated software management, software quality management, defect prevention, etc., form the different key process areas.

Feature-3: Activities in key process areas. The objective of each process area can be summarized by its key practices, also known as activities. Each activity must have goals and commitments. Key practices, according to Paulk et al. [50, p. 39], "describe 'what' is to be done, but they should not be interpreted as mandating 'how' the process should be implemented. Alternative practices may accomplish the goals of the key process area." For example, in CMM, activities for the *requirements management* KPA are *requirements review*, *change requirements review*, *requirements induced planning*, etc.

4 Designing a DWP Maturity Model

Even though the concept of data warehousing process maturity has been mooted in the literature [9], [30], [34], [35], [60], [69], work in this area has been limited to a simple specification of the levels and mapping of some of the activities from CMM, without much serious theory-based development. In this section, we develop a conceptual model of DWP maturity by grounding our work in *design-science research* [17], [18], [20] and in the literature on quality, maturity models, and IT services.

4.1 Design-Science Research

According to Hevner et al. [20], the goal of the design-science research paradigm is "to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts" (p. 75). Their framework for design-science research provides a set of guidelines. The first guideline is that design-science research should result in an *artifact*, which could be a construct, model, method, or instantiation. But design is also a process [20], [68], comprised of a set of activities that produces the artifact. *Constructs* provide the symbols and vocabulary for defining and solving problems [20]; they are the representations of the entities of interest [18]. A *model* uses the constructs to represent the design problem and its solution space [62]. A *method* defines the process for searching through the solution space. Finally, an *instantiation* is the implementation of the constructs, models, or methods in a working system.

The second guideline Hevner et al. [20] present relates to *problem relevance*. Design science efforts should be relevant to "the practitioners who plan, manage, design, implement, operate, and evaluate information systems and those who plan, manage, design, implement, operate, and evaluate the technologies that enable their development and implementation" (p. 85).

The third guideline focuses on *design evaluation*. The designed artifact could be evaluated based on metrics such as functionality, completeness, consistency, accuracy, etc. Because design is inherently an iterative activity, the evaluation phase provides the necessary feedback to the construction phase on the quality of the design process and the design artifact being developed [20].

The fourth guideline deals with *research contributions*. To be effective, design-science research must make clear contributions with respect to the design artifact, design foundations, or design methodologies. The most frequent type of contribution is the artifact itself, which helps to address unresolved problems and provides significant value to the target community.

The fifth guideline is *research rigor*. Design-science research should apply rigorous methods for developing and evaluating the artifact. But, as Hevner et al. [20] argue, research rigor should not be emphasized at the expense of relevance. Rigor is introduced by basing the research on theoretical foundations and through the effective use of research methodologies.

The last two guidelines address *search* and *communication* issues. Design involves searching a very large space for a *satisficing* solution [62]. Heuristic strategies are usually employed to make the search process manageable. Finally, the results of design-science research must be presented effectively to both technology-oriented and management-oriented audiences.

In addition, a design theory should have a *purpose and scope*, stating what the artifact is for [18]. Our aim, in this research, is to design and develop a data warehousing process maturity model. But the question that might arise is why we need a separate DWP maturity model when we already have CMM and its variants for software development. A software development process is defined as a set of activities, methods, transformations, and practices that people employ to develop and maintain software and its associated products [21], [22], [23]. It includes activities such as *requirements analysis and definition, software design, implementation, system testing,* and *maintenance.* In addition to these, a data warehousing process includes tasks that are quite different, such as data staging, metadata change management, metadata quality management, data warehouse governance, end-user cube design, information delivery management, etc. Even the requirements analysis process for DW development is quite different. As Kimball et al. [28] note:

> The approach used to gather knowledge workers' analytic requirements differs significantly from more traditional, data-driven requirements analysis. Data warehouse designers must understand the key factors driving the business to effectively determine business requirements and translate them into design considerations (p. 34).

In their business dimensional life cycle approach, the focus is on the analytic requirements elicited from business managers and executives for designing dimensional data marts. A DW process is thus quite different from a traditional software development process, thereby necessitating a separate DWP-M model, focusing on both data warehouse development and operations.

Recognizing the distinct aspects of a DW process, we also adapted Humphrey and Kellner's [23] prescriptions for a process model to the DW context, in addition to following the guidelines for design-science research. While developing the model, we addressed the following questions:

1. What are the benefits of a mature DWP?
2. What do DW managers and practitioners perceive DWP maturity levels to be?
3. What are the key process areas for each of those maturity levels? and
4. What are the activities in each of those process areas?

4.2 Initial Model

As discussed in Section 4.1, the designed artifact could be in the form of a construct. *Constructs* are the representations of the entities of interest. The ultimate artifact we are interested in designing is the DWP maturity model. Given the complexity of a DWP, the development of this model necessitates the design of intermediate constructs. First, we need to design the "maturity" construct. Second, because maturity models typically define a number of levels, we also need to define the "maturity level" construct, which represents how mature a DWP is. Third, we need to specify a set of KPAs at each maturity level, so we also have to design the "KPA" construct. Finally, each KPA includes a set of activities that need to be performed as part of a DWP, so we will have to design the "activity" construct as well. There are, therefore, four constructs for the DWP-M model: *maturity*, *maturity level*, *KPA*, and *activity*. But, as noted before, design is also a process. In this section, we describe the development of the DWP-M model in terms of the four constructs and the process.

Mullins [40] mapped the levels in CMM to levels based on how data are managed within organizations; others too have echoed similar ideas [9], [30]. Marco in a series of articles [33], [34], [35] and Watson et al. [69] also emphasized the need for a CMM-like maturity model for a DWP. Marco applied CMM to data warehousing and developed six levels of DW maturity, from Level 0 ("not performed") to Level 5 ("continuously improving"). Based on the extant literature on maturity models in different fields (discussed in Section 3) and the work in [9], [30], [33], [34], [35], and [40], Sen et al. [60] provided an *initial set of specifications* for a maturity model. The five levels of their initial model are described below. This initial model only specifies the levels and does not describe the KPAs and the associated activities.

Level 1 (*Initial*). A level-1 process has no strict rules or procedures for data management [33], [34], [35], [40]. Along similar lines, a data warehousing process at level-1 maturity lacks strict rules or procedures. Data resides in multiple files and databases using multiple formats. Redundancy is rampant. Independent, nonconforming data marts are likely to be very common at this level. Changes are typically made "on the fly" as requested by the application program development unit. The quality of the data depends on the skills of the technical programmer analysts, database analysts and designers, and coders. Groups take on large and complex projects with little knowledge of their impact, resulting in project cancellations or warehouses with low-quality data and reports. At this level, redundant data marts are often created, in addition to process and technology redundancy [34]. DW projects at level 1 tend to be expensive; while some are successful, many fail badly.

Level 2 (*Repeatable*). An organization at level-2 DWP maturity has a data management policy that specifies how and when data structures are created, changed, and managed. Although a policy is in place, it has not been institutionalized [40]. This level witnesses fewer independent data marts than in level 1 [35]. A database administrator (DBA) is usually assigned at this level. Some standard practices such as managed schema changes, performance monitoring, and database tuning are performed at this level. Some organizations at this level may have several data warehousing initiatives and associated activities. Some of these initiatives may have robust plans and may track the data warehousing efforts. Although repeatable processes exist for a department or a line of business, they are followed by that group, but not by the entire organization [40].

Level 3 (*Defined*). An organization at this level has a stated policy of treating data as a corporate asset. Best practices for developing, maintaining, and operating the data warehouse are documented and used across the enterprise. The data management policy becomes a core component of the application development life cycle [40]. The policy is enforced and tested to ensure that data quality requirements are met. A level-3 organization typically understands the business meaning of data and creates a data administration (DA) function in addition to the DBA function; there is usually a good interaction between these two functions and an appropriate use of DW tools. Usually there are very few independent data marts, and more projects tend to succeed than fail [35].

Level 4 (*Managed*). An organization at this level introduces a managed metadata environment [40]. This enables the data management group to catalog and maintain metadata for corporate data structures. The organization starts conducting data audits to measure data quality. Measurable process goals are established for each DW process [35]. Quantitative/statistical techniques are used to analyze the collected measurements. DW projects are consistently successful and the organization can predict their future performance with reasonable accuracy [35].

Level 5 (*Optimizing*). An organization at this level uses practices learned in levels 1 through 4 to continually improve data access, data quality, and data warehouse performance [40]. Very low levels of data, process, and technology redundancy exist; any remaining redundancy is well documented and understood [35]. The organization aligns its processes with its strategic business goals and tries to optimize its investments in data warehousing.

The DWP-M model that we propose includes and builds on the five levels discussed above. Each of the KPAs that we identify in this study is assigned to a specific level. KPAs for development and operations are captured in the model. Based on whether or not a firm performs the activities within each KPA at a given level, its practices are deemed to conform or not conform to that level.

4.3 Knowledge Acquisition

We interacted with DW managers and practitioners to elicit the knowledge required for developing the model. Specifically, we conducted multiple brainstorming sessions and interviews with key DW professionals from industry to identify, analyze, and understand the maturity levels, as well as the key process areas and associated activities for each level.

Three workshops were organized in June 2003, February 2004, and June 2004. Invitations were extended to a number of medium to large-sized US corporations. Knowledgeable DW executives from 13 companies volunteered to participate. These companies covered the manufacturing (aviation, electronics, and computer), retail, service (hospital, insurance, rental agency, and banking), and e-tailing (Internet travel agency) industry sectors. The group included data warehouse sponsors/users (covering business intelligence, e-intelligence, and data mining) and data warehouse managers (covering ETL developers, data warehouse administrators, and end-user developers). The growing importance of the IS-business relationship function and the emergence of IS as a service provider [42], [43] prompted us to gather feedback from DW executives working for a large cross section of industries and playing diverse roles at different levels in their organizations. The participants had, on average, five to seven years of experience in data warehousing, and their job titles included managers, directors, and vice presidents. The panel consisted of 20 members from the 13 participating companies. These members had either managed, used, or sponsored very large data warehouse projects ranging from 600 gigabytes to 700 terabytes in size. The database management systems used by these companies included Teradata, Oracle, and SQL Server. Overall, the group represented extensive expertise, experience, and diversity in perspectives.

Information acquisition was done in multiple modes, depending on the intent. At the workshops, we used *brainstorming sessions* [36] with the group to generate ideas for model conceptualization. Our objectives in this phase were to assess the potential value of a DWP maturity model, and to identify its maturity levels and the key process areas. These sessions also exposed us to the DWP tasks in diverse business domains and helped us develop the DWP-M model.

We used the *consensus decision-making* mode to evaluate the evolving model. Such types of techniques are very useful after brainstorming with multiple experts [36]. Consensus decision making attempts to find the best solution to a problem by letting the group weigh in the advantages and disadvantages of each alternative solution. We accomplished this by collecting the panelists' judgments and votes on different process areas in the DWP-M model at the end of each workshop. We also subsequently sent e-mails to the panel members to solicit their detailed opinions on various topics.

Last, we used the *concept-sorting* mode [36] to flesh out the key process areas and the corresponding activities for each maturity level. This mode of knowledge acquisition is useful once the maturity model is outlined and the main key process areas have been identified.

4.4 Evolution of the DWP-M Model

Designing the DWP-M model involved *searching* a large space of possible solutions. We describe below the method we used to make the search process manageable. The initial model that we had designed went through several rounds of changes and evolution based on feedback from industry experts.

We presented the initial version of the DWP-M model to the industry group at the first brainstorming session in a workshop held in June 2003. We had asked the participants about the key outcomes of a mature data warehousing process. We present below a summary of their consensual views on the key outcomes, along with their rationale:

1. *Predictability of data warehouse project duration*. One of the main reasons of data warehouse failures is that the project durations are not met. Data warehouse projects tend to be very expensive [30]. A mature DWP would help to develop an ability within the organization to create/deliver projects with predictable durations.
2. *Ability to perform better data analysis.* The major objective of a data warehouse is to provide high-quality data with a "single version of the truth" so that extensive analytics can be performed. A mature DWP would enable and facilitate better data analysis.
3. *Good documentation.* Data warehouse projects and operations involve many tools and people, as well as heterogeneous data sets. Coordination and intergroup communication are vital for these kinds of projects. A mature DWP provides a good set of documentation at every step, which is vital for the success of the project.
4. *Trust in the data.* Companies cannot survive with bad data in today's environment. With a variety of source systems and reporting/analysis tools, it is absolutely necessary to have trust in the quality of data. DWP maturity would force the organization to develop good data quality and data governance strategies so that the users and sponsors have trust in the data and the reports.
5. *Satisfied user base.* A mature DWP will satisfy the user base with high data quality and foster user trust.
6. *Verifiable ROI.* One of the biggest problems for the data warehousing group within an organization is to get funding for data warehouse projects. A mature DWP will make the job of getting funding easier because upper management will have a higher level of confidence in the data warehouse team's ability to deliver value.
7. *Ability to see process improvement.* The software industry has made great strides in using the CMM over the last two decades. From just a couple of firms at CMM maturity level 5 (the highest of the five levels) only two decades ago, there are now over a hundred organizations at that level [56]. The success of these firms has been attributed to the fact that they have adhered to sound software engineering principles and practices. Compared to the general field of software engineering, data warehousing is a relatively new discipline. To better understand the problems afflicting DW implementations, the DW community needs to try to focus on data warehousing as a process, similar to what the software engineering field has done. Such an endeavor would go a long way in helping organizations to better address DW problems and overcome failures.

More brainstorming sessions with the group were undertaken in a February 2004 workshop using the initial model. The group session lasted for over two and a half hours. The objective of this workshop was to allow the group to identify as many relevant KPAs as they believed were necessary using the initial version of the model as a starting point.

A *first version* (version 1.0) of a 5-level DWP maturity model focusing on the development process was developed in May 2004. This version was presented to the group of around 20 experts in data warehousing at a workshop held in June 2004. Once again, the group session lasted for over two and a half hours. As with the earlier workshops, brainstorming was the principal technique in the beginning phase of the group session. The objective in this workshop was to not only evaluate the comprehensiveness of the DWP maturity model in terms of KPAs, but also to get a sense of appropriateness in assignment of these KPAs to the maturity levels. A number of suggestions emerged for (re)assignment of the KPAs.

We developed descriptions for each level of maturity and a tentative list of 29 KPAs (vis-à-vis 19 KPAs in CMM) for levels 2 through to 5, along with activities to be performed within each KPA as shown in Table 2. This resulted in a total of 157 activities covering the 29 KPAs—43 activities covering 10 KPAs at Level 2; 51 activities supporting 10 KPAs at Level 3; 27 activities covering 4 KPAs at Level 4; and 36 activities covering 5 KPAs at Level 5.

TABLE 2
Data Warehousing Maturity Levels and KPAs (FIRST Version-June 2004)

Levels	KPAs
L-5: *Optimizing* - Analyzes the defects to understand the causes and evaluates the process to prevent the known type of defects. Continuous improvement is also done.	1. Data change management 2. Metadata change management 3. Technology change management 4. Defect prevention 5. DWP change management
L-4: *Managed* - Quantitative and statistical techniques are used to manage process performance and product quality. Focus on developing organization-wide process database to collect and analyze the process data.	1. Issue tracking 2. Data quality management 3. Quantitative process management 4. Metadata quality management
L-3: *Defined* - Project management is based on a defined process. Focus on process.	1. Metadata management 2. Data governance 3. Recovery management 4. Stakeholder management process 5. Integrated infrastructure management 6. Intergroup coordination 7. DW product engineering 8. Alignment of architecture 9. Peer review 10. Information delivery management
L-2: *Repeatable* - Documented and realistic plans are the basis for managing project. Project Management is in place.	1. DW project planning 2. Business justification 3. DW staffing 4. DW sponsor assurance 5. Scope design 6. Project tracking 7. Requirements management 8. Data quality assurance 9. Training program 10. Subcontract management
L-1: *Initial* - Project management done, but it is as good as the project manager.	

We sent a *second version* of the DWP maturity model (version 1.0.1) to each of the participants during July and August 2004 via e-mail with a request to take a detailed look and provide their feedback. Eighty percent of the original participants responded with comments/critiques on version 1.0.1.

At the end of these major sessions, we found that there were still quite a few conflicting ideas in terms of the KPAs, particularly in "where" and "how" to assign those KPAs. After another round of revisions, we developed a *third version* of the model (version 1.1). While moving to version 1.1, we developed several new insights. First, our DWP-M model actually follows the "level" concept espoused by other maturity models (see Section 3). Second, our assumption that DWP is a process that is quite different from software engineering, IT services, and other processes got validated. Third, as expected, we found that some tasks at each of the DWP-M levels share similarities with tasks in other maturity models.

4.5 Design Evaluation

As noted earlier, one of the guidelines of design-science research is that the designed artifact should be evaluated and that the evaluation should provide the feedback needed to refine the artifact being developed [20].

In the evaluation phase, it was necessary to verify whether the DWP-M model (version 1.1) that we had developed was really comprehensive enough, represented the "right" KPAs and associated activities, and could form a basis for progress within firms adopting this model for more consistent, repeatable, and better development and management of DW projects.

One of the researchers made site visits during the fall of 2004 to four of the 13 companies that had participated in the workshops for individual face-to-face meetings. Two of them were from engineering, one from retail, and one from service industry sectors. These firms were chosen to get a reasonable representative sample of DWP efforts, which ranged from two years to more than five years. During a typical visit, the researcher met with three to four members of the company for one-on-one interviews, each lasting for 2 to 3 hours.

We made significant modifications and refinements to the model based on the suggestions of the interviewees. This was the first time that the participants were evaluating the entire model instead of brainstorming the model specifics. Many interesting observations were made, starting from simple evaluations to in-depth remarks. Simple evaluations included critically studying the DWP tasks at each level and their eventual positioning in one of the maturity levels. The in-depth remarks were directed more toward a major change in the philosophy and anchoring of the model building process. For example, participant *mgr-1* in *eng1* company (names of the companies and the executives are suppressed to protect their identities) suggested, "...we will address these levels...how do you check these levels? ...they seem kind of little different from the project side versus the operations side..." Another participant, *mgr-2,* also in *eng1* company, supported this delineation of project and production as "we may be...in the project side...in level 5, but in the production side we may be in chaos." Similar thoughts were also echoed by others participating in the interview process. In essence, seeds were being sowed for a radical departure for the model to include "DW operations" in addition to the processes emphasizing "DW development."

We had initially focused on the DW development process. Similar to CMM, version 1.1 of our DWP-M model captured only the development aspects. Although we had suspected that DWP might need to go beyond mere DW development, we had not specifically considered these aspects in the design of our DWP-M model. However, during the on-site interviews, it started unfolding that, compared to traditional software development, data warehouses require much more continued postdevelopment support in the form of DW operations and customer service. Furthermore, a DW environment involves multiple stakeholder groups at all times.

Recognizing the need for significant changes to the model with respect to customer support and services, we reviewed in greater detail the theory in services and relationship marketing [47]—as well as its application in the general IS literature [26], [27], [51]—and in IT services [42], [43], [65], [66]. Drawing upon ideas from those studies and incorporating the feedback we received during the on-site interviews, we developed a *fourth version* of the DWP-M model (version 1.2). For instance, a number of aspects of the ITIL framework are covered by the operations/service KPAs of our DWP-M model (see Fig. 2 later). For example, KPA 2.10 accommodates ITIL's service support aspects 1a, 1b, and 1c; KPA 3.18 covers ITIL's 1e and 1f; KPA 4.5 covers ITIL's service delivery aspects 2a; KPA 3.16 covers ITIL's 2b; KPA 3.4 covers ITIL's 2c, 2d, and security management; KPA 4.6 covers ITIL's 2e; KPA 3.7 covers ITIL's ICT infrastructure management; and KPA 3.17 covers ITIL's software asset management.

The DWP-M model, however, is substantially different from ITIL. First, its focus is on both development and service, unlike ITIL, which focuses primarily on service activities. Second, our model places heavy emphasis on continuous improvement, including "prevention" (in maturity level 5), while some research suggests that ITIL needs to be complemented by six-sigma techniques to bring an engineering orientation and lean techniques to promote continuous improvement [72]. Third, the focus of our model is exclusively on the data warehousing process, rather than on IT governance in general. Finally, unlike our DWP-M model, which requires a clear progression through the five maturity levels and associated practices, ITIL can be implemented on an as-needed basis, focusing on those parts of the IT service delivery and management processes that are broken [46].

In the new version of the model, the number of KPAs increased from 29 to 40, and the total number of activities covering those KPAs increased from 157 to 221, focusing on both development and operations/customer service aspects. More than the increase in the number of KPAs and activities, the scope of the model expanded to include DW operations and services. There were a number of KPAs that were common across these two aspects. At this point in time, it was also necessary to identify and decide which category of stakeholders would need to interact with the DW teams in the real world in light of the different emphases—development and operations/support services.

A fourth workshop was organized in March 2005. Invitations were extended to the same companies that had participated in the three earlier workshops. This was the first time that the entire group of participants would see a very different model with two different emphases and a number of new KPAs.

Based on their comments and critiques, a *fifth version* (version 1.5) was developed and presented to the panel of DW experts via e-mail in the summer of 2005. The participants were asked to propose, discuss, and arrive at a consensual assignment of each KPA to DW development staff and/or DW Operations Staff, and identify their connections with the Business Users.

About 60 percent of the participants responded with comments and critiques on version 1.5 of the model. After a major cleanup, we created a sixth version (version 2.0) and organized a fifth workshop in September 2005. Eight of the original 13 companies and 12 experts from these companies participated this time. The group session, as before, lasted for about two and a half hours. The participants again engaged in brainstorming to generate additional KPAs/activities and ideas with respect to KPA assignment.

Based on the feedback, we revised the model. A *seventh version* (version 2.1) was e-mailed to the participants. We received individual feedback from a subset of the participants this time. We created another revised DWP-M Model (*version 3.0*) and sent out invitations for a sixth workshop in March 2006. Nine companies and 10 experts from these companies participated. Version 3.0 of the DWP-M Model was presented to the group of experts with a request to examine each maturity level and the assigned KPAs (and their associated activities) in detail one more time. At the end of this session, the group appeared to have reached closure. While assigning the KPAs to different maturity levels, the workshop participants also identified the dependencies among them. We describe those relationships below.

4.5.1 Relationships among Process Areas

In this section, we describe how we developed and captured the relationships among process areas. The relationships depict the interactions and help us understand how a KPA builds on other KPAs. As in CMMI, an interaction in our model shows the flow of information and artifacts from one KPA to another, and the prerequisite KPAs that need to be satisfied before a KPA can be implemented successfully.

We acquired the knowledge of interactions among KPAs from the panel of experts through various channels, including brainstorming sessions, teleconferences, and e-mail discussions. The panel helped us develop the relationships in multiple steps and over multiple sessions. First, we developed the relationships among KPAs for levels 2 and 3, then the relationship for levels 4 and 5, and finally the relationships between KPAs across different maturity levels. Based on the inputs from the expert panel, we developed the relationships between KPAs. At each subsequent workshop/teleconference/e-mail session, the experts evaluated the existing set of interactions and provided feedback to modify and extend the model.

In Fig. 1a, we show the interdependencies among KPAs at Level 2 of the DWP-M model. The information relationships (shown as solid arrows) are annotated with the documents and data that flow between the KPAs. The activities of these KPAs are performed to create a compelling business case to scope out and plan for a DW project. *DW sponsor assurance* (KPA 2.1) targets potential sponsors to generate awareness and interest in DW. Based on assurances from the sponsors, plans for performing DW tasks and managing the DW process are established (KPA 2.2: *DW program planning*). Senior management sponsorships for DW projects are obtained and guidelines for scope, time, and budget are established. Based on these inputs, the *Business justification* KPA (2.4) identifies the goals and objectives for DW projects and develops a business case, which includes benefit, cost, and time estimates. The business justification is then used to garner and sustain interest in DW within the organization.

Fig. 1b shows several information and prerequisite relationships (shown used dashed arrows) among some KPAs at Levels 3 and 4. These KPAs include activities for data warehouse governance and service level assurance. The *DW governance* KPA (KPA 3.14) outlines the decision rights and underlying processes to ensure consistent enforcement of the accountability framework. As the governance structure needs to be communicated to different organizational units, a list of stakeholders should be available from the *Stakeholder management process* KPA (KPA 3.5), along with communication plans developed by the *Intergroup coordination* KPA (KPA 3.8). The DW governance KPA is also responsible for enunciating and enforcing the DWP principles created by *DWP definition* KPA (KPA 3.1), as well as enforcing organizational activities described by *Organizational process focus* (KPA 3.2). Using resource plans from *Resource management* (KPA 3.17), the *DW governance* KPA develops and proposes DW investment and modernization plans. To develop service commitments in *Service level agreement* (KPA 3.13), one has to know the governance structure and recovery plan (*Recovery management*—KPA 3.4) so that it is clear whom to call in case of emergencies.

Fig. 1b also shows the KPAs at Level 3 that need to be satisfied before a couple of KPAs at Level 4 can be implemented. For example, *Quantitative process management* (KPA 4.2) has to ensure that measurement data are collected as per the procedures identified in the quality plans for KPAs 3.13 and 3.15. Similarly, the measuring domains established by the SLA in KPA 3.13 must be adhered to before *Service level management* (KPA 4.5) can be implemented.

After all the KPAs and their relationships were identified, the research team sent the refined maturity model (*Version 3.1*) to the participants to get their final confirmation of the accuracy and fidelity of the captured knowledge. Feedback from the participants indicated that theoretical saturation had been reached; this latest version was agreed upon as the final version of the DWP-M model. The final version of the model consists of a total of 41 KPAs and 219 activities with 11 KPAs and 47 activities in Level 2; 19 KPAs and 104 activities in Level 3; 6 KPAs and 35 activities in Level 4; and 5 KPAs and 33 activities in Level 5. The final DWP-M model (*Version 3.2*) is shown in Table 3 and Fig. 2. The details of these KPAs and their assignment to each level and across the two aspects—DW development and DW operations/customer service and support—and illustrations of a few KPAs and their associated activities are provided in the Appendix, which can be found in the Computer Society Digital Library at http://doi.ieeecomputersociety.org/10.1109/TSE.2011.2.

4.5.2 Validation of the Final DWP-M Model

Evaluation consists of both verification and validation. We have already described the verification process, which entailed checking if the model has been developed correctly. Validation, on the other hand, focuses on determining whether the model satisfies the users' needs.

The International Organization for Standardization (ISO) has developed a set of HCI standards, which include those for usability and product quality. Usability is defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (ISO 9241-11). The term "quality in use" is also used to cover this broader objective of usability. It measures the degree of excellence, and can be used to validate the extent to which a product meets the needs of the users [3]. Its components include functionality (effectiveness), productivity (efficiency), and usability (satisfaction).

Functionality is assessed based on measures such as accuracy, completeness, and suitability. Productivity is determined based on the time, mental effort (ease of use), and resources needed to complete a representative task using the product. Usability is defined in terms of understandability, learnability, operability, and attractiveness.

Based on the ISO standards, we developed an instrument—which includes metrics for functionality, usability, and productivity—for validating the "quality in use" of the

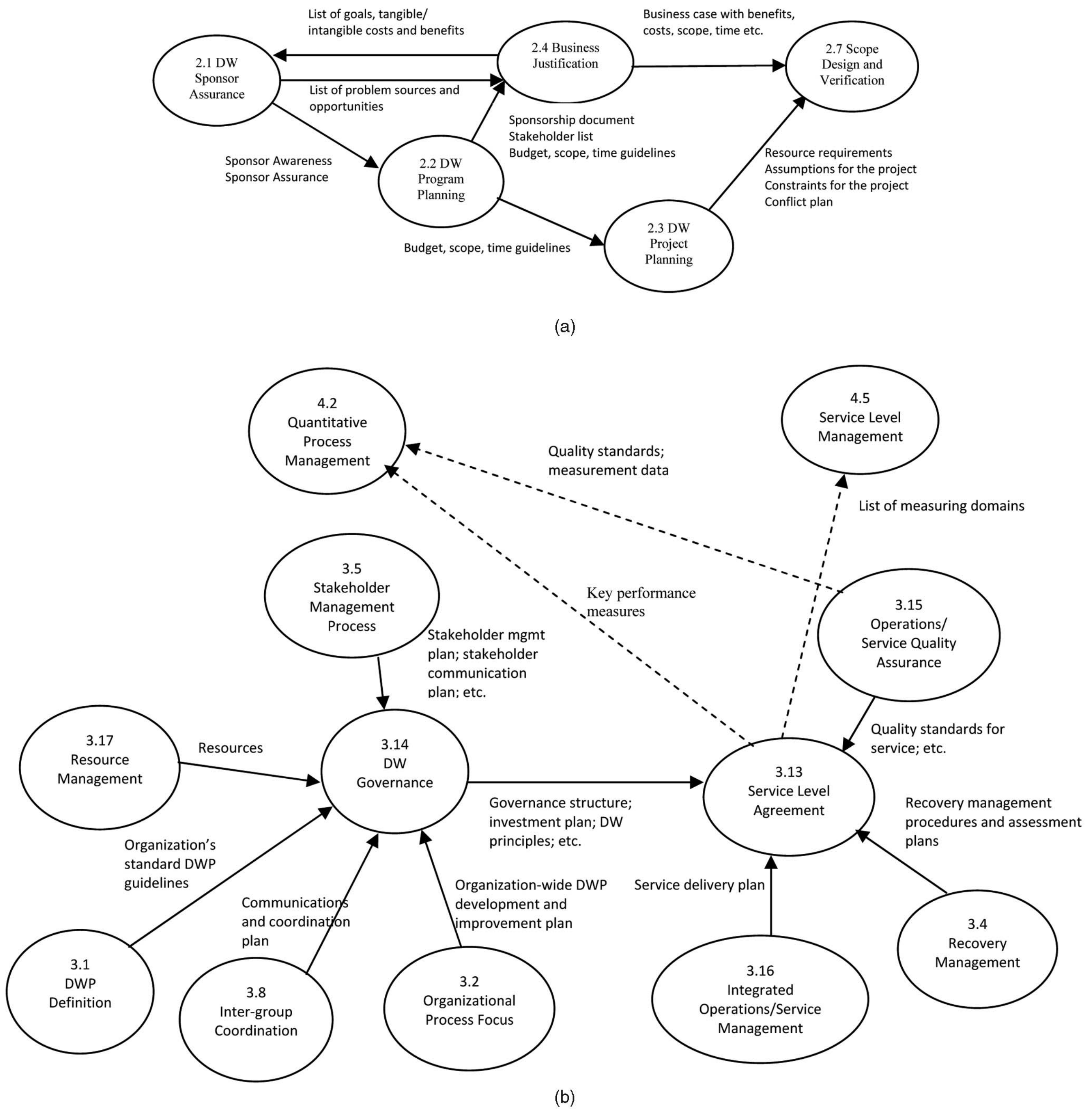

Fig. 1. Relationships among KPAs in DWP maturity model (partial): (a) Relationships in level 2. (b) Relationships in levels 3 and 4.

DWP-M model. The instrument consists of 25 statements, including those for assessing functionality/effectiveness, such as:

- The KPAs in Level X have been correctly assigned.
- The DWP-M model consists of the KPAs needed to correctly define DW process maturity.
- The KPAs in the DWP-M model are effective in determining DW process maturity.
- Overall, the DWP-M model is effective at communicating the activities that my organization needs to perform in key areas to achieve higher levels of process maturity.

and also several statements for assessing productivity and usability of the model, based on metrics for ease of use, satisfaction, and understandability, such as:

- It takes a lot of mental effort to assess if my organization satisfies a KPA in the DWP-M model.
- The description of the KPAs in Level X is not easy to understand.
- The rationale for assigning the KPAs to their corresponding levels is not difficult to understand.
- Overall, I am satisfied with the DWP-M model.

We sought the services of three separate data warehousing experts for validating the final model. The first

TABLE 3
FINAL Version of Data Warehousing Maturity Levels and KPAs (Distinguishing Development and Operations)

Levels	KPAs for "Development"	KPAs for "Operations/Services"
Optimizing	Analyzes the defects to understand their causes and evaluates the process to prevent the known type of defects. Continuous improvement is also done. KPAs are: 5.1 Metadata change management 5.2 DW technology change management 5.3 Defect prevention 5.4 DWP improvement program	Analyzes the defects to understand their causes and evaluates the process to prevent the known type of defects. Continuous improvement is also done. KPAs are: 5.1 Metadata change management 5.2 DW technology change management 5.3 Defect prevention 5.4 DWP improvement program 5.5 Data governance
Managed	Quantitative and statistical techniques are used to manage process performance and quality of DW products under development. Focus on developing organization-wide process database to collect and analyze the process data. KPAs are: 4.1 Data quality management 4.2 Quantitative process management 4.3 Integrated metadata quality management 4.4 Data change management 4.5 Service level management	Quantitative and statistical techniques are used to manage process performance and quality of DW product in operation/service. Focus on developing organization-wide process database to collect and analyze the process data. KPAs are: 4.1 Data quality management 4.2 Quantitative process management 4.3 Integrated metadata quality management 4.5 Service level management 4.6 Financial services management
Defined	Project management is based on a defined process. Focus on process. KPAs are: 3.1 DWP definition 3.2 Organization process focus 3.3. Business metadata management 3.5 Stakeholder management process 3.6 Alignment of architecture 3.7 Integrated infrastructure management 3.8 Inter-group coordination 3.9 Data quality assurance 3.10 DW product engineering 3.11 Peer review 3.13 Service level agreement 3.17 Resource management 3.18 Configuration management 3.19 Training program	DW operations/service management is based on a defined process. Focus on process. KPAs are: 3.1 DWP definition 3.2 Organization process focus 3.3 Business metadata management 3.4 Recovery management 3.5 Stakeholder management process 3.8 Inter-group coordination 3.9 Data quality assurance 3.12 Information delivery management 3.13 Service level agreement 3.14 DW governance 3.15 Operations/service quality assurance 3.16 Integrated operations/service mgmt. 3.17 Resource management 3.18 Configuration management 3.19 Training program
Repeatable	Documented and realistic plans are the basis for managing project. Project Management is in place. KPAs are: 2.1 DW sponsor assurance 2.2 DW program planning 2.3 DW project planning 2.4 Business justification 2.5 DW staffing 2.6 Requirements management 2.7 Scope design and verification 2.8 Project tracking 2.9 Subcontract management 2.10 Issue tracking 2.11 Standards setting	Documented and realistic policies and procedures are the basis for managing operations. DW operations/service management is in place. KPAs are: 2.1 DW sponsor assurance 2.5 DW staffing 2.9 Subcontract management 2.10 Issue tracking 2.11 Standards setting
Initial	1.0 Project management done, but it is as good as the development project manager	1.0 DW operations/service management done, but it is as good as the operations/service manager

Legend: Underlined KPAs are common to both DW development and DW operations/Customer service process aspects

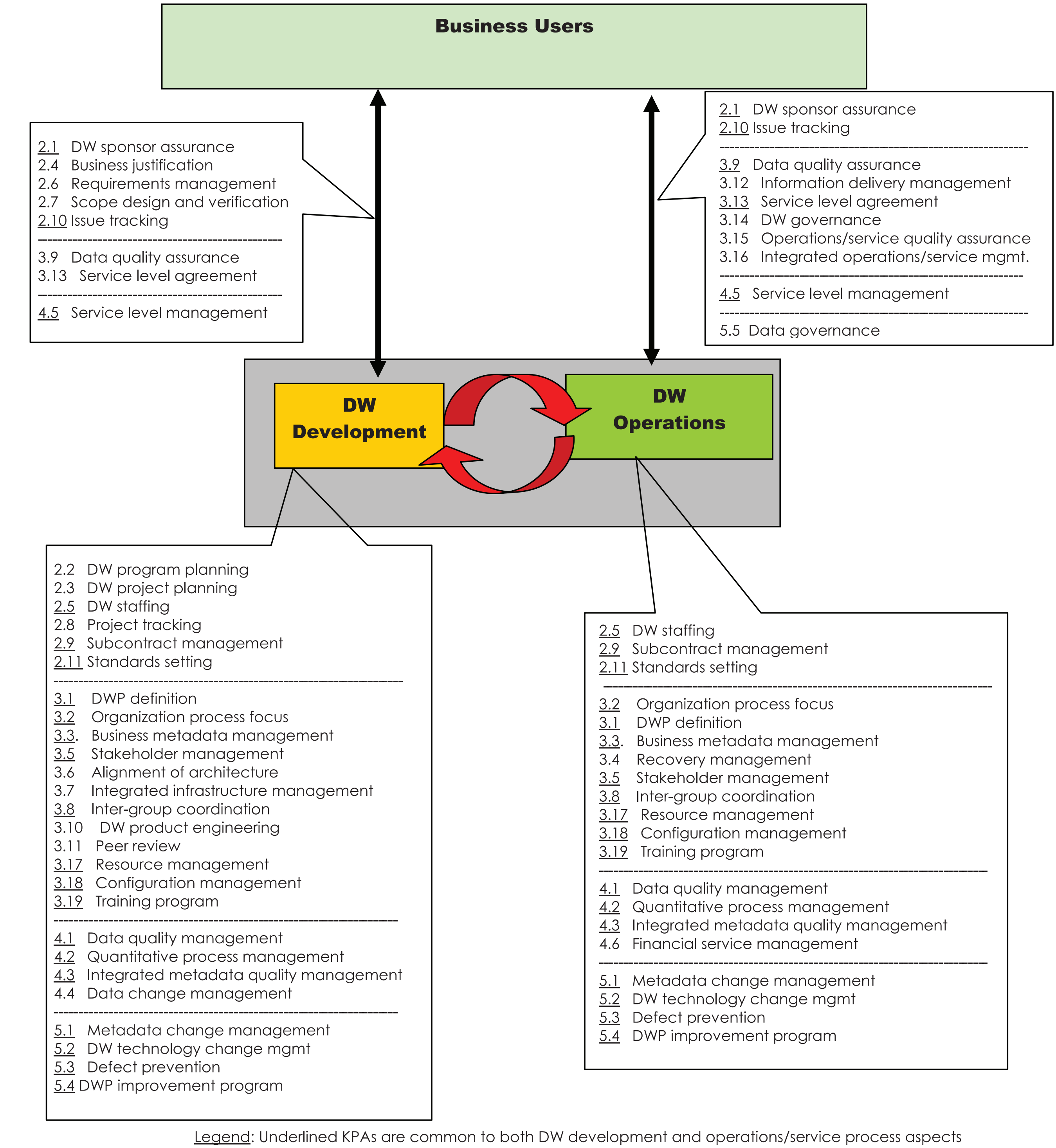

Fig. 2. Data warehousing process maturity model and KPAs (FINAL version).

expert, a Director of Data Warehousing at one of the largest web-based travel companies, was also one of the key persons involved during the knowledge acquisition phase of model development. The two other experts were not involved in the model development at all. Because they had not seen the model before, their assessments can be considered to be totally unbiased. One of them is a BI Analyst at a major US-based manufacturing firm and the other is Director of BI & Data Warehousing at one of the largest healthcare companies in the US.

All three experts were provided with detailed documentation of the DWP-M model. The experts were asked to respond to each of the 25 statements on a 5-point Likert scale, with 1 being "strongly disagree" and 5 being "strongly agree." To guard against mechanistic responses, several questions were framed in the negative (e.g., *The DWP-M model is not helpful in assessing my organization's DW process maturity*). We determined the interrater reliability among the three raters using the intraclass correlation coefficient [37] using SPSS. The average measure for the intraclass correlation coefficient for the subjective scores assigned by the three raters is 0.901, which is significant at the $p < 0.000$ level. The coefficient is higher than the normal threshold of 0.80, indicating that there is a high degree of reliability between the scores assigned by the three experts.

We followed the practice of past assessment studies which employed an overall measure of usability. For example, Brooke [5] developed the System Usability Scale (SUS), which provides a global view of subjective usability assessments. SUS computes a composite measure representing overall usability by summing the scores on each item.

We developed our instrument in a similar fashion, but instead of using a 10-item questionnaire, we made it more comprehensive by including 25 items. We determined the overall "quality in use" of the DWP-M model, which is a composite score based on the individual items. The overall score is computed by summing the scores across all the 25 items, with each item contributing between 0 and 4 (for a positive item, the contribution toward the overall score is the item score minus 1, and for a negatively phrased item, the contribution is 5 minus the item score). The overall quality in use score therefore ranges from 0 to 100. Based on the responses of the three experts, the overall quality in use scores for the DWP-M model are 73, 75, and 74. These scores are quite high when one considers the fact that human respondents are typically averse to rating any product at extreme ends of a scale. The average quality in use score is 74, providing strong evidence of the external validity of our model—in the eyes of DW experts—with respect to functionality, productivity, and usability.

We also asked the experts to provide their estimates of the time it would take their organizations to transition to the next higher level of maturity (as described in the DWP-M model). The first two experts indicated it would take two years, while the third expert indicated it would take one year. The interesting thing to note is that both of the first two experts rated the current DWP maturity of their organizations at Level 2, while the third expert rated his at Level 1. The longer time frame estimates of experts 1 and 2 could be because it takes more time to ascend up the maturity ladder at higher levels.

Finally, we asked two questions to solicit the experts' responses on whether achieving higher levels of DWP maturity would help their organizations: 1) implement DW projects more consistently with respect to time, cost, and quality targets and 2) reduce the overall cost of providing correct information and DW services over the long term. All three experts were in almost unanimous agreement and rated the statements very high (4.67 on a 1-5 scale), implying strongly that higher maturity levels would result in significant cost savings.

5 Discussion

In this paper, we have described the development of a design artifact—the DWP-M model. A data warehousing process revolves around data. The DWP-M model reflects this emphasis by focusing on activities geared toward data extraction, data transformation, data loading, data analysis, data change management, metadata management, data quality assurance, data warehouse governance, etc.

In instances where KPAs overlap between DWP-M and CMM/CMMI, there could be a KPA in CMM that is not assigned to the same level in DWP-M. For example, the configuration management KPA, which is at level 2 in CMM, is at level 3 in the DWP-M model. It is important to note that the objective of configuration management in data warehousing is different from that in software development. In software development, the process involves, among other things, products like use cases, object classes, messages, operations, packages, components, etc., which are closely linked to one another. On the other hand, a DW process involves diverse products, such as ETL scripts, operational data, historical data, operational metadata, ETL metadata, end-user metadata, ETL scripts, OLAP cubes, etc., which need to be configured. These DW products belong to development and/or operations, and are used differently in many subprojects with their own lifecycles. These subprojects are usually staffed by different teams that can be dispersed in different parts of the world. For example, one of the experts in the panel belongs to a company where ETL projects are done offshore, while reporting services projects are done in the US. Configuration management in DWP integrates multiple heterogeneous components and projects across different sites, and is quite different from and more advanced than configuring software.

Note, however, that some activities of the configuration management KPA in CMM are indirectly supported by level 2 KPAs in DWP-M, such as DW program planning, scope design and verification, and issue tracking. It is also important to note that the interdependencies among KPAs (see Fig. 1) helped us to group them and assign them to appropriate DWP maturity levels. For instance, configuration management, along with integrated infrastructure management (KPA 3.7) and DW product engineering (KPA 3.10), interacts with alignment of architecture (KPA 3.6), necessitating that it reside in level 3. In contrast, the KPAs at level 2 are more fundamental than configuration management, focusing on activities such as sponsor assurance, program planning, project planning, requirements management, scope design, etc.

Another example of a disparity between level assignments in CMM and DWP-M is the assignment of the data change management KPA to level 4 in DWP-M. This is in contrast to CMM, where change management KPAs are usually assigned to level 5. The metadata change management KPA is assigned to level 5, adhering to the convention of placing metadata one level higher than data, and metamodels one level higher than models in the OMG Meta Data Architecture [52].

The DWP-M model development process went through several rounds of rigorous knowledge acquisition and evaluation sessions. The iterations allowed us to obtain critical feedback from the industry experts during the evaluation to extend and refine the construction of the design artifacts. We rigorously verified each version of the model using multiple approaches (see Section 4.5). We complemented the on-site visits with group processes involving multiple industry experts from different organizations. In essence, individual site visits (and the multiple detailed interviews that were individually conducted on-site) were interspersed with group-based processes involving industry experts at several workshops, organized especially to capture group dynamics and collective learning. Such an approach served as a very powerful mechanism for evaluation of the intellectual capital underlying the final DWP-M model.

Drawing upon ISO standards relating to functionality, productivity and usability, we also had the DWP-M model validated by DW experts. These validation results provide strong support for the "quality in use" of our model, in terms of functionality, productivity, and usability. Another important finding is the consensus among the experts that higher levels of DWP maturity would help an organization in implementing its DW projects more consistently based on time, cost, and quality targets, and would also help it reduce the overall cost of providing services.

Our work should be viewed as an initial attempt to develop a *design theory* [18], [68] for a data warehousing process. We have defined in detail the constructs needed to represent the entities of interest in the DW domain and composed the maturity artifact based on those constructs. We clearly specified the model's purpose and scope, or its metarequirements. Our initial design theory provides an architecture, albeit partial, in terms of maturity levels and KPAs. It lays the groundwork for future implementation as a full-scale DWP maturity assessment system.

6 Conclusion and Future Directions

The main contribution of this study is in the development of an innovative artifact—the DWP-M model—which addresses the pressing issues associated with a DWP. The model defines several KPAs and activities, which would enable a firm to examine its DWP, identify the problems, and help it to attain a higher level of maturity by addressing those problems. These KPAs and activities are also design artifacts, more specifically the constructs or representations of interest in the DWP maturity domain. The DWP-M model also captures the relationships among process areas, depicting the interactions among the KPAs in terms of information flow and prerequisite KPAs.

The DWP-M model addresses several important and relevant problems that organizations face in their DW initiatives, including those related to data quality, data changes, metadata management, data warehouse governance, trust, and end-user satisfaction. The model has a total of 41 KPAs, several of which are unique to a data warehousing process. For example, it includes KPAs such as DWP definition, business metadata management, DW product engineering, information delivery management, DW governance, integrated metadata quality management, data change management, metadata change management, DW technology change management, etc., that are germane to DW process maturity but that fall outside the scope of traditional software process maturity assessment.

We proposed that an immature DWP could be a major reason behind the failure of so many DW initiatives. By providing consistent, high quality, and "single-version of the truth" data in a timely manner to business managers and executives, a mature DWP could mitigate large-scale failures. But because of its nascent stage, the concept of DWP maturity has hardly been addressed.

A mature DWP promotes the ability to effectively and efficiently manage data warehouse development and its operations. It accurately communicates the DWP steps so that development, operations, and service personnel can carry out activities in conformity with a planned process. In a mature setting, DWP steps are systematically enforced and documented, and there is scope for continuous improvement. There is organization-wide involvement and managers are able to monitor and predict the quality of DW products and the processes that produce them on an objective basis. The comprehensive DWP-M model we have presented in this paper would help organizations effectively address the problems they face with respect to immature DW processes.

DW compatibility and complexity can influence the implementation and diffusion, or spread of use, of data warehousing within an organization [53]. Technical incompatibilities with respect to standards, data modeling, data staging, and platforms can negatively influence DW implementation and diffusion. Deploying a data warehouse in the workplace may not only change the operational processes and individual work roles, but it may also require major rewrites or reprogramming of existing systems, thereby increasing the complexity manifold. To address issues related to DW compatibility and complexity, we included two KPAs: data warehouse governance and data governance. The data warehouse governance KPA is unique in that it sets up an organizational structure that outlines decision rights and underlying processes to ensure consistent enforcement of accountability. The data governance KPA develops and enforces a plan of interaction with the end-user community and DW project workers—focusing on issues such as data quality, data availability, data accessibility—to understand and address their concerns.

The DWP-M model can be employed to assess the maturity of a firm's data warehousing process. Using the model, a firm can identify the strengths and weaknesses of its DWP, based on the extent to which it satisfies a set of core KPAs. The model would also provide useful guidelines to firms interested in transitioning to higher maturity levels.

Systematic use of the DWP-M model will help a firm measure its ability, commitment, goals, and roadblocks with respect to its performance on the KPAs. We envision the following streams of research emerging out of our maturity model. Following the software process maturity paradigm [29], the first stream of research would focus on organizational attempts at characterizing DW practices by empirically examining the consensual benefits attributed to a mature DWP. For instance, it is important that the maturity model be used to systematically measure a company's *ability*, *commitment*, *goals*, and *roadblocks* for evaluating its performance on the KPAs and for developing benchmarks to transition to higher levels of maturity. In this research stream, the basic premise is that consistent application of well-defined and measured DW processes, coupled with continuous process improvement, will streamline DW project management and substantially improve the productivity and data quality of data warehouses. Such an endeavor would necessitate the development of a *DWP Assessment Instrument* consisting of detailed metrics and a process for calibrating and assessing DWP maturity of DW units within firms.

A second stream of research could focus on the elements of the DWP-M model itself. Based on the evaluation results, the model appears to be comprehensive and complete. But it is unclear if all the KPAs and their activities are of equal value with respect to DWP maturity assessment. There is also a need to know if all the activities within each KPA are quantifiable and measurable. It would be also interesting to conduct field studies (in the form of surveys) that relate a number of organizational (e.g., size, system architecture, structural attributes, resources, management attitude, and culture) and environmental (e.g., industry maturity, institutional and competitive forces, industry and technology support structures) determinants of efforts that firms exert in pursuing initiatives to upgrade their DWP maturity levels.

Finally, the *case study* approach could be used to investigate the results of applying the DWP-M model in a real-world organizational setting. Yin [75] defines the scope of a case study as an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and context are not clearly evident. This is pertinent to this study because an important future direction would be to employ our model to assess DWP maturity in different organizational settings and, based on those assessments, test a set of hypotheses relating to the consequents of maturity.

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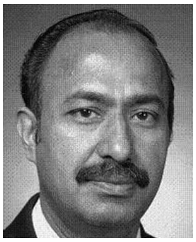

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