Evaluation of Data Quality Assessment

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Abstract. The paper provides an evaluation of fives modern data quality (DQ) assessment methods. Due to the diversity and complexity of these assessment methods, fundamentals regarding data quality and classification for assessment method are first presented. With the extension of DQ fundamentals, the paper then reviews five data quality assessment methods and evaluates them in terms of their capability of targeted data types, steps, phases, strategies, techniques, targeted data quality dimensions and cost. The goal of this article is to propose a practical methods in combination of existing methods for data quality assessment in the context of continuous integration (CI) and continuous delivery (CD) application in the field of software engineering. The paper concludes with a suitable method proposal based on the evaluation result and discusses future work and challenges.

1 Introduction

With the Machine Learning, Deep Learning and Artificial Intelligence on the rise, the demand of data analysis has never been higher. Both academy and industry sectors are eager to explore more opportunity by employing these techniques. However, another issue quickly arises: How does one acquire high-quality data? Or, more preciosity, how to defines the quality of a set of data? There is a famous saying in the field Machine Learning: "Garbage input equals garbage output!". That is, only with systematic method to assess data set, are ML application feasible for different domain. Traditionally, data labeling and assessment are done in either primitive or laborious manner, which becomes almost impossible in the big data era. The goal of this paper is to give an overview of methods to assess data quality and review the most popular data properties that can be analyzed. Moreover, this paper reviews several proposed data quality improvement methods after data quality is assessed. The application of the assessment methods are also presented.

The rest of the paper is structured as follows: Data Quality Fundamentals, Literature Review, Evaluation and Conclusion. For the first section, the overview of data quality and classification of assessment methods are presented, which includes data type, data problem, phases and steps, strategies and techniques, dimensions and cost. In second section, literature review of five data quality assessment method, phases and concepts are introduced in brief. In the third part,

evaluation on these five methods is performed in terms of data quality fundamental attributes of previous section . In the end of paper, a conclusion is made based on evaluation result in the context of CI/CD application in software engineering. The proposed method, future work and challenges are discussed in brief. This paper is requested and written under the subtopic of seminar, Advanced Software Engineering:Non-Functional Aspects in Software Engineering.

Main references are base on following paper and journal: Cai and Zhu [2], Pipino and Wang [5] and Carlo [3] Wang and Strong [6] Borek et al. [1] Cinzia Cappiello [4]

2   Data Quality Fundamentals

In this section, fundamentals of data and classifications of assessment methods are introduced. First, in data fundamentals, concepts ans definition of the data type, data quality problem and data quality dimensions are presented. Secondly, in classifications assessment methods, the paper discussed the most common process, pipelines for analysing DQ are introduced. This topics regarding these methodologies includes steps and phases, strategies and techniques, dimensions, costs.

2.1   Data Types

The ultimate goal of a DQ methodology is the analysis of data. The real world objects need to be created in a format that could further be stored, retrieved and processed by software programs. In the field of data and computer science, data are either implicitly or explicitly distinguished by three types:

- Structured data, is aggregations or generalizations of items described by elementary attributes defined within a domain. Domains represent the range of values that can be assigned to attributes and usually correspond to elementary data types of programming languages, such as numeric values or text strings. Relational tables and statistical data represent the most common type of structured data.

- Unstructured data, is a generic sequence of symbols, typically coded in natural language. Typical examples of unstructured data are a questionnaire containing free text answering open questions or the body of an e-mail.

- Semistructured data, is data that have a structure which has some degree of flexibility. Semistructured data are also referred to as schemaless or self-describing. For example, XML, a the markup language commonly used to represent semistructured data, is semistructured.

Data quality techniques become increasingly complex as data lose structure. For example, let us consider a registry describing personal information such as Name, Surname, Region, and StateOfBirth. Figure 1 shows the representation of Mr. Patrick Metzisi, born in the Masai Mara region in Kenya, by using a structured Figure 1(a), unstructured (Figure 1(b)), and semistructured (Figure

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Fig. 1. Data Type.

1(c)) type of data. The same quality dimension will have different metrics according to the type of data. This would be explained in later subsection. The large majority of research contributions in the data quality literature focuses on structured and semistructured data. For this reason, this report focuses on structured and semistructured data.

2.2 Data Quality Problems

The data quality problem could be classified into four categories depending on two factor: context-independence and role perspective. Table 1 provides a brief definition for each DQ problem. In the context independent category, spelling errors, missing data, and incorrect values are self-explanatory DQ problems. Duplicate data problems occur when rows are duplicated or when schemas contain redundancies. Data format problems occur when two or more semantically equivalent data values have different representations, including inconsistent and text formatting. Syntax violation problems occur when a pre-specified format has been assigned to an attribute and a data value for this attribute does not adhere to this format, including incomplete data format. Problems with violations of integrity constraints arise when data values do not adhere to pre-specified database integrity constraints; we also therefore include unique value violations, rather than have these as a separate problem, because unique value violations are one type of database integrity constraint. Note that, despite its position in Table we treat outdated data to be a user perspective problem because whether data is out of date depends on the purpose it is used for.

For the context dependent category, the problem of violation of domain constraints is when an attribute value must be in a pre-specified context-dependent domain of values. Violation of organizational business rules is when any set of values do not adhere to a pre-specified rules assigned by the organization. Violation of company and governmental regulations is when any set of values do not adhere to a prespecified rules assigned imposed on the organization by legislating bodies. Similarly, violation of constraints provided by the database administrator is when any set of values do not adhere to a pre-specified rules assigned by the

database administrator. In 2.5, the problems are define in different dimensions with specific indicators.

	Data Perspective	User Perspective
Context-independent	Spelling error Missing data Duplicate data Incorrect value Inconsistent data format Outdated data Incomplete data format Syntax violation Unique value violation Violation of integrity constraints Text formatting	The information is inaccessible The information is insecure The information is hardly retrievable The information is difficult to aggregate Errors in the information transformation
Context-dependent	Violation of domain constraints Violation of organizationâs business rules Violation of company and government regulations Violation of constraints provided by the database administrator	The information is not based on fact The information is of doubtful credibility The information presents an impartial view The information is irrelevant to the work The information is incomplete The information is compactly represented The information is hard to manipulate The information is hard to understand

Table 1. Types of Data Quality Problem

2.3 Phases and Steps

In the most general case, the sequence of activities of a data quality methodology is composed of three phases: (1) State reconstruction, which is aimed at collecting contextual information on organizational processes and services, data collections and related management procedures, quality issues and corresponding costs; this phase can be skipped if contextual information is available from previous analyses. (2) Assessment, which measures the quality of data collections along relevant quality dimensions; the term measurement is used to address the issue of measuring the value of a set of data quality dimensions. (3) Improvement concerns the selection of the steps, strategies, and techniques for reaching new data quality targets.

Assessment Steps includes: (1) Data Analysis, which examines data schemas and performs interviews to reach a complete understanding of data and related architectural and management rules; (2) DQ Requirements Analysis, which surveys the opinion of data users and administrators to identify quality issues and set new quality targets; (3) Identification of Critical Areas, which selects the most relevant databases and data flows to be assessed quantitatively; (4) Process Modeling, which provides a model of the processes producing or updating

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data; (5) Measurement of Quality, which selects the quality dimensions affected by the quality issues identified in the DQ requirements analysis step and defines corresponding metrics.

Improvement Steps includes: (1) Evaluation of Costs, which estimates the direct and indirect costs of data quality; (2) Assignment of Process responsibilities, which identifies the process owners and defines their responsibilities on data production and management activities; (3) Assignment of Data Responsibilities, which identifies the data owners and defines their data management responsibilities; (4) Identification of the Causes of Errors, which identifies the causes of quality problems; (5) Selection of Strategies and Techniques, which identifies all the data improvement strategies and corresponding techniques, that comply with contextual knowledge, quality objectives, and budget constraints; (6) Design of Data Improvement Solutions; (7) Process Control; (8) Process Redesign; (9) Improvement Management; (10) Improvement Monitoring;

Note that in all the steps of the assessment phase, a relevant role is played by metadata that store complementary information on data for a variety of purposes, including data quality. Metadata often provide the information necessary to understand data and/or evaluate them.

2.4 Strategies and Techniques

Strategies Data-Driven Strategies - (1) acquisition of new data, which improves data by acquiring higher-quality data to replace the values that raise quality problems; - (2) standardization (or normalization), which replaces or complements nonstandard data values with corresponding values that comply with the standard. For example, nicknames are replaced with corresponding names, for example, Bob with Robert, and abbreviations are replaced with corresponding full names, for example, Channel Str. with Channel Street. - (3) Record linkage, which identifies that data representations in two (or multiple) tables that might refer to the same real-world object; - (4) data and schema integration, which define a unified view of the data provided by heterogeneous data sources. Integration has the main purpose of allowing a user to access the data stored by heterogeneous data sources through a unified view of these data. In distributed, cooperative, and P2P information systems (see Section 2.6), data sources are characterized by various kinds of heterogeneities that can be generally classified into (1) technological heterogeneities, (2) schema heterogeneities, and (3) instance-level heterogeneities. Technological heterogeneities are due to the use of products by different vendors, employed at various layers of an information and communication infrastructure. Schema heterogeneities are primarily caused by the use of (1) different data models, as in the case of a source that adopts the relational data model and a different source that adopts the XML data model, and (2) different representations for the same object, such as two relational sources that represent an object as a table and an attribute. Instance-level heterogeneities are caused by different, conflicting data values provided by

distinct sources for the same objects. For instance, this type of heterogeneity can be caused by independent and poorly coordinated processes that feed the different data sources. Data integration must face all the types of these listed heterogeneities. - (5) Source trustworthiness, which selects data sources on the basis of the quality of their data; - (6) error localization and correction, which identify and eliminate data quality errors by detecting the records that do not satisfy a given set of quality rules. These techniques are mainly studied in the statistical domain. Compared to elementary data, aggregate statistical data, such as average, sum, max, and so forth are less sensitive to possibly erroneous probabilistic localization and correction of values. Techniques for error localization and correction have been proposed for inconsistencies, incomplete data, and outliers [Dasu and Johnson 2003]; [Batini and Scannapieco 2006]. - (7) Cost optimization, defines quality improvement actions along a set of dimensions by minimizing costs.

Process-Driven Strategies - Process control inserts checks and control procedures in the data production process when: (1) new data are created, (2) data sets are updated, or (3) new data sets are accessed by the process. In this way, a reactive strategy is applied to data modification events, thus avoiding data degradation and error propagation. - Process redesign redesigns processes in order to remove the causes of poor quality and introduces new activities that produce data of higher quality. If process redesign is radical, this technique is referred to as business process reengineering [Hammer and Champy 2001]; [Stoica et al. 2003].

. The comparison focuses on: - (1) acquisition of new data, - (2) record linkage, - (3) error localization and correction, - (4) process control, and (5) process redesign techniques.

Techniques - Column analysis: Number of (unique) values and the number of instances per value as percentage from the total number of instances in that column - Cross-domain analysis - Data validation - Domain analysis - Lexical analysis - Matching algorithms: identify duplicates - Primary key and foreign key analysis (PK/FK analysis) : are good candidates for a PK/FK - Schema matching: two attributes are semantically equivalent - Semantic profiling


2.5   Data Quality Dimensions

To deifne data quality dimension, a data quality is proposed, as shown in Figure 3. With each dimension, there is underlying data qulity elements and indicators. In Cai and Zhu [2], they chose data quality dimensions commonly accepted and widely used as big data quality standards and redefined their basic concepts based on actual business needs. Each dimension was divided into many typical elements associated with it, and each element has its own corresponding quality indicators: Accessibility , Timeliness , Authorization , Credibility , Definition/-Documentation , MetaData , Accuracy , Consistency , Integrity , Completeness , Auditability , Fitness , Readability ,and Structure. In this way, hierarchical

quality standards for big data were used for evaluation. Figure 3 shows a universal two-layer data quality standard. Detailed correspondence dimension, element and indicators are shown in Figure 4.
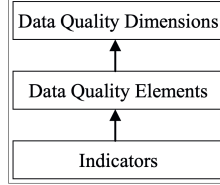
Fig. 2. Data quality framework.
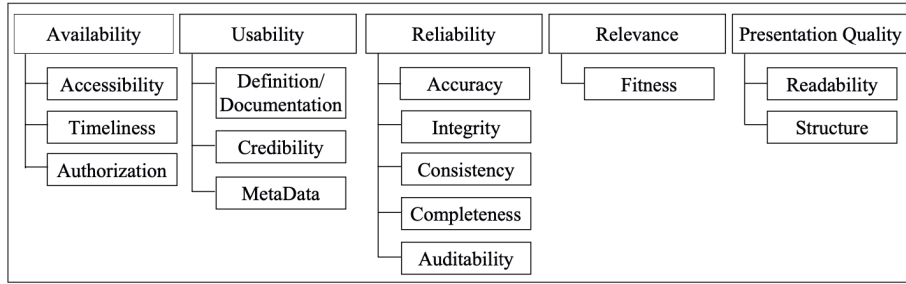
Fig. 3. A universal, two-layer big data quality standard for assessment.

For instance, syntactic accuracy is measured as described in Section 2.3 in the case of structured data. With semistructured data, the distance function should consider a global distance related to the shape of the XML tree in addition to the local distance of fields.

2.6 Cost

The cost of a data quality program can be considered a preventive cost that is incurred by organizations to reduce data errors. This cost category includes the cost of all phases and steps that compose a data quality assessment and improvement process (see Section 2.1). The costs of poor quality can be classified as follows [English 1999]: (1) process costs, such as the costs associated with the re-execution of the whole process due to data errors; (2) opportunity costs due to lost and missed revenues. The cost of poor data quality is strongly context-dependent as opposed to the cost of a data quality program. This makes its evaluation particularly difficult, as the same data value and corresponding level

Dimensions	Elements	Indicators
1) Availability	1) Accessibility	■ Whether a data access interface is provided ■ Data can be easily made public or easy to purchase
	2) Timeliness	■ Within a given time, whether the data arrive on time ■ Whether data are regularly updated ■ Whether the time interval from data collection and processing to release meets requirements
2) Usability	1) Credibility	■ Data come from specialized organizations of a country, field, or industry ■ Experts or specialists regularly audit and check the correctness of the data content ■ Data exist in the range of known or acceptable values
3) Reliability	1) Accuracy	■ Data provided are accurate ■ Data representation (or value) well reflects the true state of the source information ■ Information (data) representation will not cause ambiguity
	2) Consistency	■ After data have been processed, their concepts, value domains, and formats still match as before processing ■ During a certain time, data remain consistent and verifiable ■ Data and the data from other data sources are consistent or verifiable
	3) Integrity	■ Data format is clear and meets the criteria ■ Data are consistent with structural integrity ■ Data are consistent with content integrity
	4) Completeness	■ Whether the deficiency of a component will impact use of the data for data with multi-components ■ Whether the deficiency of a component will impact data accuracy and integrity
4) Relevance	1) Fitness	■ The data collected do not completely match the theme, but they expound one aspect ■ Most datasets retrieved are within the retrieval theme users need ■ Information theme provides matches with users' retrieval theme
5) Presentation Quality	1) Readability	■ Data (content, format, etc.) are clear and understandable ■ It is easy to judge that the data provided meet needs ■ Data description, classification, and coding content satisfy specification and are easy to understand

Fig. 4. The hierarchical big data quality assessment framework(partial content).

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of quality has a different impact depending on the recipient. For example, an active trader receiving obsolete information on a stock may incur considerable economic losses as a consequence of wrong investment decisions. In contrast, a newspaper receiving the same obsolete information to publish monthly trading reports may not experience any economic loss.

3 Literature Review

In this section, fives data quality assessment methods are introduced in brief, summarizing their characteristics and steps. These methods are Total Data Quality Management (TDQM), Total Information Quality Management (TIQM), Data Quality Assessment (DQA), Information Quality Measurement(IQM), and Comprehensive methodology for Data Quality management(CDQ). The details comparison will be presented in section Evaluation.

3.1 Total Data Quality Management (TDQM)

The TDQM methodology was the first general methodology published in the data quality literature [Wang 1998]. TDQM is the outcome of academic research, but has been extensively used as a guide to organizational data reengineering initiatives. Given requirements, reengineering must start from modeling operating processes. Consistent with these tenets, TDQM proposes a language for the description of information production (IP) processes, called IP-MAP [Shankaranarayan et al. 2000]. IP-MAP has been variously extended, towards UML and also to support organizational design. A example of IP-MAP is shown in Figure 5.

TDQM's goal is to support the entire end-to-end quality improvement process, from requirements analysis to implementation.

As shown in Figure 6, TDQM Cycle consists of four phases that implement a continuous quality improvement process: definition, measurement, analysis, and improvement. The roles responsible for the different phases of the quality improvement process are also defined in TDQM. Four roles are distinguished: (1) information suppliers, which create or collect data for the IP, (2) information manufacturers, which design, develop, or maintain data and related system infrastructure, (3) information consumers, which use data in their work, and (4) information process managers, which are responsible for managing the entire information production process throughout the information life cycle.

TDQM relies on the information quality literature for IQ Criteria and IQ improvement techniques and relates quality issues to corresponding improvement techniques. TDQM is comprehensive also from an implementation perspective, as it provides guidelines as to how to apply the methodology.

3.2 Total Information Quality Management (TIQM)

The TIQM methodology [English 1999] has been designed to support data warehouse projects. The methodology assumes the consolidation of operational data

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Fig. 5. Example of an IP-MAP).

Phase 1: **Definition**
          Input → Information product
          Data Analysis: Definition of the characteristics at two levels: (1) high level: description of functionalities for information consumers
                (2) low level description of the basic units and components of the information product and their relationships
          DQ Requirements Analysis: Definition of the IQ requirements from the perspective of IP suppliers, manufacturers, consumers and
                managers.
          Process Modeling: Definition of the Information Manufacturing System
          Output → Logical and physical design of the Information Product with the necessary quality attributes.
                A quality entity-relationship model that defines the IP and its IQ requirements
                An information manufacturing system that describes how the IP has been produced
Phase 2: **Measurement**
          Input→ IQ dimensions
          Measurement of quality: Definition of the IQ metrics
          Output → IQ problems
Phase 3: **Analysis**
          Input → IQ problems
          Identification of the causes of errors: Determination root causes of discrepancies
          Output → Actions for improving data quality
Phase 4: **Improvement**
          Input → IQ metrics
          Selection of strategies and techniques: Identification of key areas for improvement
          Output → IQ improvement techniques

Fig. 6. TDQM Phases.

sources into a unique, integrated database, used in all types of aggregations performed to build the data warehouse. This consolidation eliminates errors and heterogeneities of source databases. TIQM focuses on the management activities that are responsible for the integration of operational data sources, by discussing the strategy that has to be followed by the organization in order to make effective technical choices. Cost-benefit analyses are supported from a managerial perspective. The methodology provides a detailed classification of costs and benefits.
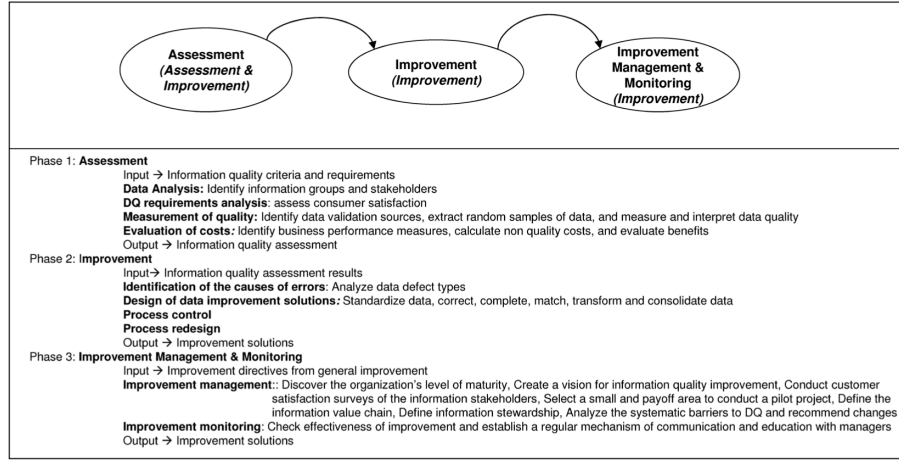

Fig. 7. TIQM Phases.

Figure 7 shows the phases of the TIQM methodology. From the TIQM's managerial perspective, there are three main phases: assessment, improvement, and improvement management and monitoring. One of the valuable contributions of the methodology is the definition of this last phase, which provides guidelines to manage changes in the organizationâs structure according to data quality management requirements. Furthermore, the economics approach introduces cost benefit evaluation to justify data quality interventions. The goal is not only the achievement of higher data quality level, but to undertake improvement actions only if they are feasible; thus only if benefits are greater than costs.

3.3 Data Quality Assessment (DQA)

The DQA methodology [Pipino et al. 2002] has been designed to provide the general principles guiding the definition of data quality metrics. In the literature, data quality metrics are mostly defined ad hoc to solve specific problems and thus, are dependent on the considered scenario. The DQA methodology is
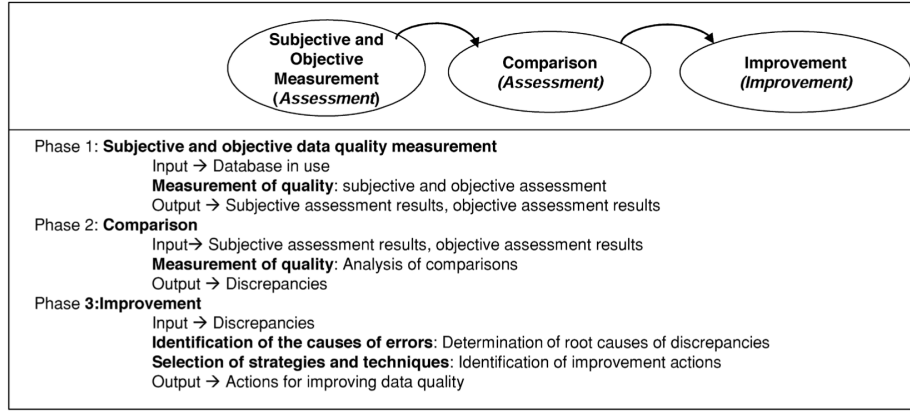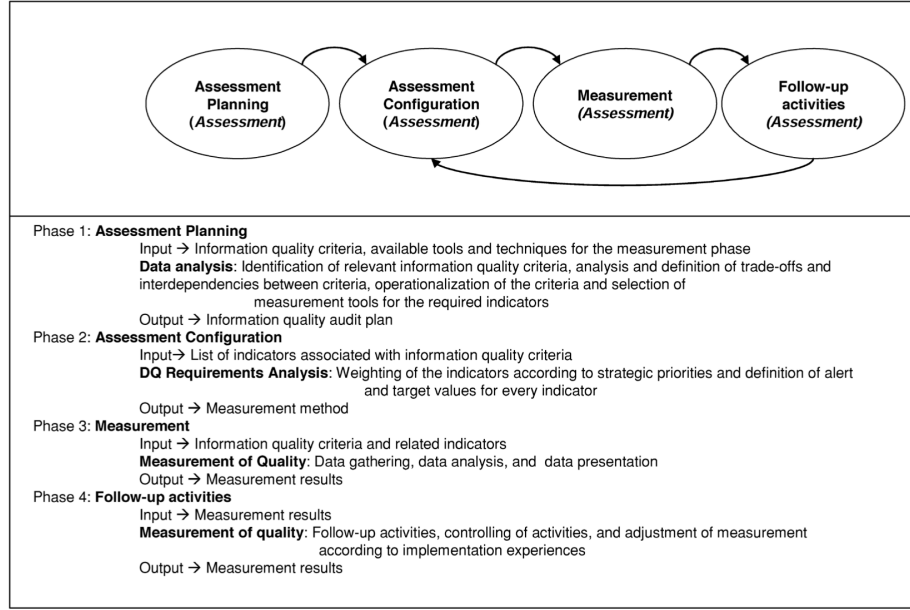
Fig. 8. DQA Phases.

aimed at identifying the general quality measurement principles common to previous research. Figure 8 shows the phases. The methodology makes a distinction between subjective and objective quality metrics. Subjective metrics measure the perceptions, needs, and experiences of the stakeholders. Objective metrics are then classified into task-independent and task-dependent. The first assess the quality of data without contextual knowledge of the application, while the second are defined for specific application contexts and include business rules, company and government regulations, and constraints provided by the database administration. Both metrics are divided into three classes: simple ratio, min or max value, and weighed average.

3.4 Information Quality Measurement (IQM)

The fundamental objective of the IQM methodology [Eppler and Mu Ìnzenmaier 2002] is to provide an information quality framework tailored to Web data. In particular, IQM helps the quality-based selection and personalization of the tools that support Webmasters in creating, managing, and maintaining Web sites.

The IQM methodology provides guidelines to ensure that software tools evaluate all the fundamental information quality dimensions. The methodology provides two sets of guidelines: the information quality framework defining quality criteria, and the action plan explaining how to perform quality measurements. The main phases of IQM methodology are reported in 9. The first phase defines the measurement plan. The information quality framework is defined as a list of relevant information quality criteria identified by interviewing the information stake- holders. The framework is the input for an information quality audit that associates the information quality criteria with the methods and tools that will be used in the measurement process. Some criteria require multiple measurement methods. The IQM methodology coordinates the application of multiple measurement methods.

Phase 1: **Assessment Planning**
      Input → Information quality criteria, available tools and techniques for the measurement phase
      Data analysis: Identification of relevant information quality criteria, analysis and definition of trade-offs and
      interdependencies between criteria, operationalization of the criteria and selection of
          measurement tools for the required indicators
      Output → Information quality audit plan
Phase 2: **Assessment Configuration**
      Input→ List of indicators associated with information quality criteria
      DQ Requirements Analysis: Weighting of the indicators according to strategic priorities and definition of alert
          and target values for every indicator
      Output → Measurement method
Phase 3: **Measurement**
      Input → Information quality criteria and related indicators
      Measurement of Quality: Data gathering, data analysis, and data presentation
      Output → Measurement results
Phase 4: **Follow-up activities**
      Input → Measurement results
      Measurement of quality: Follow-up activities, controlling of activities, and adjustment of measurement
          according to implementation experiences
      Output → Measurement results

Fig. 9. IQM Phases.

3.5 Comprehensive methodology for Data Quality management (CDQ)

The CDQ methodology [Batini and Scannapieco 2006; Batini et al. 2008] is conceived to be at the same time complete, flexible, and simple to apply.

The CDQ provides support to select the optimal quality improvement process that maximizes benefits within given budget limits and emphasizes the initial requirements elicitation phase. The focus is on how to reach total data quality without providing indications as to how to use contextual knowledge. A goal of CDQ is instead to obtain a quantitative assessment of the extent to which business processes are affected by bad information.

Three main phases characterize the methodology: state reconstruction, assessment, and choice of the optimal improvement process shown in Figure 10. In the first phase of the methodology, the relationships among organizational units, processes, services, and data are reconstructed. These relationships are modelled by using matrices that describe which organizational units use data and their roles in the different business processes. Furthermore, in this phase, processes are described along with their contribution in the production of goods/services and the legal and organizational rules that discipline workflows. The second phase sets new target quality levels that are needed to improve process qualities, and evaluates corresponding costs and benefits. This phase locates the critical variables affected by poor quality. Since improvement activities are complex and costly, it is advisable to focus on the parts of the databases and data flows that

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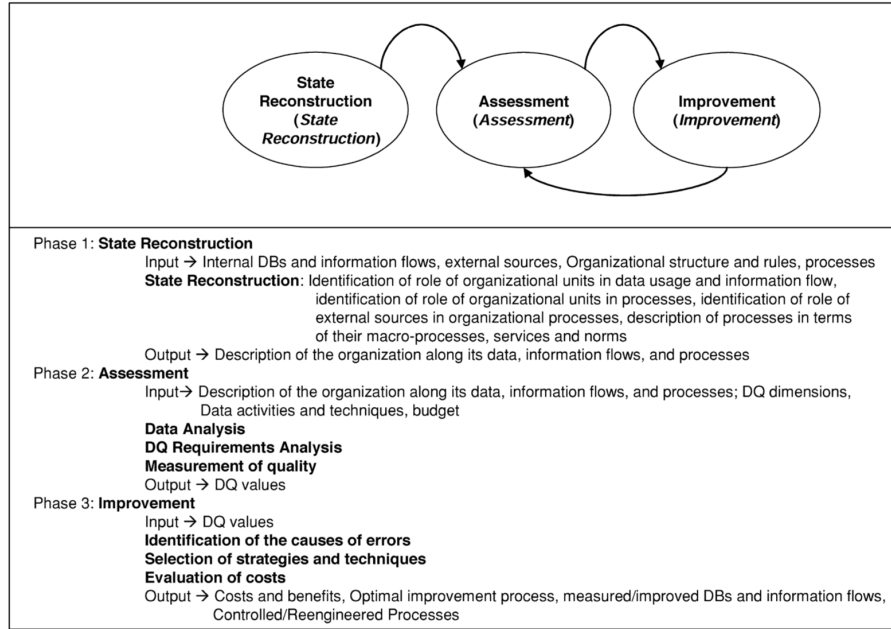
Fig. 10. CDQ Phases.

raise major problems. Finally, the third phase consists of five steps and is aimed at the identification of the optimal improvement process: the sequence of activities that has the highest cost/effectiveness ratio. New target quality levels are set by considering costs and benefits. Different improvement activities can be performed to reach new quality targets. The methodology recommends the identification of all the data-driven and process-driven improvement techniques for the different databases affected by poor quality. A set of mutually consistent improvement techniques constitutes an improvement process. Finally, the most suitable improvement process is selected by performing a cost-benefit analysis.

4 Evaluation

In this section evaluation in terns of process, techniques, and performances are discussed across these methods.

4.1 Types of Data

4.2 Phases and Steps

Assessment Phases The most commonly addressed steps of the assessment phase are data analysis and measurement of quality. However, they are performed according to different approaches. For example, the measurement of quality step

Step/Meth. Acronym	Data Analysis	DQ Requirement Analysis	Identification of Critical Areas	Process Modeling	Measurement of Quality	Extensible to Other Dimensions and Metrics
TDQM	+		+	+	+	Fixed
TIQM	+	+	+	+	+	Fixed
DQA	+		+		+	Open
IQM	+				+	Open
CDQ	+	+	+	+	+	Open

Table 2. Methodologies and Assessment Steps

Strategy/Meth. Acronym	Structured	Semistructured
TDQM	x	x
TIQM	x	Implicitly considered
DQA	x	
IQM	x	x
CDQ	x	x

is performed with questionnaires in AIMQ, with a combination of subjective and objective metrics in DQA Different measurement approaches meet the specific requirements of different organizational contexts, processes, users or services. Only a few methodologies consider the DQ requirements analysis step, identifying DQ issues and collecting new target quality levels from users. This step is particularly relevant for evaluating and solving conflicts in target DQ levels from different stakeholders.

Step/Meth. Acronym	Data Analysis	Assignment of Process Responsibilities	Assignment of Data Responsibilities	Process Modeling	Selection Strategies and Techniques	Identification the Causes of Errors
TDQM	+	+	+	+	+	+
TIQM	+	+		+	+	+
DQA	+					+
IQM						
CDQ	+	+	+	+	+	+

Improvement Phases The identification of the causes of errors is the most widely addressed improvement step. DQA emphasizes the importance of the identification of the causes of errors step, but it does not discuss its execution. The last column of Table IV specifies whether the methodology allows extensibility to dimensions (and metrics) other than those explicitly dealt with in the methodology. For example, CDQ explicitly mentions dimensions among those

that will be described in Section 3.3, but the approach can be easily generalized to other dimensions.

In contrast, the management of the improvement solution step is explicitly performed only by TDQM. Other methodologies refer to the broad range of management techniques and best practices available from the change management field [Kettinger and Grover 1995]. Furthermore, it is possible to repeat the assessment phase of the methodology in order to evaluate the results of the improvement phase. As an example, DQA explicitly recommends the application of previous methodological steps to evaluate the effectiveness of improvement. Finally, the relationship among data quality, process, and organization is considered by TIQM, TDQM, and CDQ. These methodologies thoroughly discuss the assignment of responsibilities on processes and data. These steps are supported by the results of the state reconstruction phase. CDQ discusses a set of matrices to represent the relationship among processes, organizational units, and databases, which are produced during the state reconstruction phase and are subsequently used in the assignment of responsibilities steps.

Step/Meth Acronym	TDQM	TIQM	DQA	IQM	CDQ
Evaluation of Costs	+	+			+
Assignment of Process Responsibilities	+	+			+
Assignment of Data Responsibilities	+	+			+
Selection Strategies and Techniques	+	+			+
Identification the Causes of Errors	+	+	+		+
Process Control					+
Design of data Improvement Solutions		+			+
Process Redesign	+	+			+
Improvement Management	+				
Improvement Monitoring	+	+			+

Table 3. Methodologies and Improvement Steps

Strategy/Meth. Acronym	Data-driven	Process-driven
TDQM		Process Redesign
TIQM	Data cleansing Normalization Error localization and correction	Process Redesign
CDQ	Normalization Record Linkage Data and schema integration Error localization and correction	Process Redesign

Table 4. Methodologies and Types of Strategies

4.3 Strategies and Techniques

Table VII shows the strategies and techniques adopted by different methodologies. A methodology is associated with a strategy if it provides guidelines to select and design corresponding techniques. Notice that the column labelled Process-driven in Table VII provides the same in- formation as columns, Process control and Process redesign of Table VI. The column labelled Data-driven explicitly mentions the data-driven techniques implicitly considered in Tables V and VI. Table VII shows that five DQ methodologies adopt mixed strategies, variously combining data-driven and process-driven techniques. The methodology applying the wider range of data- and process-driven techniques is TIQM. Conversely, TDQM provides guidelines to apply process-driven strategies by using the Information Manufacturing Analysis Matrix [Ballou et al. 1998], which suggests when and how to improve data. Normalization, record linkage, data and schema integration, represent the data- driven techniques most widely adopted in DQ methodologies, while process redesign, as discussed in previous section, is most relevant in process-driven methodologies. We now discuss specific contributions related to the data- and process-driven techniques considered in Section 2.2.

Data-Driven Techniques Normalization techniques have been proposed in several domains, including census and territorial data domains. CDQ provide normalization techniques improving DQ by comparing data with look-up tables and defining a common metaschema. Record linkage has been investigated in the database research since the â50s and has been applied in many contexts such as healthcare, administrative, and census applications. In such contexts, it is crucial to produce efficient computer-assisted matching procedures that can reduce the use of clerical resources, and at the same time, minimize matching errors. CDQ discusses three types of record linkage techniques:

(1) Probabilistic techniques, based on the broad set of methods developed over the past two centuries within statistics and probability theory, ranging from Bayesian net- works to data mining. (2) Empirical techniques that make use of algorithmic techniques such as sorting, tree analysis, neighbor comparison, and pruning. (3) Knowledge-based techniques, extracting knowledge from files and applying reasoning strategies. Criteria for choosing among these three types of techniques are discussed within the CDQ methodology.

CDQ follows an approach similar to ISTAT, with more emphasis on the autonomy of organizations in the cooperative system. In fact, the resolution of heterogeneities in the case studies, proposed as best practices, is performed through record linkage on a very thin layer of data, namely the identifiers. All other data are reconciled only in case of autonomous decisions of the agencies involved.

Process-Driven Techniques Methodologies addressing the process redesign step tend to borrow corresponding techniques from the literature on business process reengineering (BPR) [Muthu et al. 1999; Hammer 1990]. TDQM represents an exception in this respect, as it proposes an original process redesign

control approach that is referred to as an âinformation manufacturing system for the Information Productâ [Ballou et al. 1998]. This methodology proposes the Information Production Map (IP-MAP) model [Shankaranarayan et al. 2000] that is used to model the information products managed by the manufacturing processes. An information production map is a graphical model designed to help analysts to visualize the information production process, identify the ownership of process phases, understand information and organizational boundaries, and estimate the time and quality metrics associated with the current production process. The description of processes is a mandatory activity, consistent with the general orientation of process-driven strategies. After modelling and assessing the information production process, new process control activities are identified and/or process redesign decisions are taken.

Complex solutions such as IP-MAP cannot always be adopted due to their high costs and, in some cases, the practical unfeasibility of a thorough process modeling step. For this reason, other methodologies adopt less formal, but more feasible solutions. For example, CDQ is based on a set of matrices that describe the main relationships among data, information flows, processes, and organizational units. The relationship between organizational units and processes has also been modeled in extensions of IP-MAP proposed in the literature [Scannapieco et al. 2002].

4.4   Data Quality Dimensions

Table VIII shows the quality dimensions considered by the methodologies surveyed in this article. In Table VIII, a dimension is associated with a methodology, if the methodology provides a corresponding definition. For each methodologyâs dimensions, we address the corresponding references (see Table III).

Notice the large variety of dimensions defined in the methodologies, which confirms the complexity of the data quality concept. This is not surprising, since nowadays a large number of phenomena can be described in terms of data. Multiple classifications of quality dimensions are proposed by the methodologies. TIQM classifies dimensions as inherent and pragmatic. CDQ proposes schema and data dimensions.

Table IX shows the metrics provided for quality dimensions by different methodologies. We do not include metrics for semantic accuracy because the methodology addressing it, CDQ, do not provide specific measurement methods. In general, multiple metrics are defined for each dimension, and each dimension accordingly has multiple entries in the table. Note that subjective metrics such as user surveys have been defined for almost all quality dimensions. Different metrics for the same dimension are identified by acronyms, which are used in Table X to associate them with the methodologies in which they are used and/or defined.

The last column of Table X provides for each dimension and each metric associated with the dimension, (1) the number of methodologies that use the metrics, and (2) the total number of methodologies that mention the corresponding dimension. The ratio between these values measures the degree of consensus on

Strategy/Meth. Acronym	Data Quality Dimension
TDQM	Accessibility, Appropriateness, Believability, Completeness, Concise/Consistent representation, Ease of manipulation, Value added, Free of error, Interpretability, Objectivity, Relevance, Reputation, Security, Timeliness, Understandability
TIQM	Inherent dimensions: Definition conformance (consistency), Completeness, Business rules conformance, Accuracy (to surrogate source), Accuracy (to reality), Precision, Nonduplication, Equivalence of redundant data, Concurrency of redundant data, Pragmatic dimensions: accessibility, timeliness, contextual clarity, Derivation integrity, Usability, Rightness (fact completeness), cost.Reputation, Security, Timeliness, Understandability
DQA	Accessibility, Appropriate amount of data, Believability, Completeness, Freedom from errors, Consistency, Concise Representation, Relevance, Ease of manipulation, Interpretability, Objectivity, Reputation, Security, Timeliness, Understandability, Value added.
IQM	Accessibility, Consistency, Timeliness, Conciseness, Maintainability, Currency, Applicability, Convenience, Speed, Comprehensiveness, Clarity, Accuracy, Traceability, Security, Correctness, Interactivity.
CDQ	Schema: Correctness with respect to the model, Correctness with respect to Requirements, Completeness, Pertinence, Readability, Normalization, Data: Syntactic/Semantic Accuracy, Semantic Accuracy, Completeness, Consistency, Currency, Timeliness, Volatility, Completability, Reputation, Accessibility, Cost.

dimension metrics among methodologies. Such consensus is high for accuracy, completeness, and consistency, while it is significantly lower for two of the time-related dimensions, timeliness and currency, and almost all other dimensions.

The majority of metrics with only one occurrence in methodologies are mentioned in IQM, which analyzes the quality of Web information. Such metrics are defined by considering the measurement tools that are available in the specific Web context. For example, using a site analyzer, it is possible to assess dimensions such as accessibility, consistency, timeliness, conciseness, and maintainability. Traffic analyzers can be used to assess applicability and convenience, while port scanners are useful to assess security. The high number of measurement tools in the Web context results in a high number of metrics specific to IQM.

4.5 Cost

The cost dimension is considered only in TIQM and CDQ and exist two views: (1) cost classifications, and (2) criteria provided for cost quantification.

Cost Classifications TIQM provide detailed classifications for costs. In TIQM, data quality costs correspond to the costs of business processes and data management processes due to poor data quality. Costs for information quality assessment or inspection measure data quality dimensions to verify that processes are performing properly. Finally, process improvement and defect prevention costs involve activities to improve the quality of data, with the goal of eliminating, or

reducing, the costs of poor data quality. Costs due to poor data quality are analyzed in depth in the TIQM approach, and are subdivided into three categories: (1) Process failure costs are incurred when poor quality data causes a process not to per- form properly. As an example, inaccurate mailing addresses cause correspondence to be misdelivered. (2) Information scrap and rework. When data is of poor quality, they involve several types of defect management activities, such as reworking, cleaning, or rejecting. (3) Loss and missed opportunity costs correspond to the revenues and profits lost because of poor data quality. For example, due to low accuracy of customer e-mail addresses, a percentage of customers already acquired cannot be reached by periodic advertising campaigns, resulting in lower revenues, roughly proportional to the decrease of the accuracy of addresses.

Criteria for Cost Quantification The assessment of the total cost of data quality supports the selection of the types of data quality activities to be performed and their prioritization. TIQM and CDQ are the only methodologies providing criteria for this activity.

In TIQM, selection and prioritization are achieved with the following steps: (1) Identify current users and uses of data; (2) List the errors that negatively affect data quality; (3) Identify the business units most often impacted by poor quality data; (4) Estimate the direct cost of the current data quality program; (5) Estimate the costs of data errors for all users and uses of data, grouped by business unit; (6) Use costs to justify and prioritize data quality initiatives, including the institutionalization of a continuous quality improvement program. Each type of error occurs with a given frequency and involves a cost. Note that the cost of different error categories is a contingent value that varies with the process that makes use of the data. Models for process representation allow the identification of the activities affected by data errors. Since activities are typically associated with a total organizational cost, the cost of rework can provide quantitative and objective estimates.

In CDQ the minimization of the cost of the data quality program is the main criterion for choosing among alternative improvement processes. First, different improvement processes are identified as paths of data- and process-driven techniques applied to the data bases, data flows, and document bases involved in the improvement. Then, the costs of the different processes are evaluated and compared, and the minimum-cost process is selected.

4.6   Summary of Methodologies

We can classify these methodologies into 3 categories based on their emphasis on improvement, assessment, cost and quality dimensions. Figures 11 show the methods positioned on a two-dimensional coordinated. The categories are: (1) Complete methodologies, which provide support to both the assessment and improvement phases, and address both technical and economic issues; (2) Audit methodologies, which focus on the assessment phase and provide limited support to the improvement phase; (3) Operational methodologies, which focus on

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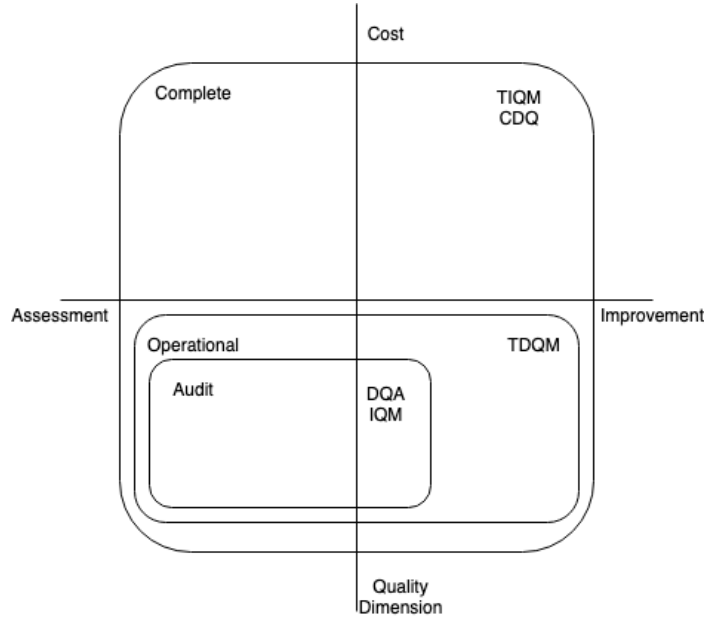
Fig. 11. A classification of methodologies.

the technical issues of both the assessment and improvement phases, but do not address economic issues. (4) Economic methodologies, which focus on the evaluation of costs.

Operational focus DQ assessment on identifying the issues for which their improvement approach works best. One of the main contributions is the identification of a set of relevant dimensions to improve and the description of a few straightforward methods to assess them. For example, TDQM is a general-purpose methodology and suggests a complete set of relevant dimensions and improvement methods that can be applied in different contexts.

Complete are extremely helpful in providing a comprehensive frame- work to guide large DQ programs in organizations that process critical data and attribute to DQ a high strategic priority, such as banks and insurance companies. On the other hand, they show the classical trade-off between the applicability of the methodology and the lack of personalization to specific application domains or technological contexts. Being high-level and rather context independent, complete methodologies are only marginally affected by the evolution of ICT technologies and, over time have been revised to encompass the variety of data types, sources, and flows that are part of modern information systems.

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Audit Most audit and improvement methodologies have a cost evaluation step. However, they mostly focus on the cost of DQ initiatives, while a complete cost-benefit analysis should also consider the cost of doing nothing, the cost of poor data quality, which is typically of an organizational nature. Economic methodologies,complement other methodologies and can be easily positioned within the overall framework provided by any complete methodology, focus on both aspects.

In CDQ, the overall evaluation of the cost of poor quality is further developed to take into account the fact that the same quality improvement can be obtained with different priorities and paths and the minimization of the cost of the data quality program is the main criterion to choose among alternative improvement processes. The methodology suggests that different improvement processes can identified as paths of data- and process-driven techniques applied to the data bases, data flows and document bases involved in the improvement. Then, the costs of the different processes should be evaluated and compared, to select the minimum-cost process.

5 Conclusion

This section summarizes all the topics in report. The conclusions of evaluation of different method are drew. From the best suitable methods, new ideas and customization are proposed to be adapted in the context of CI/CD application in software engineering. In the end, the future work of data quality assessment for CI/CD application are proposed.

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