A METHODOLOGY FOR INFORMATION QUALITY ASSESSMENT IN THE DESIGNING AND MANUFACTURING PROCESSES OF MECHANICAL PRODUCTS

(Research-in-Progress)

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ABSTRACT: Product Information Quality (PIQ) is critical in manufacturing enterprises. Yet, the field lacks comprehensive methodologies for its evaluation. In this paper, the authors attempt to develop such a methodology, which is called Activity-based Measuring and Evaluating of PIQ (AMEQ) to form a basis for PIQ measurement and evaluation. The methodology encompasses a road map to measure and improve PIQ, an indicator system based on characteristics and logic-temporal sequences of processes, and a set of models to quantificationally describe, operate and measure the designing and manufacturing processes of mechanical product information. The methodology is illustrated through a business case. The results of the methodology are useful for determining and reviewing the best area for PIQ improvement activities.

Key Words: Product Information Quality, Information Quality, Information Product Quality, Product Information, Data Quality

1. INTRODUCTION

In this information age, there are two kinds of manifestation for products in manufacturing enterprises (MEs): one is physical form, which is called entity product; the other is information form, which is called information product. An entity product is the result of information product materialized, such as automobile, machine tool, pump, tool, and bearing; an information product usually comes from an entity product, such as data, message, information, knowledge, arithmetic, software, document, drawing, language, news, service and consultation. The information gathered and processed in ever increasing quantities, if presented in a timely and accurate manner, can make a life-or-death within a company. Enterprise Resource Planning (ERP) developers and implementers have always considered the quality of information to be important. A survey of the reasons for ERP failures showed that information quality (IQ) is listed as one of the six categories in ERP design and implementations.[1] Over the last decade, IQ research activities have increased significantly to meet the needs of organizations attempting to measure and improve the quality of information.[2][3][4] In industry, IQ has been rated regularly as a top concern in computer-based Management Information Systems (MIS) and data warehousing projects.[5][6][7]

Despite a decade of research and practice, hardly any techniques are available for measuring, analyzing, and improving product information quality (PIQ) in business processes of MEs. As a result, knowledge workers in MEs are unable to develop comprehensive measures of the quality of their information and to benchmark their efforts against that of other professionals. Without the ability to assess the quality of their information, knowledge workers cannot assess the status of their PIQ and monitor its improvement. The challenge for this research is to develop an overall model with an accompanying assessment instrument for measuring PIQ. Furthermore, techniques must be developed to compare the assessment results against enterprise objectives and cross stakeholders. Such techniques are necessary for prioritizing PIQ improvement efforts.

This research was designed to meet these challenges. A methodology called activity-based measuring and evaluating of PIQ (AMEQ) has been developed to provide a rigorous and pragmatic basis for PIQ assessments and relationships with enterprise goals. It has four components. The first component is a framework of what IQ means to performance measurement [8]. This framework is process oriented and contains IQ metrics as one of the six internal measures.

Based on Su and Yu's dynamic integrated performance measurement system (DIPMS) [8], in Section 2, a road map for continuously improving PIQ is given to facilitate the processes of PIQ definition, measurement, assessment, and improvement. The road map consists of five processes of measuring and improving PIQ and provides a big-picture view of the AMEQ Methodology. It will help you understand the context for PIQ improvement, so that as you read about a specific step, you have an understanding of how it fits into the overall methodology.

In Section 3, an indicator system of PIQ dimensions grouped by characteristics and time-series of activities is developed, which is the result of process 1 explained in the road map. This system has four specific cases and one generic case. Several IQ dimensions together measure PIQ for each activity depending upon upstream-downstream relationships of the activity. It can be applied to assessing the PIQ in the designing and manufacturing processes.

In Section 4, three models for AMEQ used to describe, operate and measure the PIQ are presented. They are used in process 2 and 4 prescribed by the road map. In Section 5, the application of AMEQ is illustrated by showing an example of a small manufacturing company. Finally, Section 6 offers the merits of AMEQ methodology.

2. A Road Map for Improvement

A solution should be found as to how to measure and improve PIQ in the business processes. A road map is developed for DIPMS. PIQ improvement is not an end to itself; rather it is a means for improving business performance and customer satisfaction. The road map consists of the following five phases, (see Figure.1).

2.1. Phase 1: Establish IQ Environment

Phase 1 is more than a single process. It represents the systemic, managing, and cultural requirements for a sustainable PIQ improvement environment. This phase is treated first because it is foundational to the long-term IQ improvement. By managing IQ, an IQ team is established to define what PIQ is, and how to manage the information or information flow over its life cycle. In reality, you will have to conduct activities from the other four phases.

This phase assesses the cultural readiness of organization, using the Information Quality Management Maturity Grid (IQMMG). One of the most important outputs of phase 1 is the multiple dimensions of PIQ divided by characteristics and time-series of business activities (See Section 3).

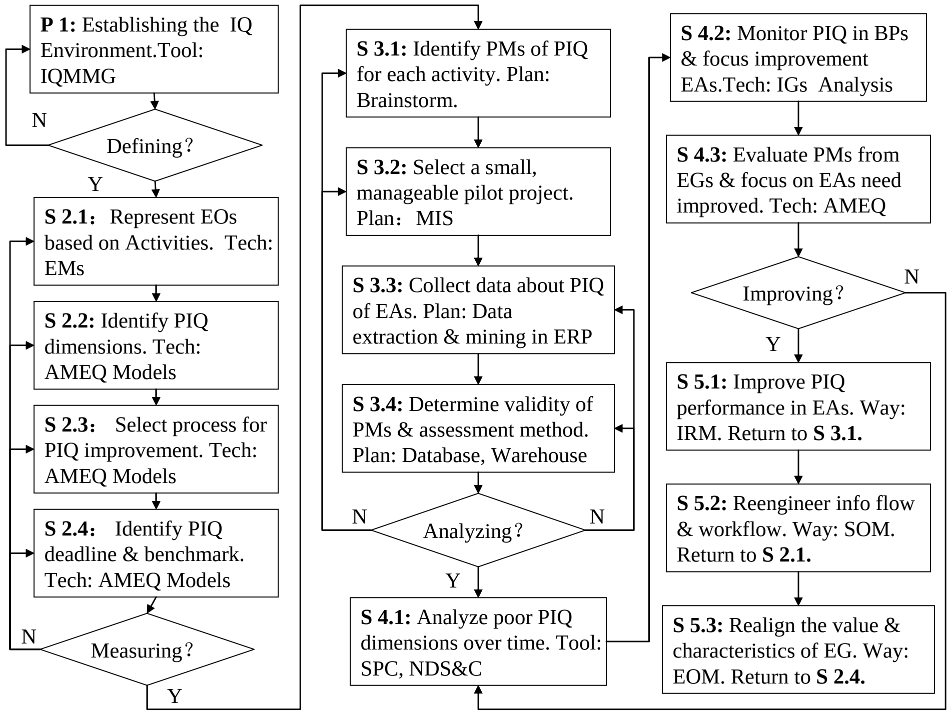


Figure 1. The road map for PIQ improvement

2.2. Phase 2: Define PIQ

The phase of PIQ definition is a precursor to measuring IQ. One cannot measure the quality of a product without knowing that the product specifications themselves are accurate and are what they should be. In order to measure PIQ out of a business process, it is necessary to establish the mapping from enterprise goals to activity PIQ measures first.

Step 2.1 represents the enterprise objects (EOs) based on activity.

Step 2.2 identifies the PIQ dimensions of Enterprise Activity using the results of Phase 1.

Step 2.3 selects the process for PIQ improvement using the AMEQ models (see section 4).

Step 2.4 identifies benchmarks and deadlines of enterprise goals (EGs) about PIQ. These PIQ benchmarks constitute the EG Objects.

2.3. Phase 3: Measure PIQ

To measure PIQ in business processes, MEs must develop a suitable set of metrics to perform the necessary measurements. The requirement for measuring is inextricably intertwined with the needs to analyze and improve PIQ. Based on the definition of PIQ dimensions, four steps are proposed that the IQ managers must recognize and use.

Step 3.1 identifies PMs of PIQ for each activity. The first step is the development of 6-12 items for PIQ dimensions. Then, IQ researchers make sure that they have covered the dimensions and have not included those that are overlapped. The items for each activity are also reviewed by users to ensure that they are meaningful to information consumers who would be completing the survey. As a result of these reviews, items were added, deleted, and revised. This process of reviewing and editing was repeated until an agreement was reached on an initial set of the three items per PIQ dimension.

Step 3.2 selects a small, manageable pilot project. The purpose of the pilot project is to provide an initial assessment of the reliability of the items for each of the dimensions and to use this to reduce the number of items per dimension. To facilitate the comprehensive assessment, the scale used in assessing each item is ranged from 0 to 1 where 0 is labeled ‘‘not at all’’ and 1 is labeled ‘‘completely’’.

Step 3.3 uses the complementary metrics and final questionnaire to collect data about PIQ of EAs. Statistical analyses were made using some software tools that can integrate with ERP system to facilitate the data extraction and data mining.

Step 3.4 determines the validities of measures about EA and the assessment method of business processes on the foundation of data analysis.

2.4. Phase 4: Analyze PIQ

From the measurement results, the IQ team investigates the root cause for potential PIQ problems. The methods and tools for performing this task can be simple or complex.

Step 4.1 analyzes the poor IQ dimensions over time by using statistical process control (SPC), nonlinear dynamic systems and chaos (NDS&C).

Step 4.2 conducts information gap analysis to monitor the PIQ in business processes and to focus improvement activities. Two analysis techniques, Semantic Gaps and Pragmatic Gaps, are used to identify PIM problem areas.

Step 4.3 adopts the AMEQ models (see section 4) to synthetically evaluate the PMs of EAs from EGs and to focus on the EAs that most need to be improved.

2.5. Phase 5: Improve PIQ

Once the analysis phase is complete, the PIQ improvement phase can start. It is important that both technical solutions and business processes be introduced, disseminated, and institutionalized in the organization over time in order to sustain the long-term improvement of PIQ. The IQ team needs to identify key areas for improvement.

Step 5.1 carries out information resource management (IRM) to improve the PIQ performance in enterprise activities.

Step 5.2 conducts self-organization management (SOM) to reengineer information flow and workflow with infrastructure.

Step 5.3 develops enterprise objective management (EOM) to realign the value and characteristics of EG.

3. ACTIVITY-BASED DEFINING TO THE DIMENSIONS FOR PIQ

For a manufacturing firm, the concept of quality encompasses much more than material defects. David A. Garvin proposed an analytic framework encompassing eight dimensions of quality: performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality. [9]

Just as product quality has multiple dimensions, IQ also has multiple dimensions. The choice of these dimensions is primarily based on three approaches that have been used in the literature of IQ study: Intuitive, Systematic, and User-based.

Activity Taxonomy	Upstream Activity	Downstream. Activity	Definition Approach	Reference Dimensions of PIQ for Upstream Activity
CASE Ⅰ	Non-Structured	Non-Structured	User-based	Consistent representation, Interpretability, Case of understanding, Concise representation, Timeliness, Completeness (Ballou and Pazer [10]), Value-added, relevance, appropriate, Meaningfulness, Lack of confusion (Goodhue [16]). Arrangement, Readable, Reasonable (Zmud [17]).
CASE Ⅱ	Non-Structured	Structured	Intuitive	Precision, Reliability, freedom from bias (Delone and McLean [15]).
CASE Ⅲ	Structured	Non-Structured	User-based	See also **CASE Ⅰ**
CASE Ⅳ	Structured	Structured	System	Data Deficiency, Design Deficiencies, Operation Deficiencies (Huang, Lee, and Wang [2]).
Inherent PIQ	Accuracy, Cost, Objectivity, Believability, Reputation, Accessibility, (Wang and Strong [14]). Correctness, Unambiguous (Wand, and Wang [13]). Consistency (English, [5]).			

TABLE 1. Activity-based defining to the dimensions of PIQ

An intuitive approach is taken when the selection of IQ attributes in a specific study is based on the individual's experience or intuitive understanding about what attributes are important. Many IQ studies fall into this category [11][12].

A system approach to IQ focuses on how information may become deficient during the information manufacturing process. Wand, and Wang use an ontological approach in which attributes of IQ are derived based on data deficiencies, which are defined as the inconsistencies between the view of a real-world system that can be inferred from a representing information system and the view that can be obtained by directly observing the real-world system. [13]

The advantage of using an intuitive approach is that each study can select the attributes most relevant to the particular goals of that study. The advantage of a system approach has potential to provide a comprehensive set of IQ attributes that are intrinsic to information. The problem with both of these approaches is that they focus on the information product in terms of development characteristics instead of application characteristics. They are not directed to capturing the voice of the consumer.

User-based approach analyzes information collected from information consumers to determine the characteristics they use to assess whether information is fit for use in their tasks. The advantage of the user-based is that it captures the voice of the customer. However, this is a highly subjective view of IQ which gives rise to two types of problem. First, there is the problem of aggregating widely different individual preferences, which can lead to meaningful definitions of quality in terms of the design of information products and services. The second is how to distinguish between those information attributes that connote quality and those that simply maximize consumer satisfaction.

The coexistence of these different approaches to IQ in business processes may result in conflicting views of PIQ among information providers and business users. These differences can cause serous breakdowns in communications both among information suppliers and between information suppliers and users. But even with improved communication among them, each of the principal approaches to PIQ shares a common problem: each offers only a partial and sometimes vague view of the basic elements of PIQ.

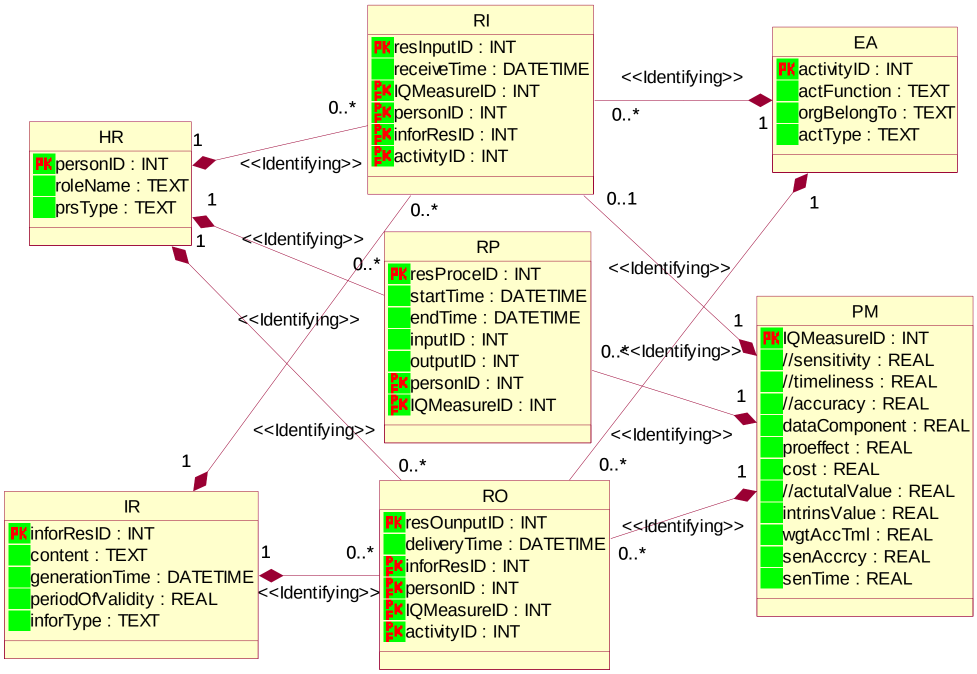


Figure 2. The relationship diagram of Enterprise Objects

In order to fully exploit favorable conditions of these approaches and avoid unfavorable ones, we present a definition approach of PIQ that is based on characteristics of enterprise activities (EAs) precedence relationship between them (TABLE 1). EAs are processing steps within a process transforming objects and requiring resources for their execution. An activity can be classified as a structured activity if it is computable and controllable. Otherwise, it is categorized as a non-structured activity. Manufacturing activities are typical examples of structured activities because they are defined by a process plan for a given part type, and many of them are executed by numerically controlled machines (NC) driven by a computer reading NC instructions. Accounting, planning, inventory control, and scheduling activities are other examples of structured activities. Typical examples of non-structured activities are human-based activities such as design, reasoning, or thinking activities. TABLE 1 gives the reference dimensions of upstream activity regarding the context in the business processes.

4. MODELS OF THE DESIGNING AND MANUFACTURING PROCESSES

The key techniques of the AMEQ are a set of models of enterprise object, coupling operation and IQ measure. These models are proposed based on the object-oriented approach (OOA).

The OOA makes the basic assumption that the world is made of an organized collection of objects. According to this hypothesis, anything within an enterprise is also considered an object characterized by its unique and invariant identifier, its object class, and its state defined by the values of its attributes. [18] An enterprise object (EO) might be concrete things (e.g. an equipment, an employee, or a product), abstract things (e.g. an enterprise goal, a business process, an enterprise activity, a performance measure, or an operation), or relationships among things (e.g. a logical link between two objects).

4.1. Models of Enterprise Object

Models of Enterprise Object (EO) are the most important building blocks of our AMEQ methodology. From the OOA point of view, they are a description of a set of abstract EOs that share the same attributes. Our models of EO are made of eight kinds of objects:

Human Resource (HR): main body of cognition for information.

Information Resource (IR): direct or indirect formulization about states, processes, controls, forms, meanings and effectiveness of things expressed by main body.

Enterprise Activity (EA): a set of elementary actions executed to realize some task with an enterprise, requiring time and resources for its execution, and transforming an input state into an output state.

Resource Input (RI): logical relation reflected by HR when receiving IR in an EA.

Resource Process (RP): transition among the IRs made by HR.

Resource Output (RO): logical relation reflected by HR when senting IR in an EA.

Performance Measure (PM): a metric used to quantify the dimensions of PIQ for an EA.

Enterprise goal (EG): the measurable aspirations that managers set for a business. Goals are determined by reference to business strategy. Goals may be financial, for example, achieving 14% return on sales; or nonfinancial, for example, increasing market share from 6% to 9%.

In this paper only the attributes of EOs closely related to PIQ research are given. The relationship among seven objects, their attributes and domains can be represented graphically in a class diagram as shown in Figure 2. The formal expression of models follows.

4.1.1. Human Resource

Human resource (HR) can be defined as a 3-tuple:

$$HR = \{(\text{personID}, \text{roleName}, \text{prsType})\} \quad (1)$$

Where *personID* is the identifier of a human resource; *roleName* is defined as the role of a person in the business process; *prsType* is the type of a person when he processes information resources, such as Listener, Processor and Dispatcher.

4.1.2. Information Resource

An Information Resource (IR) can be defined as a 5-tuple:

$$IR = \{(\text{inforResID}, \text{content}, \text{generationTime}, \text{periodOfValidity}, \text{inforType})\} \quad (2)$$

Where *inforResID* is the identifier of IR; *content* includes three components: clear definition or meaning of data, correct value(s), and understandable presentation (the format represented to HRs); *generationTime* refers to the time when the IR comes into being; *periodOfValidity* refers to the age of the IR remaining valid; *inforType* is the type of the IR which can be classified as environmental, inner and efferent.

4.1.3. Enterprise Activity

An enterprise activity (EA) is defined as a 9-tuple:

$$EA = \{(\text{activityID}, \text{actFunction}, \text{orgBelongTo}, \text{actType})\} \quad (3)$$

Where *activityID* is the identifier of an EA; *actFunction* is defined as the function of EA; *orgBelongTo* defines the organization to which activity belongs; *actType* refers to the type of activity which can be cataloged as a structured activity and a non-structured activity.

4.1.4. Resource Input

A Resource Input (RI) can be formalized as a 6-tuple:

$$RI = \{(resInputID, receiveTime, activityID, inforResID, personID, IQMeasureID)\} \quad (4)$$

Where *resInputID* is the identifier of a RI; *receiveTime* refers to the time when an IR is obtained; *activityID* is the identifier of an EA; *inforResID* is the identifier of an IR; *personID* is the identifier of a listener; *IQMeasureID* is the identifier of a PM.

4.1.5. Resource Process

A Resource Process (RP) Objects can be formalized as a 7-tuple:

$$RP = \{((resProceID, startTime, endTime, outputID, inputID, personID, IQMeasureID)) \quad (5)$$

Where *resProceID* is the identifier of RP; *startTime* refers to the time when a HR starts to process an IR; *endTime* refers to the time when a HR finishes to process an IR; *outputID* is the identifier of an output EA; *inputID* is the identifier of an input EA; *personID* is the identifier of a processor; *IQMeasureID* is the identifier of a PM.

4.1.6. Resource Output

A Resource Output (RO) can be formalized as a 6-tuple:

$$RO = \{(resOunputID, deliveryTime, activityID, inforResID, personID, IQMeasureID)\} \quad (6)$$

Where *resOunputID* is the identifier of a RO; *deliveryTime* refers to the time when an IR is delivered to the customer; *activityID* is the identifier of an EA; *inforResID* is the identifier of an IR; *personID* is the identifier of a dispatcher; *IQMeasureID* is the identifier of a PM.

4.1.7 Performance Measure

The object of a performance measure (PM) is defined as a 12-tuple:

$$\begin{aligned} PM = \{(&IQMeasureID, senCryVty, timeliness, accuracy, dataCmpAcy, proEffect, \\ &cost, actutalValue, intrinsValue, wgtAccTml, senAccrcy, senTime)\} \end{aligned} \quad (7)$$

Where *IQMeasureID* is the identifier of PM; *timeliness***,** *accuracy***,** *cost***,** and *actutalValue* are the targeted values of PIQ; *senCryVty, senAccrcy and senTime* are three parameters that allows us to control the sensitivity of ratios; *dataCmpAcy is* the accuracy of data component; *proEffect* is a measure of processing effectiveness; *intrinsvalue* is the intrinsic value of an IR; *wgtAccTml* is the weight that captures the relative importance to the customer of IR accuracy and IR timeliness.

Among these attributes, *timeliness, accuracy, cost***,** and *actutalValue* are derived attributes of the PM which can be computed by other attributes through models of coupling operation and PIQ measure. In Section 4.3, we will propose the various formulas to calculate these attributes. In the next section, we will present the models of coupling operation.

4.1.8 Enterprise Goal

An enterprise goal (EG) can be defined as a 7-tuple:

$$EG=\{(id, name, value, unit, startDate, finishDate, type)\} \quad (8)$$

Where *id* is the identifier of EG; *name* is defined as the name of EG; *value* defines an assigned or calculated numerical quantity of EG; *unit* is the magnitude of the value; *startTime*, *finishTime* are start time and finish time of an EG; type is the dimension of PIQ to which an enterprise goal belongs (refer to **TABLE 1**).

4.2. Models of Coupling Operation

The coupling operation consists of a set of operations that take one or two sets as the input and produce a new set as their result. The fundamental operations in the coupling operation are S***elect, Project, Cartesian product*** and ***Associative***.

4.2.1. The *Select* Operation

The ***Select*** operation selects tuples that satisfy a given predicate. We use the lowercase Greek letter sigma (σ) to denote selection. The predicate appears as a subscript to σ . The argument relation is in parentheses after the σ . Thus, to select those tuples of the IR in Equation (2) object where the *inforResID* is "1", we write: $\sigma_{\textit{inforResID} = \text{"1"}}(IR)$

In general, we allow comparisons using $=, \neq, <, \leqslant, >, \geqslant, \nless, \ngtr$ in the selection predicate. Furthermore, we can combine several predicates into a larger predicate by using the connectives and ($\wedge$), or ($\vee$), and not ($\neg$).

4.2.2. The *Project* Operation

Suppose we want to list all names and values of IR, but do not care about the identifier of IR. The ***Project*** operation allows us to produce this relation. The project operation is a unary operation that returns its argument relation, with certain attributes left out. Since a relation is a set, any duplicate rows are eliminated. Projection is denoted by the uppercase Greek letter pi (Π). We list those attributes that we wish to appear in the result as a subscript to Π. The argument relation follows in parentheses. Thus, we write the query to list all *periodOfValidity* of IR as: $\Pi_{\textit{periodOfValidity}}(IR)$

4.2.3. Composition of Coupling Operations

The fact that the result of a coupling operation is itself a set is important. Consider the more complicated query "Find *periodOfValidity* of the IR which *inforResID* is 1". We write:

$$\Pi_{\textit{periodOfVality}}(\sigma_{\inf or \operatorname{Re} sID=1}(IR)) \quad (9)$$

4.2.4. The *Cartesian-Product* Operation

The ***Cartesian-product*** operation, denoted by a cross (×), allows us to combine information from any two objects. We write the Cartesian product of object o_1 and o_2 as $o_1 \times o_2$.

4.2.5 The Naming Operation

However, since the same attribute name may appear in both o_1 and o_2, we devise a naming operation to distinguish the object from which the attribute originally came. For example, the relation schema for R = IR × RI is:

$$\begin{aligned}\mathrm{IR} \times \mathrm{RI} = \{(&\mathrm{IR.inforResID, IR.content, IR.generationTime, IR.periodOfValidity, IR.inforType} \\ &\mathrm{RI.resInputID, RI.receiveTime, RI.activityID, RI.inforResID, RI.personID, RI.IQMeasure})\}\end{aligned}$$

With this operation, we can distinguish IR.*inforResID* from RI.*inforResID*. For those attributes that appear in only one of the two objects, we shall usually drop the relation-name prefix. This simplification does not lead to any ambiguity. We can then write the relation schema for R as

$$\begin{aligned}\mathrm{IR} \times \mathrm{RI} = \{(&\mathrm{IR.inforResID, content, generationTime, periodOfValidity, inforType} \\ &\mathrm{resInputID, receiveTime, activityID, RI.inforResID, personID, IQMeasure})\}\end{aligned}$$

4.2.6. The *Associative* Operation

It is often desirable to simplify certain operations that require a Cartesian product. Usually, an operation that involves a Cartesian product includes a selection operation on the result of the Cartesian product. Consider the operation "Find the *contents* of all IRs which come into the object of RI, along with the *peridodOfValidity* and *generationTime*." Then, we select those tuples that pertain to only the same *inforResID*, followed by the projection of the resulting *content*, *generationTime* and *peridodOfValidity*:

$$\Pi_{\mathrm{content,\ generationTime,\ periodOfValidity}}(\sigma_{\mathrm{IR.inforResID=RI.inforResID}}(\mathrm{IR} \times \mathrm{RI}))$$

The ***Associative*** Operation is a binary operation that allows us to combine certain selections and a Cartesian product into one operation. It is denoted by the "join" symbol ")". The associative Operation forms a Cartesian product of its two arguments, performs a selection forcing equality on those attributes that appear in both relation objects, and finally removes the duplicate attributes.

Although the definition of an associative operation is complicated, the operation is easy to apply. As an illustration, consider again the example "Find the *contents* of all IRs which come into the object of RI, along with the *peridodOfValidity* and *generationTime*." We express this operation by using the associative operation as following:

$$\Pi_{\mathrm{content,\ generationTime,\ periodOfValidity}}(\sigma(\mathrm{IR}\ )\ \ \mathrm{RI}))$$

4.3. Models of PIQ Measure

Despite the availability of the various approaches to developing IQ measures, none of them attempted to quantify them. In this section we only consider four local measures and one global measure of PIQ: *timeliness*, *accuracy*, *cost*, and *value* are local attributes of PM; *profit* is a global attribute of information designing and manufacturing process. To evaluate the PIQ, these measures must be quantified and expressed using two kinds of models provided by preceding sections.

4.3.1. Timeliness of Information Resource

Our approach postulates that the timeliness of an information resource is dependent upon when the IR is received by the customer. Thus timeliness cannot be known until it is received. The purpose of producing a timeliness measure is to have a metric that can be used to gauge the effectiveness of improving the information manufacturing process.

The timeliness of an object of information resource (IR) is governed by two factors. The first, *currency*, refers to the age of the IR from generation to status change. The second, *Period of Validity*, refers to how long the item remains valid. The currency dimension is solely a characteristic of the capture of the IR; in no sense is it an intrinsic property. The validity of the IR is, however, an intrinsic property unrelated to the designing and manufacturing processes of product information (Eq. 2). The currency of an IR is good or bad depending on the IR's period of validity. A large value of currency is unimportant if the useful-life is infinite. On the other hand, a small value of currency can be deleterious if the useful-life is very short. This suggests that timeliness is a function of the ratio of currency and a period of validity. This consideration in turn motivates the following timeliness measure for IRs.

$$Timeliness = \{\max[(1 - \frac{currency}{IR.periodOfValidity}),0]\}^{PM.\mathrm{senCryVty}} \quad (10)$$

According to Equation (9) in Section 4.2.3, *periodOfValidity* of the IR whose identifier is 1 can be captured. The exponent *PM.senCryVty* is a parameter that allows us to control the sensitivity of timeliness to the currency validity ratio and can be obtained from Equation (7) in Section 4.1.7.We use three status to indicate when the IR was received, processed and delivered (the lower right rectangle in Figure 3)in an activity. Therefore, three kinds of timeliness measure need to be presented.

1. Timeliness measure for information acquisition (T_A). Suppose, for example, that the identifier of the IR received by EA is 1, and the identifier of input EA is 2. The currency measure can be obtained as follow:

$$currency = \Pi_{generationTime}(\sigma_{\inf or \operatorname{Re} sId=1}(IR)) - \Pi_{recevieTime}(\sigma_{\inf or \operatorname{Re} sID=1 \wedge activityID=2}(RI)) \quad (11)$$

$\mathbf{T_A}$ can be computed via Equation (10).

2. Timeliness measure for information processing (T_P). Our goal is to attach a timeliness measure to each IR output. Each such output is the result of certain processing and various inputs. Each IR input, where we call inner IR, in turn can be the result of other processing and inputs. Each IR output is processed by the activity, both structured and non-structured.

In a structured activity, output IR (*y*) can be expressed by function $y = f(x_1, x_2, \cdots, x_n)$. If *y. inforResID*= 2, the identifier of input IR (*i*) can be obtained $i \in \{\Pi_{inputID}(\sigma_{outputID=2}(RP))\}$. The currency measure for x_i is computed as follow:

$$currency(x_i) = \Pi_{generationTime}(\sigma_{\inf orSesID=i}(IR)) - \Pi_{startTime}(\sigma_{inputID=i}(RP)) \quad (12)$$

$T_P(x_i)$ denotes the timeliness measure for x_i and is calculated via Equation (10). Then we propose the following to represent or measure the timeliness of y.

$$T_P(y) = \sum_{i=1}^{n} \omega_i * T(x_i) \Big/ \sum_{i=1}^{n} \omega_i \qquad \text{where } \omega_i = \left|\frac{\partial f}{\partial x_i}\right| * |x_i| . \quad (13)$$

In a non-structured activity, input IR can undergo the processing that does not involve any arithmetical operation, then T(y) is the minimal value of $T(x_i)$.

$$T(y) = \min(T(x_1), T(x_2), \cdots, T(x_n)) \quad (14)$$

3. Timeliness measure for information transfer (T_T). Suppose, for example, that the identifier of the IR disseminated by EA is 2, and the identifier of output EA is 1. Currency measure can be obtained as follow:

$$Currency = \Pi_{generationTime}(\sigma_{\inf orSesID=2}(IR)) - \Pi_{delievryTime}(\sigma_{\inf orSesID=2 \wedge activityID=1}(RO)) \quad (15)$$

$\mathbf{T_T}$ can be computed via Equation(10).

4.3.2. Accuracy of Information Resource

Information resources (IRs) are manufacturing in the multiple stages of processing and are based on data that have various levels of accuracy. Let DA(x_i) denote a measure of the data accuracy of data unit x_i. It can be determined by the number of error $N_{err}(x_i)$ and the total number of spot-check N(x_i).

$$DA(x_i) = 1 - N_{err}(x_i) / N(x_i) \quad (16)$$

We use a scale from 0 to 1 as the domain for DA(x_i) with 1 representing data without error and 0 representing those with intolerable error. If all data items should have a data accuracy measure equal to 1 and if all processing is correct, then the output accuracy measure should be 1 as well. Conversely, if the accuracy of all inputs IRs is 0, then the accuracy of the output IR should be 0 as well.

Given this reasoning, we form a weighted average of the DA(x_i) value for the data accuracy of the output. Let y be determined by data items x_1, x_2, …, x_n, i.e., let $y = f(x_1, x_2, \cdots, x_n)$. Then accuracy of Data Component (*dataCmpAcy*), an estimate for the data accuracy of output y resulting solely from deficiencies in the input IR, can be obtained from

$$\text{dataCmpAcy} = \sum_{i=1}^{n} \omega_i * DA(\mathrm{x}_i) \Big/ \sum_{i=1}^{n} \omega_i \quad \text{where } \omega_i = \left|\frac{\partial f}{\partial \mathrm{x}_i}\right| * |\mathrm{x}_i| . \quad (17)$$

Although it has been implicitly assumed that the processing activities are non-structured, this is not necessarily the case. In most processes, some of the processing activities, such as product design, have manual components. Especially in this situation, the processing itself can introduce errors. Let proEffect be a measure of processing effectiveness; If proEffect=1, then the processing never introduces errors. If proEffect=0, then the processing corrupts the output to such a degree that the data accuracy measure for that output should be 0. Thus, the output accuracy of y, is determined by both input data accuracy and processing effectiveness, i.e.,

$$Accuracy(y) = \sqrt{dataCmpAcy * proEffect} \quad (18)$$

4.3.3. Cost of Information quality

The real cost of poor-quality information is most tangible, directly affecting the enterprise performance in two way. The first is in the form of direct cost as a result of “information scrap and rework.” The second is in the form of missed and lost opportunity. Missed and lost opportunity due to poor PIQ, while intangible, can be estimated fairly accurately given customer attrition patterns and complaint data.

Information production has both fixed and variable cost. Fixed costs are those required to begin producing information. They are the costs of developing applications and databases. Variable costs are those incurred in operating the applications in which information is created, updated, and used.

There are three categories of PIQ costs:

Non-quality information costs. These are the costs incurred as a result of missing, inaccurate, untimely, imprecise, not well presented, or misleading or misunderstood information, which are avoidable. These

costs include: Process failure costs, Information scrap & rework costs, Lost & missed opportunity costs.
IQ assessment or inspection costs. These costs are to assure processes which are performing properly. Minimize these costs.
IQ process improvement and defect prevention costs. The real business payoff is in improving processes that eliminate the costs of poor quality information.

In our methodology we adopt the activity-based costing (ABC), which facilitates the estimation of the product information's cost in a straightforward manner. Let C(i, j) be a the portion of the cost of IR *j* assigned to customer *i*. It can be obtained from

$$C(i, j) = PM.\cos t(i, j) \Big/ \sum_{i=1}^{M}\sum_{j=1}^{N} PM.\cos t(i, j) \qquad (19)$$

4.3.4. Value to the knowledge worker

Ultimately, the measure that counts is the value of the information resource (IR) to the knowledge worker in manufacturing enterprises. The intrinsic value of an IR includes two components: one is the actual value that a customer has applied; the other is the potential value that can not be utilized by the customer. Any potential value can transform the actual value depending upon the quality of the IRs and the capabilities of the workers. Since our concern is with evaluating alternative business process so as to improve either timeliness or accuracy or both, it is natural in this context to limit consideration of the determinants of value to these dimensions. Thus for each knowledge worker C, the actual value V_A is a function of the intrinsic value $V_{I,}$ the timeliness T and accuracy A, and could be

$$V_A = V_I(\text{wgtAccTml}(A)^{\text{senAccrcy}} + (1 - \text{wgtAccTml})T^{\text{senTime}}) \qquad (20)$$

Here V_I, *wgtAccTml, senAccrcy* and *senTime* are object dependent, and have been defined in Equation (7) in previous research efforts (see Section 4.1.7).

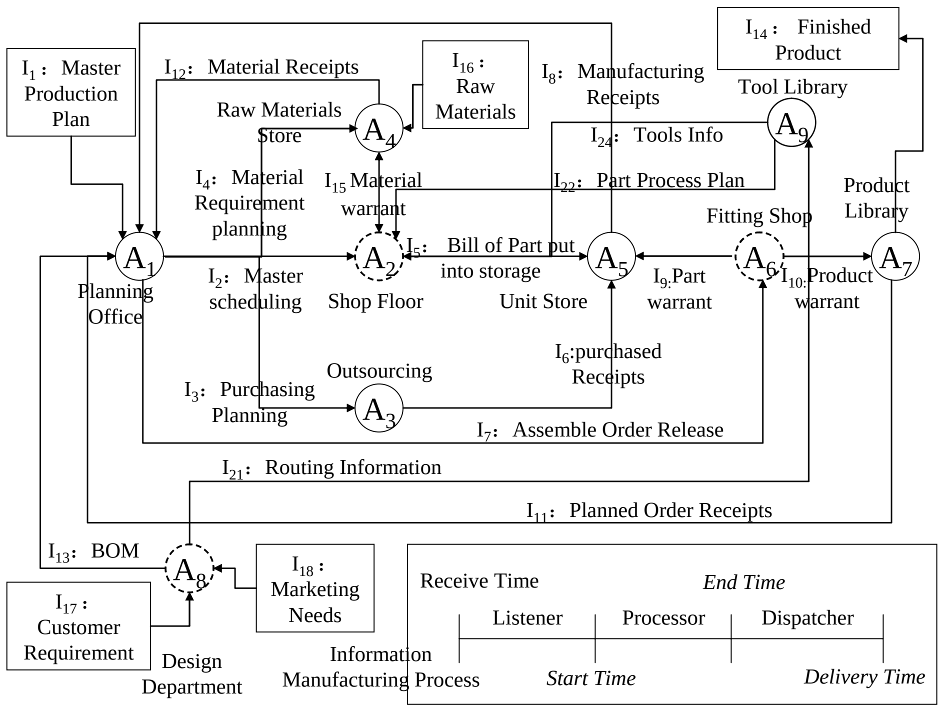
4.3.5. Profit for the Whole Process

The principal purpose of improving PIQ is to maximize the profit *P* (total actual value V_A minus total cost *C(i, j)*) received by all customers for all information resource in the whole process. Suppose there are M customers and N information resources. Then for each customer I and IR j, the total profit can be expressed

$$P = \sum_{i=1}^{M}\sum_{j=1}^{N}[V_A(i, j) - C(i, j)] \;\; subjct\ to: 0 \le \mathrm{V_A}(i, j) \le 1, 1 \le i \le M, 0 \le \mathrm{C}(i, j) \le 1, 1 \le j \le N. \qquad (21)$$

Here, V_A can be captured in Equation (20), and *C(i, j)* can be computed via Equation (19).

We have presented the core techniques of AMEQ for determining the local measures of each activity, such as timeliness, accuracy, cost, and value; and a global measure profit to the whole process. In the next section, an example is presented to illustrate some of the conceptual and computational issues that will be encountered when the process model is applied to real world scenarios.



Figue.3: Activity Model for the product manufacturing of QCYYJ Ltd

5. ILLUSTRATIVE CASE

Let us consider a manufacturing enterprise called QCYYJ Ltd. The company produces special paddle pumps of different sizes and complexity for automobile factories on demand. Figure.3 presents the core process of the scenario described for the pump manufacturing. The processing steps for improving PIQ incorporate the road map (Figure 1) and are illustrated as follow:

Step 2.1: Enterprise objects, such as HR, IR, EA, are represented firstly by the IQ team. HR＝{(1, Plan Officer, Listener), (2,Planner1,Processor), (3,Planner2,Dispatcher), (4,Shop Statistician, Listener)…(26, Operator3, Listener)}; IR={(1, Master Production Plan, 2002-11-25, 60, inner),(2, Manufacturing Plan, 2002-12-26, 60, inner),(3, Purchasing Planning, 2002-12-22, 120, inner),(4, Material Requirement planning, 2002-12-23, 180, inner), (5, Bill of Part Put into Storage, 2003-1-26, 30, inner), (6, Purchased Receipts, 2003-2-20, 30, inner), …, (24, Tools Information, 2003-5-30, 1, inner)}; EA＝{(1, Plan & Control Production, Planning Department, structured), (2, Manufacturing, Shop Floor, non-structured), (3, Provide Purchasing Part, Outsourcing Enterprise, structured), (4, Storage & Retrieval Material, Materials Store, structured), (5, Storage & Retrieval Part, Unit Store, structured), (6, Assembling, Fitting Shop, non-structured), (7, Storage & Retrieval Product, Product Library, structured), (8, Product Design, Designing Department, non-structured), (9, Provide Tools, Tool Library, structured)};

RI={(1, 2002-12-13, 1, 1, 1, 1), (2, 2002-12-15, 1, 12, 1, 2), (3, 2002-12-3, 1, 8, 1, 3), (4, 2002-10-11, 1, 13, 1, 4), (5, 2003-1-2, 2, 2, 4, 5), (6, 2003-1-11, 3, 3, 7, 6), …, (18, 2003-5-30, 2, 23, 26, 57), (19, 2003-5-30, 2, 24, 26, 58)};RO={(1, 2002-12-27, 1, 2, 3, 13), (2, 2002-12-24, 1, 3, 3, 14), (3, 2002-12-28, 1, 4, 3, 15), (4, 2003-1-24, 1, 7, 3, 16), …, (14, 2003-5-11, 7, 11, 21, 26), (15, 2003-4-20, 4, 19, 12, 55)};RP={(1, 2002-12-24, 2002-12-26, 2, 1, 2, 27), (2, 2002-12-1, 2002-12-26, 2, 13, 2, 28), (3, 2002-12-23, 2002-12-26, 2, 8, 2, 29), (4, 2002-12-16, 2002-12-22, 3, 1, 2, 30), (5, 2002-11-11, 2002-12-22, 3, 13, 2, 31), (6, 2002-12-18, 2002-12-22, 3, 8, 2, 32), (22, 2003-1-6, 2003-1-22, 15, 2, 6, 51), …, (23, 2003-1-

13, 2003-4-18, 19, 4, 11, 53), (24, 2003-3-18, 2003-4-18, 19, 16, 11, 54)}. Here we only provide the identifiers of PMs the values of which can not be determined until step 3.4.

EA	IR	Period Of Validity	Generation Time	Receive Time	cost	Timeli-ness	Accuracy	*Actual Value*	Cost	Profit
A_1	I_1	60	2002-11-25	2002-12-13	1000	.343	.849	.723	.015	.708
	I_{12}	5	2002-12-11	2002-12-15	2500	.089	.9	.574	.037	.537
	I_8	15	2002-12-1	2002-12-3	2500	.867	.96	.86	.037	.823
	I_{13}	200	2002-6-21	2002-10-11	2500	.663	.839	.831	.037	.794
	I_{11}	10	2002-12-9	2002-12-18	2500	.1	.96	.583	.037	.546
A_2	I_2	60	2002-12-26	2003-1-2	2000	.78	.5	.398	.029	.369
A_3	I_3	120	2002-12-22	2003-1-11	600	.913	.5	.582	.009	.573
A_4	I_4	180	2002-12-23	2003-1-3	800	.969	.524	.427	.012	.415
	I_{15}	5	2003-1-22	2003-1-23	450	.894	.5	.413	.007	.406
	I_{16}	180	2003-3-11	2003-3-12	450	.989	.5	.425	.007	.418
A_5	I_5	30	2003-1-26	2003-1-30	1569	.931	.5	.418	.023	.395
	I_6	30	2003-2-20	2003-2-25	789	.841	.5	.406	.012	.394
A_6	I_7	15	2003-1-22	2003-1-23	456	.966	.5	.296	.007	.289
A_7	I_{10}	10	2003-2-14	2003-5-11	987	0	.5	.177	.015	.162
A_8	I_{17}	150	2002-4-11	2002-5-14	4000	.78	.899	.87	.059	.811
	I_{18}	65	2002-4-15	2002-5-15	3000	.734	.798	.831	.044	.787

TABLE 2. Evaluation of PIQ when Information Resources are Received

Step 2.2 we consider four dimensions of PIQ in this example: Timeliness, Accuracy, Cost, and Value-added.

Step 2.3 we select a designing and manufacturing process of ZYB0809s01-001 pump for improvement.

EA	IR	PeriodOf Validity	Generation Time	Delivery Time	cost	Timeli-ness	Accuracy	*Actual Value*	Cost	Profit
A_1	I_2	60	2002-12-26	2002-12-27	639	.975	.5	.424	.009	.415
	I_3	120	2002-12-22	2002-12-24	547	.987	.689	.593	.008	.585
	I_4	180	2002-12-23	2002-12-28	652	.982	.5	.637	.01	.627
	I_7	15	2003-1-22	2003-1-24	4782	.931	.5	.418	.07	.348
A_2	I_5	30	2003-1-26	2003-1-30	123	.807	.274	.355	.002	.353
	I_{15}	5	2003-1-22	2003-1-26	654	.447	.5	.344	.01	.334
A_3	I_6	30	2003-2-20	2003-2-24	951	.931	.5	.418	.014	.404
A_4	I_{12}	5	2002-12-11	2002-12-16	425	0	.474	.172	.006	.166
	I_{19}	5	2003-4-18	2003-4-20	680	.465	.798	.394	.01	.384
A_5	I_{20}	15	2003-2-28	2003-3-11	754	.516	.5	.356	.011	.345
A_6	I_9	10	2003-1-26	2003-1-27	456	.949	.5	.417	.007	.41
	I_{10}	10	2003-2-14	2003-2-16	754	.894	.5	.396	.011	.385
A_7	I_{14}	360	2003-5-11	2003-5-11	632	1	.5	.427	.009	.418
	I_{11}	10	2002-12-9	2003-5-11	852	0	.5	.177	.013	.164
A_8	I_{13}	200	2002-6-21	2002-12-3	487	.175	.899	.588	.007	.581

TABLE 3. Evaluation of PIQ when Information Resources are Delivered

Step 2.4: EG＝ {(1, Increase total net value of all the knowledge workers in the processes, 0.8,N, 2002–1-1,2003-1-1,PRF)}.

In phase 3, we can obtain PM={(1, 3, .5, .5, .9, .8, 1000, .5, .96, .5, .5, .5), (2, 1.5, .6, .5, .9, .9, 2500, .5, .92, .5, .5, .5), (3, 1, .5, .5, .97, .95, 2500, .5, .9, .5, .5, .5),…, (5, 2, .5, .5, .5, .5, 2000, .9,.5, .5, .5, .5), (6, .5, .5, .5, .5, .5, 600, .5, .7, .5, .5, .5), (7, .5, .5, .5, .5, .55, 800, .5, .5, .5, .5, .5), (8, .5, .5, .5, .5, .5, 450, .5, .5, .5, .5, .5), (9, .5, .5, .85, .5, .5, 1569, .5, .5, .5, .5, .5), (10, .95, .5, .5, .5, .5, 789, .5, .5, .5, .5, .5), …, (56, .5, .5, .5, .5, .5, .5, .5, .5, .5, .5, .5), (57, .5, .5, .5, .75, .5, .5, .5, .5, .5, .5, .5), (58, .5, .5, .5, .85, .5, .5, .5, .5, .5, .5, .5)}

In phase 4, we can use the data in IR, HR, RI, EA and PM to compute the PIQ measures when information resources enter into all the activities. The parameters required to evaluate the PIQ can be obtained as following:

$$\Pi_{\substack{\text{IR.periodOfValidity,IR.generationTime,RI.receiveTime,PM.senCryVty,PM.dataCmpAcy,}\\ \text{PM.proEffect,PM.cost,PM.intrinsValue,PM.wgtAccTml,PM.senAccrcy,PM.senTime}}} (\sigma_{\text{RI.activityID)=i}} (\text{IR} \ \ \text{RI}) \cup (\text{HR} \ \ \text{RI}) \cup (\text{EA} \ \ \text{RI}) \cup (\text{PM} \ \ \text{RI})) \quad (22)$$

TABLE 2 provides *periodOfValidity, generationTime, receiveTime*, and *cost* required to evaluate the IRs received by the customers in activity *i*. The relevant *Cost* is obtained from Equation (19). As discussed in the pervious section, determining the timeliness value requires *currency* value which can be determined by Equation (11). Therefore, the *timeliness* value for information acquisition can be determined by Equation (10). By using the parameters coming from formula (22), the *accuracy* value can be computed through Equation (18). Then the *actualValue* to the customers can be obtained from Equation (20). The profit for each activity can be computed through Equation (21).

In a similar manner, we can use the data in IR, HR, RO, EA and PM to compute the PIQ measures when information resources are sent out from the activities. The parameters required to evaluate the PIQ can be obtained as following

$$\Pi_{\substack{\text{IR.periodOfValidity,IR.generationTime,RO.deliveryTime,PM.senCryVty,PM.dataCmpAcy,}\\ \text{PM.proEffect,PM.cost,PM.intrinsValue,PM.wgtAccTml,PM.senAccrcy,PM.senTime}}} (\sigma_{\text{RO.activityID)=i}} (\text{IR} \ \ \text{RO}) \cup (\text{HR} \ \ \text{RO}) \cup (\text{EA} \ \ \text{RO}) \cup (\text{PM} \ \ \text{RO})) \quad (23)$$

TABLE 3 provides part of the parameters required to evaluate the IRs sent by the dispatcher and results of PIQ measures. The currency value for information transfer can be determined by Equation (15), therefore the timeliness measure can be computed via Equation (10).

The parameters required to evaluate the PIQ for information processing can be obtained as following:

$$\Pi_{\substack{\text{IR.periodOfValidity,IR.generationTime,RP.startTime,RP.endTime,PM.senCryVty,PM.dataCmpAcy,}\\ \text{PM.proEffect,PM.cost,PM.intrinsValue,PM.wgtAccTml,PM.senAccrcy,PM.senTime}}} (\sigma_{\text{RO.activityID)=i}} (\sigma_{IR\text{.inforResID =RP.inputID}} \text{IR} \times \text{RP}) \cup (\sigma_{IR\text{.inforResID =RP.outputID}} \text{IR} \times \text{RP}) \cup (\text{HR} \ \ \text{RP}) \cup (\text{EA} \ \ \text{RP}) \cup (\text{PM} \ \ \text{RP})) \quad (24)$$

TABLE 4 presents part of the parameters and results. The Timeliness value can be determined by Equation(10), (12), (13), and (14).

I	O	Start Time	End Time	Intrins Value	cost	Timeliness	Accuracy	*Actual Value*	Cost	Profit
I_1	I_2	2002-12-24	2002-12-26	.85	1547	.267	.75	.588	.023	.565
I_{13}		2002-12-1	2002-12-26	.95	1456	.185	.86	.645	.021	.624
I_8		2002-12-23	2002-12-26	.65	7541	0	.844	.299	.111	.188
I_1	I_3	2002-12-16	2002-12-22	.75	562	.524	.698	.585	.008	.577
I_{13}		2002-11-11	2002-12-22	.95	650	.049	.819	.535	.01	.525
I_8		2002-12-18	2002-12-22	.85	854	0	.798	.38	.013	.367
I_1	I_4	2002-12-20	2002-12-23	.5	147	.446	.771	.386	.002	.384
I_{13}		2002-12-15	2002-12-23	.5	1263	.339	.693	.354	.019	.335
I_{12}		2002-12-16	2002-12-23	.88	784	0	.698	.368	.012	.356
I_1	I_7	2003-5-11	2003-5-11	.5	417	0	.5	.177	.006	.171
I_2	I_5	2003-1-11	2003-1-31	.7	487	.856	.5	.571	.007	.564
	I_{15}	2003-1-6	2003-1-22	.5	430	.817	.5	.403	.006	.397
I_3	I_6	2003-1-15	2003-2-18	.5	201	.894	.524	.417	.003	.414
I_4	I_{19}	2003-1-13	2003-4-18	.6	1600	.883	.798	.55	.024	.526
I_{16}		2003-3-18	2003-4-18	.5	750	.98	.5	.424	.011	.413
I_5	I_{20}	2003-2-5	2003-2-28	.5	365	.816	.5	.403	.005	.398
I_6		2003-2-26	2003-2-28	.5	456	.809	.5	.402	.007	.395
I_7	I_9	2003-1-24	2003-1-26	.35	789	.931	.5	.293	.012	.281
	I_{10}	2003-1-28	2003-2-8	.5	157	.775	.5	.397	.002	.395
I_{10}	I_{14}	2003-5-11	2003-5-11	.5	820	0	.5	.177	.012	.165
	I_{11}	2003-5-11	2003-5-11	.5	985	0	.5	.177	.014	.163
I_{17}	I_{13}	2002-6-11	2002-11-21	.9	5600	.77	.748	.784	.082	.702
I_{18}		2002-5-17	2002-11-21	.8	690	.737	.784	.698	.01	.688

TABLE 4. Evaluation of PIQ when Information Resources are Processed

6. CONCLUDING REMARKS

We have developed the AMEQ methodology for assessing and benchmarking PIQ in business processes. This encompasses three major components except DIPMS research framework: the road map for PIQ improvement, the activity-based approach of defining PIQ, and the AMEQ techniques.

The road map for PIQ improvement describes the processes, steps, tools, and techniques to measure and assess PIQ of MEs. It provides a pragmatic basis for PIQ definition, measurement, assessment, and improvement as a management tool for business performance excellence.

The activity-based approach for defining the dimensions of PIQ lays a foundation for the whole road map. It can help MEs identify measures of activities more objectively and comprehensively. It is a prerequisite for the AMEQ techniques.

The AMEQ techniques provide the models by which organizations can represent their enterprise, setup the measures for basic activities, create a mapping between the goals and measures, and compute the performance of processes. Using these techniques, organizations can self-assess their PIQ based on benchmarks identified beforehand and determine appropriate areas to focus improvement efforts.

The key contribution of the overall research, however, stems from the integration and synthesis of these components. The AMEQ methodology as a whole provides a practical PIQ tool to organizations. It can be applied in MEs and integrated with process-oriented ERP systems. The methodology is useful in identifying PIQ problems, prioritizing areas for PIQ improvement, and monitoring PIQ improvements over time.

REFERENCES

[1] Graeme Shanks, Peter B. Seddon, and Leskie P. Willcocks.. Second wave enterprise resource planning systems: implementing for effectiveness New York: Cambridge University Press, 2003.

[2] Kuan-Tsea Huang, Yang W. Lee, and Richard Y. Wang. Quality information and knowledge [M]. Upper Saddle River, N.J. : Prentice Hall PTR, 1999.

[3] ZHANG Bo-peng, Investigation on TQM for manufacturing Information—part one) [J], Manufacturing Automation, 2002, 8(24): p.1-5.

[4] Guy V. Tozer. Information quality management [M]. Oxford; Cambridge, Mass.: NCC Blackwell, 2001.

[5] English, Larry P. Improving data warehouse and business information quality: methods for reducing costs and increasing profits [M].New York: Wiley, 1999..

[6] K. Orr, Data quality and systems theory, Communications of the ACM 41 (2), 1998, pp. 66–71.

[7] Redman, Thomas C. Data quality: the field guide. Boston: Digital Press, c2001.

[8] SU Ying. Yu Ming. Zhang B.P. Performance Measurement and Application Technologies in Business Process of Manufacturing Enterprise [C]. IE&EM'2002, 19-21 September 2002, Tsinghua University, Beijing, P. R. China.

[9] Garvin, David A. Managing quality: the strategic and competitive edge [M]. New York: Free Press; London: Collier Macmillan, c1988.

[10] D.P. Ballon and H.L.Pazer, "Modeling data and process quality multy-input, multi-output information systems." Management Science. vol.31.no.2,pp 150-162,1985.

[11] Laudon, K. C., Data Quality and Due Process in Large Interorganizational Record Systems [J]. Communications of the ACM, 29(1), 1986, pp.4-11.

[12] Morey, R.C. Estimating and Improving the Quality of Information in the MIS [J]. Communications of the ACM, 25(5), 1982, pp.337-342.

[13] Wand, Y. and R. Y. Wang, Anchoring Data Quality Dimensions in Ontological Foundations [J]. Communications of the ACM, 39(11) 1996, pp. 86-95.

[14] R.Y. Wang, D.M. Strong, Beyond accuracy: what data quality means to data consumers, Journal of Management Information Systems 12 (4), 1996, pp. 5–34.

[15] W.H. Delone, E.R. McLean, Information systems success: the quest for the dependent variable, Information systems research 3 (1), 1992, pp. 60–95.

[16] D.L. Goodhue, Understanding user evaluations of information systems, Management Science 41 (12), 1995, pp. 1827–1844.

[17] R. Zmud, Concepts, theories and techniques: an empirical investigation of the dimensionality of the concept of information, Decision Sciences 9 (2), 1978, pp. 187–195.

[18] Vernadat, F., Enterprise modeling and integration: principles and applications. London; New York: Chapman & Hall, 1996.