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Using Six Sigma for Continuous Improvement of Asset Management Information Quality

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Abstract

Information is the most important asset of any organization. It is particularly important for information driven businesses like engineering asset management organizations. These businesses maintain the lifeline of economy and, therefore, it is important that the information that they capture if of high quality, processed in right systems, communicated through right channels, and presented to its stakeholders in right format. This highlights that information quality management calls for business organizations to be proactive as well as reactive, i.e. information quality concerns should be proactively addressed for every stage of information lifecycle, and at the same time it should be monitored regularly so as to take corrective action could be taken to ensure smooth functioning of information dependent business areas. The intertwined nature of information quality dimensions, such as timeliness and accuracy, adds more complexity to the already difficult scenario of information quality monitoring. This paper takes a product perspective of information and utilizes an information improvement cycle based on plan, do, check, act principle to propose a framework for information quality monitoring and improvement. It utilizes analytical hierarchy process and six sigma methodologies to obtain objective measurement of information quality by focusing on systematic assessment of multiple dimensions of information quality.

Keywords

Information quality, Asset management, Information quality assessment, Six sigma.

1. Introduction

Asset lifecycle management is information intensive. The variety of asset lifecycle processes generate, process, and analyze enormous amount of information on daily basis. Information systems utilized for asset management not only have to provide for the control of lifecycle management tasks, but also have to act as instruments for decision support. Asset lifecycle management can, thus, be viewed as a combination of decisions associated with strategic, tactical, and operational levels of the organization. The term asset in engineering organizations is defined as the physical component of a manufacturing, production or service facility, which has value, enables services to be provided, and has an economic life greater than twelve months

(IIMM 2006). Some examples include, manufacturing plants, roads, bridges, railway carriages, aircrafts, water pumps, and oil and gas rigs.

Asset managing engineering enterprises have twofold interest in information and related technologies, first that they should provide a broad base of consistent logically organized information concerning asset management processes; and, second that they make available real time updated asset related information available to asset lifecycle stakeholders for strategic asset management decision support (Haider & Koronios 2005). This means that the ultimate goal of using information systems for asset management is to create information enabled integrated view of asset management so that asset managers have complete information about an asset available to them, i.e. starting from their planning through to retirement, including their operational and value profile, maintenance demands and treatment history, health assessments, degradation pattern, and financial requirements to keep them operating at near original specifications. In theory information systems in asset management, therefore, have three major roles; firstly, information systems are utilized in collection, storage, and analysis of information spanning asset lifecycle processes; secondly, information systems provide decision support capabilities through the analytic conclusions arrived at from analysis of data; and thirdly, information systems provide for asset management functional integration.

However, in practice, data is captured both electronically and manually, in a variety of formats, shared among an assortment of off the shelf and customized operational and administrative systems, communicated through a range of sources and to an array of business partners and sub-contractors; and consequently inconsistencies in completeness, timeliness, and inaccuracy of information leads to the inability of quality decision support for asset lifecycle management (Haider and Koronios 2005). In crux, information systems utilized for asset management are not aligned with strategic business considerations and the enterprise architecture presents a haphazard data, systems, and application view. As a result, these systems could be best described as pools of data that lacks quality and value, and are not being put to effective use or to create value for the stakeholders. This paper investigates the issue of information quality (IQ). It takes a product perspective of information and proposes a framework for IQ improvement. It starts with an explanation of a common IQ issues prevalent in engineering asset managing organization, followed by a discussion of the application of plan, do, check, act cycle to IQ. The paper then presents an IQ management framework using six sigma methodology and an explanation of its constituent parts. The paper concludes with elucidating the application of the framework and necessary follow ups for IQ monitoring.

2. IQ problems and EIIA Cycle

IQ and its integration in business processes has been dealt from a variety of aspects in literature (see for example, Naumann & Rolker 2000; Jarke et al. 2003). Moreover, research about finding causes of poor information in engineering asset management has been categorized between organizational factors and technology factors. Figure 1 shows the list of both factors and its facilitators.

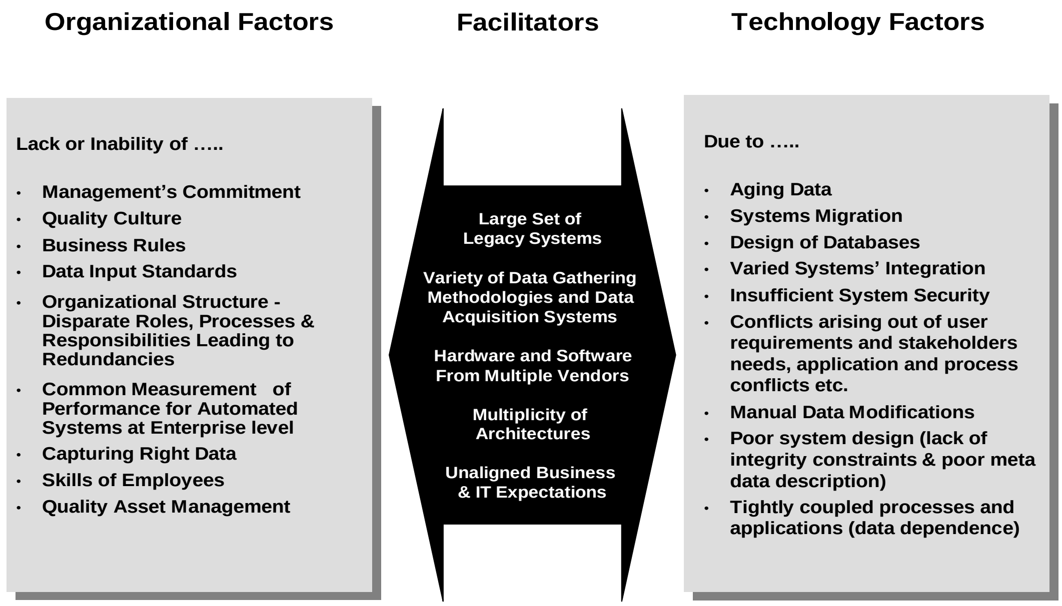


Figure 1: Causes of poor information in engineering asset management
Source: (Haider & Koronios 2003)

Even though many research studies have revealed the attributes of information and causes of poor information, managing high quality of information continually has been proven that is an extremely difficult task because it addresses technical, human, and semantic dimensions of IQ as well as different classification of IQ problems. IQ problems can roughly be divided into two categories (figure 2), such as single source and multi-source problems, each of these two categories is further divided into two sections, i.e. schema and instance related problems. Schema level problems may replicate in instances, and can be resolved at the schema level by an improved schema design, schema translation and schema integration. Instance level issues signify information errors and inconsistencies not visible at the schema level. Most common examples of poor information (Jarke et al. 2003) are, format differences; information hidden in free-form text; violation of integrity rules; missing values; and schema differences.

Therefore, maintaining high quality of information and conforming to user requirements is required to have comprehensive IQ framework which contains a proven quality initiative. This research, therefore, borrowed the concept of Plan, DO, Check, Act (PDCA) Cycle to manage information systematically.

Figure 3 illustrates the main concept of proposed IQ framework, named EIIA cycle, which includes,

- Establishing stage, i.e. to establish IQ objectives and requirements from customers of information to ascertain their information related issues/problems/complaints, and how to transform the complaints in accordance with the business rules.
- Identifying stage, i.e. the pre-processing of the IQ measurement and analysis. As IQ cannot be 'objectively' measured due to the complexities of IQ dimensions; unlike the Do stage in

PDCA cycle that aims at small scale change or experimental test, the 'identifying stage' reveals details, correlation, and impact of IQ dimensions on each other as well as overall IQ.

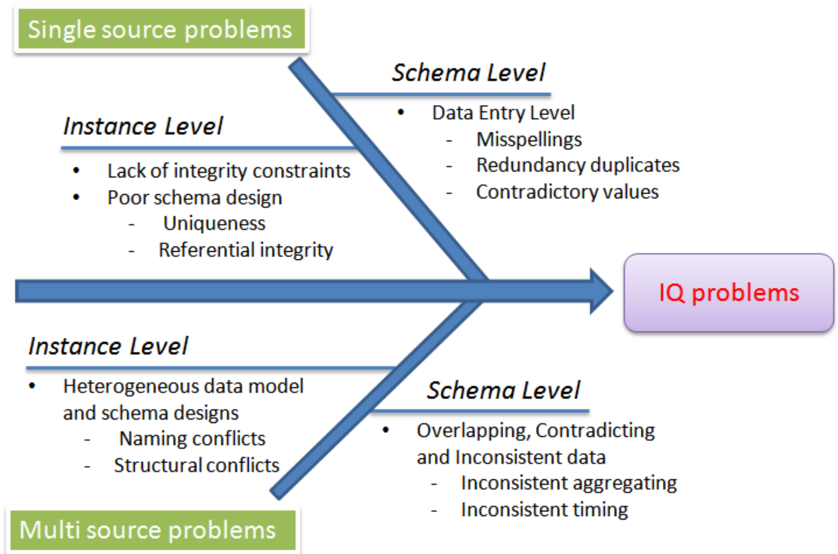


Figure 2: Categorized IQ problems
Source: (Rahm & Do 2000)

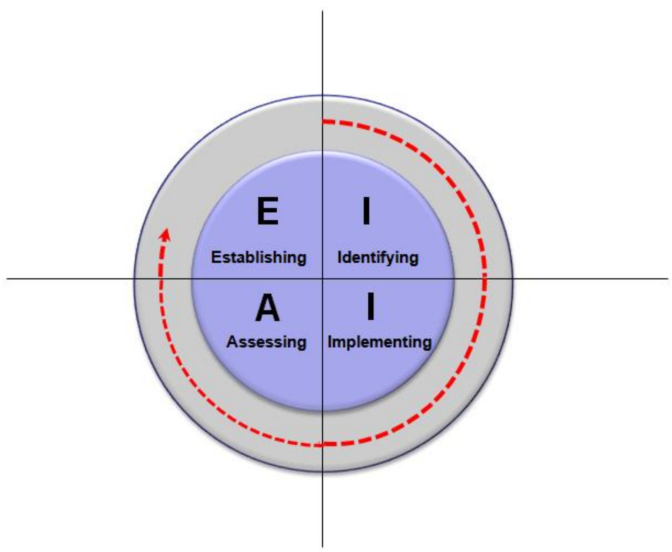


Figure 3: EIIA Cycle for continuous improvement of information

- Implementing stage, i.e. the measurement of IQ. In this stage, the identified IQ dimensions in identifying stage are applied. IQ dimensions are measured and analyzed by revealing critical factors and root causes of poor information. Just like the PDCA Cycle, if the outcome is not successful it is necessary to return to the establish stage and start the cycle again.
- Assessing stage, i.e. to compare current IQ measurement results with improved IQ measurement results though continuous IQ monitoring.

3. Six-sigma Methodology for Information Quality Management

As IQ is a broad term, literature reflects its many different definitions; however, Tayi and Ballou (1998) term IQ as 'fitness for use' is most widely used in IQ area. The brevity of this definition covers most important aspects of information usage. Haider and Koronios (2003) argues that the most IQ related issues are tightly linked with how users actually use information in the system. This is because the users ultimately judge of the quality of the information produced for them. In engineering asset management, even there are various reasons, the most issue of IQ has its roots in multiplicity of information acquisition techniques and methodologies, and the processing of the information thus captured within an assortment of disparate systems. As a result, the information requirements of asset management processes are not properly fulfilled.

Wang (1998) argues that IQ should be controlled first before an attempt is made to manage it. In other words, IQ control is prerequisite clause of IQ management. Without controlling IQ, problems relating to poor information cannot be resolved completely and sophisticated IQ management framework cannot be derived. In order to control IQ, it is important to assess quality if information residing in the organizational information systems. However, it is relatively easy to ascertain the quality of information relating to specific IQ dimensions, but assessing the impact of an IQ dimension on other dimensions is extremely difficult. Nevertheless, by understating how each IQ dimension works and how it affects other IQ dimension is critical for controlling overall quality of information being captured, processed, and maintained in the organizational information systems. However, to ascertain the IQ control requirements it is essential to view information as a product of information systems.

Treating information as a product is to provide a well-defined product process and produce high quality information product rather than treating information solely as the by-product of business process execution. This is the key idea that this paper uses to apply six-sigma methodology to IQ area for quality improvement and IQ assessment. Six-sigma is an organized and systematic method for manufacturing process improvement that relies on statistical methods and the scientific method to make reductions in defect rates (Linderman et al. 2003). Applying six-sigma methodology to IQ assessment, therefore, provides benefits, such as defining critical factors to quality, measuring current quality (sigma) level, analyzing deficiencies in information and identifying the root causes of poor information, improving quality of information products, and controlling standardized IQ assessment framework. Table 1 shows the analogy between product manufacturing and information manufacturing to manage information as a product.

	Product Manufacturing	**Information Manufacturing**
Input	Raw Material	Raw Data
Process	Assembly Line	Information System
Output	Physical Products	Information Products

Table 1: Product vs. information manufacturing
Source: (Wang 1998)

Using a product perspective of information, figure 4 presents a six-sigma we develop an IQ assessment framework. Although this framework appears as assessing IQ, its fundamental core is based on continuous IQ improvement.

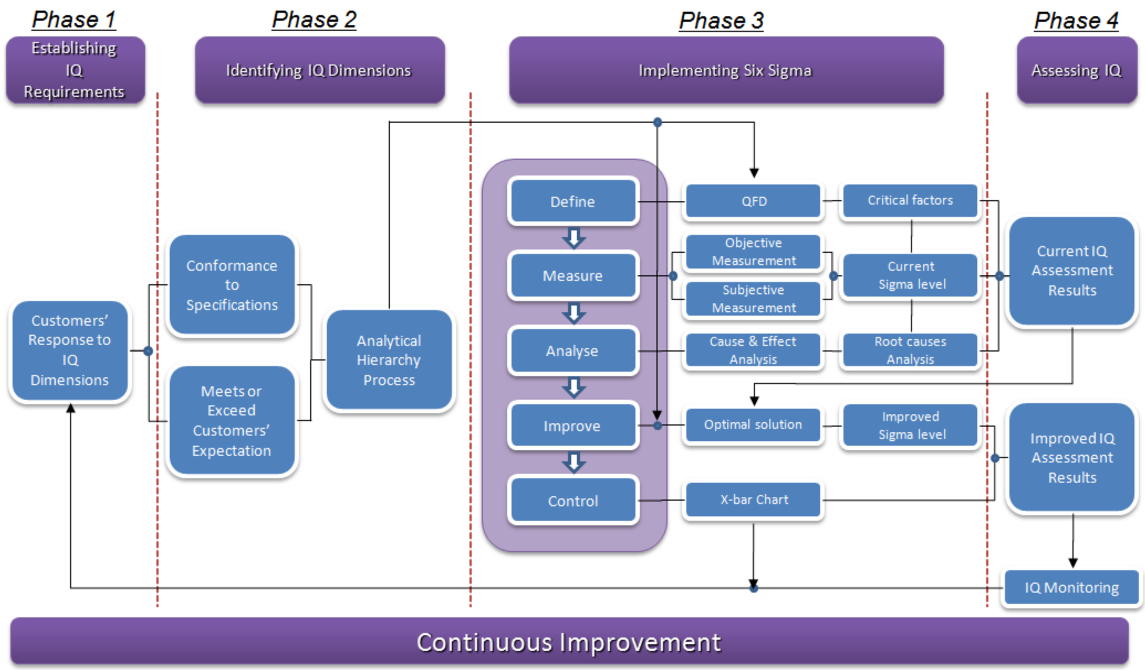


Figure 4: IQ Assessment Framework Using EIIA Approach

3.1 Establishing IQ Requirements (Phase 1)

At the initial stage, the proposed framework seeks information stakeholders' requirements in terms of IQ. These requirements are then translated or mapped to the various IQ dimensions, such as free of error, timeliness, completeness, accessibility, and security. The authors propose to survey information stakeholders to collect their responses to IQ.

Considering the fact that these stakeholders represent a variety of job functions, their interpretation of IQ and related dimensions is not standard. It is therefore important to view customer's response with regards to business rules, in order to reduce the level of abstraction. Here, the business rules are categorized by attribute domain constraints, relational integrity, historical information, and data dependency rules to ensure quality of data. The IQ requirements of customers are, thus, linked to IQ dimensions.

3.2 Identifying IQ Dimensions (Phase 2)

At this stage, IQ dimensions from phase 1 are corresponded to the IQ hierarchy. The IQ dimensions are categorized by the 'conformance to specifications' i.e. product quality; and the 'meets or exceeds customers' expectation', i.e. service quality, respectively. Here, the product quality or information quality implies quality dimensions associated with information, and the service quality include dimensions that are related to the process of delivering right information at right time to right stakeholders. The end result of this exercise is a set of hierarchy or IQ dimensions as shown in table 2. Analytical Hierarchy Process (AHP) is utilized to correlate these dimensions and assign weights of relative importance. AHP is a hierarchical representation of a system assigning weights to a group of elements by a pair-wise comparison (Saaty 2007). The pair-wise comparisons operate by comparing two elements at one time regarding their relative importance throughout the whole hierarchy. Therefore, it helps to capture the importance of desired measurement objects in comparison to other objects in the same hierarchy. The assigned weights to IQ dimensions are applied to quality function deployment (QFD) by providing the weights of importance as a scale of importance.

	Categories	Quality Perspective	Assessments Items
Information Quality Dimensions for Assessments	Conformance to Specifications	Product Quality	Free of Error
			Conciseness
			Completeness
			Consistent Representation
		Service Quality	Timeliness
			Security
	Meets or Exceeds Customer's Expectations	Product Quality	Appropriate Amount
			Relevancy
			Understandability
			Interpretability
			Objectivity
		Service Quality	Believability
			Accessibility
			Easy of operation
			Reputation

Table 2: Hierarchy of IQ dimensions
Source: (Kahn & Strong 1998)

The most important deliverable of this research will be a correlation matrix that will identify how each IQ is related to other IQ dimension(s), and how each dimension could be improved in relation to associated dimensions to improve the overall quality of information. Each piece of information has a variety of quality dimensions, and each dimension is dependent on the other dimension(s) of quality. For example consider the following scenario. A company is dealing with customer information as show in figure 5. The current information reflects that the customer Simon lives in Hallett Cove, whereas the customer has actually moved to a new address. In this case the current address has not been updated in the information system.

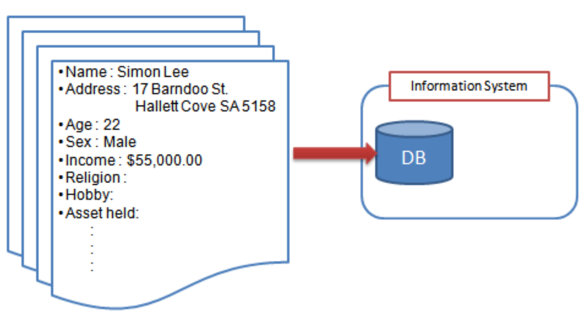
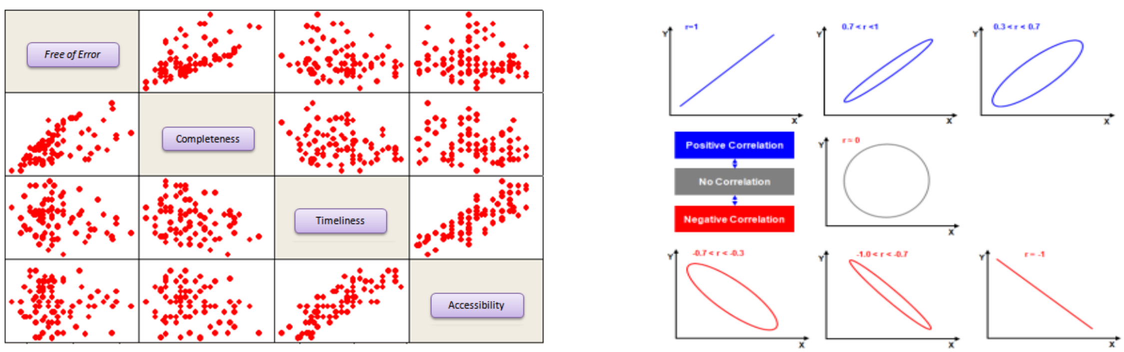


Figure 5: A customer data entry form

Apparently, this is a problem of data 'relevancy' because the data is not valid in the information system. This problem of the IQ dimension of 'relevancy' is further dependent upon 'timeless', and 'accessibility'. 'Timeliness', because the updating cycle of data in the system is large and the current data is not available. It could be due to factors such as lack of onsite data processing, lack

of information integration, batch processing, or quality assurance/control checks etc. Similarly, in terms of ‘accessibility’ dimension, there is a possibility that information is not accessible/ available to the custodians of this information system. This case scenario signifies that it is essential to deal with ‘timeliness’, and ‘accessibility’, dimensions of IQ to improve ‘relevancy’ of information in the information system. At this stage, we need to find out what is the correlation between ‘relevancy’ and other quality dimensions. It is obvious that finding out their positive/negative or No correlation is critical for enhancing the quality of information.
Now consider another case scenario relating to ‘completeness’ dimension. In order to improve upon this quality dimension, the customer data (as discussed in the earlier case scenario) contains data fields such as age, hobby, children, income, assets held, religion etc. These attributes are significant for information use/reuse for customer profiling. However, by adding more attributes, the information has also become vulnerable to data entry errors, which may affect information ‘free of error’. Furthermore there is also the possibility that the information may now be ‘incomplete’, ‘incorrect’, or ‘inadequate’, and collectively they affect (positively or negatively) the ‘reputation’, or ‘believability’ of information. Hence, understanding of correlations between IQ dimensions can be the purpose of this phase. An example of output image of correlations matrix is shown in figure 6 (a).



(a) Sample Correlation Matrix (b) Coefficient ‘r’

Figure 6: Example of correlation matrix and coefficient ‘r’

The different IQ dimensions are placed in X-Y axis and their relationship, obtained from information system, will be place in it. Once matrix is designed, their correlation coefficients ‘r’ is figured out and these coefficients is represented as positive and negative correlations of IQ dimensions like figure 6 (b). Here, ‘r’ has range from ‘+1’ to ‘-1’ and ‘+1’ /‘-1’ represent strong positive/negative correlation. This matrix can be basis of trade-off criterion of IQ dimensions.

3.3 Implementing Six-sigma (Phase 3)

This phase applies six-sigma methodology to IQ dimensions, based on DMAIC (Define, Measure, Analyze, Improve, and Control). Table 3 shows each perspective, procedure, and expected output.

- **Define Phase**

The define phase consists of three stages: Process, Scope, and Requirements. At process stage, overall structure of information flow is drawn to provide a top down view of IQ from a business perspective. In the scope stage, the scope of IQ from an information system perspective is defined to profile IQ dimensions and to identify IQ problems related IQ assessment. In the requirements stage, the specifications of each IQ dimension and IQ rule are defined to meet the customers' requirements utilizing the results of the phase 2 by creating the QFD to identify the correlation of each IQ dimension. In order to implement Six Sigma into IQ assessment, the specifications will be different according to different users at different levels. This is because quality is defined differently at different levels and with different viewpoints. Therefore, customized IQ specifications based on IQ dimensions as assessment criteria must be established in this phase. Each IQ dimension criteria can be utilized in the assessing IQ phase as inspection list. Simultaneously, definition of CTQ (Critical to Quality) must be conducted at the beginning of this phase. CTQs must be interpreted from qualitative customers' requirements and be measured in the measure phase.

- **Measure Phase**

The measure phase consists of two stages, i.e. information collection and information measurement. In the information collecting stage, identifying criteria, measurement systems, scales and sampling methods are considered. Once the information collecting stage is complete, the information measurement calculates current sigma level with the specification of each IQ dimension and IQ rules. In the information measurements stage, the method of IQ measurement can be categorized to objective and subjective measurement.

- **Analyze Phase**

The analyze phase consists of two stages: identifying poor information and analyzing root cause. In the identifying poor information stage, the deficiencies of information products are revealed according to the results of the measure phase and tracing the mapping between the CTQs and IQ rules. In the analyzing root cause stage, the cause and effect analysis is utilized by generating comprehensive lists of possible causes to discover the reason for a particular effect and understand of how information products may become deficient in information systems. In this stage, a cause and effect diagram is designed based on the results of define and the measure phases to perform root causes analysis. This root cause analysis focuses on specific problems by resolving into basic elements of problems.

- **Improve Phase**

The improve phase consists of two stages, i.e. eliminating root causes and improving sigma level. The main objective of this phase is to identify an improvement of information systems by increasing quality of information products. In the eliminating root causes stage, determining of an optimal solution and finding the optimal trade-off values of IQ dimensions for IQ improvement is designed by eliminating the root causes which are discovered in the analyse phase. In the improving sigma level stage, all the results from define, measure, and analyse phases are integrated to lead the improved sigma level for IQ improvement.

- **Control Phase**

The control phase consists of two stages, i.e. controlling and monitoring. The main objective of this phase is to maintain high quality of information. In the controlling stage, representing IQ assessment results for information system, standardizing the IQ assessment framework are conducted, and documents are generated. In the monitoring stage, an X-bar chart representing each IQ dimensions with upper and lower control level and inspection lists of each IQ dimension are designed. The X-bar chart is a control chart used for monitoring information by collecting sample at regular intervals (Linderman et al. 2003). Each IQ dimension of sampled information in information system is monitored by using the X-bar chart at regular intervals to prevent production of poor information and to ensure the high quality of information.

Six-sigma Phases	Six-sigma Perspective	IQ Perspective	Procedure	Expected Output
Define	Defining the process and customers' satisfactions	Representing customers' requirements (Specification) to IQ and Identifying IQ problems related IQ assessment.	Mapping and representing customer's satisfactions to IQ dimensions and requirements.	Failure Mode & Effects Analysis QFD (Quality Function Deployment)
Measure	Collecting and comparing data to determine problems	Identifying criteria, systems, scales and scope for IQ measurement. Identifying data sampling method.	Implementing measurement of each IQ dimensions and calculating sigma level.	Determining current sigma level (Performance).
Analyze	Analyze the causes of defects	Identifying poor information and root cause of poor Information.	Critical factor analysis based on measurement results. Applying correlations matrix.	Root causes of poor information Fish-born diagram/Logic tree.
Improve	Eliminating variations and creating alternative process	IQ improvement by eliminating root cause of poor information.	Identify and define specific process improvements for information system	Assessment results IQ assessment framework
Control	Monitoring and controlling the improved process	Standardize IQ	Interpret and report information quality. Document improvement.	X-bar Chart for IQ monitoring

Table 3: Six Sigma perspectives to IQ perspectives

3.4 Assessing IQ (Phase 4)

Based on the phase 3 (Implementing Six Sigma), current IQ and improved IQ assessment results are compared to evaluate IQ assessment results. In order to ensure the improved IQ continually, the X-bar chart derived in the Control phase of the phase 3 is applied. By using the X-bar chart, if a certain dimension exceeds the specified limits, then the X-bar chart would raise alarm about that dimension. Figure 7 shows an example of IQ monitoring. In this case, “timeliness” exceeds the accepted limits, which indicates that sampled information in an information system is deficient in the “timeliness” dimension. Here, “timeliness” could belong to the service quality and conformance to specifications during product manufacturing process. For example, one stakeholder may be interested in timeliness of information on how much he/she has to manufacture and the other one may be interested in timeliness of information on how much has been manufactured. In this case if the same standard specification for timeliness is applied for both the information users, then sigma level will decline. This is because quality is defined differently at different levels and different viewpoints. In other words, a certain six sigma level

IQ dimensions' specification will be acceptable to operator of information systems but not to information users for decision support or business intelligence. Hence, the tolerance of sigma level needs to be carefully designed while identifying IQ dimensions according to the different viewpoints and the inspection list which is developed from the define phase of the phase 3.

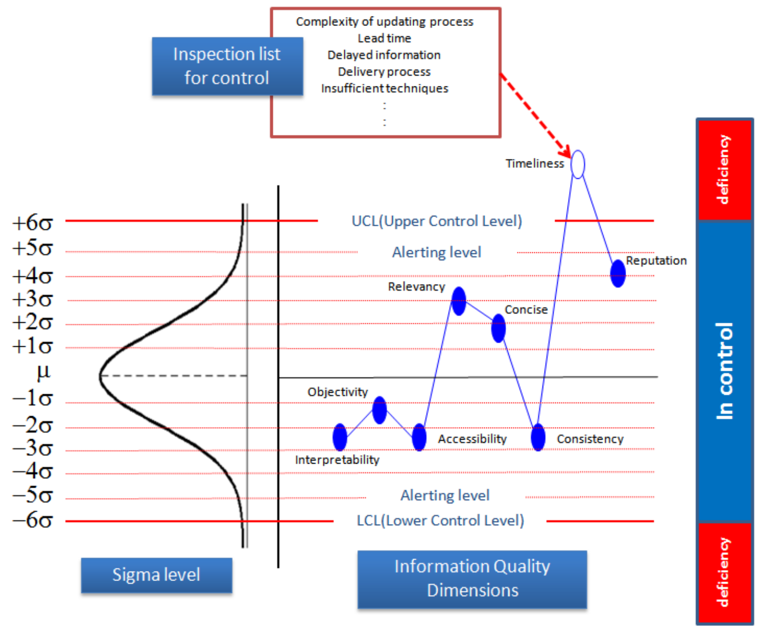


Figure 7: X-bar chart for IQ monitoring

4. Conclusions

Central to this research has been the questions of how IQ can be improved continually and what methodology should be placed in beyond complexity of IQ dimensions and its problems. In order to answer these questions, we have presented a methodology for IQ assessment and management based on the six-sigma approach. By discovering causes of poor information from the organizational and technology factors, this research leads us to EIIA cycle. By treating information as a product, transforming six-sigma perspectives to IQ perspectives, and mapping information on to the six-sigma design, we derived six-sigma centric IQ framework which is capable of providing benefits such as, defining critical factors for quality of information, measuring current quality (sigma) level, analyzing deficiencies in information and identifying the root causes of poor information, improving quality of information products, and controlling and standardization of IQ through continuous measurement of data for anomalies. The proposes framework is, thus, able to provide accurate, systematic and pragmatic assessment results. Although the proposed framework offered broad guideline toward IQ improvement, there is still much to be learned about specifications determining of each IQ dimension because the specifications directly affect the level of quality.

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