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ENVIRONMENT-BASED DESIGN (EBD) APPROACH TO DEVELOPING QUALITY MANAGEMENT SYSTEMS: A CASE STUDY

Xuan Sun
Yong Zeng
Concordia Institute for Information Systems Engineering, Concordia University, Montreal, Canada

Fayi Zhou
City of Edmonton, Alberta, Canada

This paper shows how to develop a manual for Quality Management System (QMS) by using a design methodology - Environment Based Design (EBD). The EBD includes three interdependent design activities: environment analysis, conflict identification and solution generation. The EBD is particularly effective when customers' wants are not clearly understood where designers can be given the right direction through the analysis of the product's working environment. In the case study presented in this paper, the customer wanted to develop a quality manual for a flow monitoring service. The challenge was that the content and structure of the final manual were not clear to the designers. By taking this task as a design problem, the EBD was applied to analyse the current service including the organization structure, the business processes, and the existing documents. After critical conflicts were identified, the quality manual and a data processing software system were produced for the client. This application of the EBD shows its effectiveness as a generic design methodology.

Keywords: *quality management system (QMS); environment-based design (EBD); quality manual; environment monitoring system*

1. Introduction

A Quality Management System (QMS) can be defined as "a management system to direct and control an organization with regard to quality" (ISO9000, 2000). The organization should establish, document, implement and maintain a quality management system, as well as continually improve its effectiveness to meet the requirements of some international standard (ISO9001, 2000). How to develop an effective QMS has always been a challenging problem due to the complexity to achieve performance excellence such as enhancing productivity, reducing cost, increasing customer loyalty and bring other general benefits to an organization (Yang, 2006).

Over the last few decades, theories and methodologies have been proposed to guide the development of quality management systems. Vainio and Mattila (1996) developed a model of total quality management system through group work, which is the place where the supervisors and employees in question participated, for an electricity company based on ISO 9001 and ISO 9004-2. ISO 9000 is used to help the companies to improve quality in terms of work procedures, product and service quality, team spirit, subcontractor control, efficiency and complaints (Lee et al., 1999). Houston and Rees (1999) developed a quality management system for a postgraduate education programme by using a multiple methods including literature search, project group discussions, informal and formal meetings with academic staff and students, flow charting processes, matrix mapping to make comparisons and the assimilation of existing quality and other written material. Six Sigma, as a methodology for total quality management system (Klefsjö et al., 2001), has been widely used to select the tools and to support the values of organizations, in order to cut organizations' costs. Matthews (Matthews, 2001) introduced a case study about implementing quality management systems in an academic department based on action research, which is an approach for organizational change and management development through combining action with research. Advanced Product Quality Planning (APQP) – a concept belonging to standardized quality management is often used in designing, understanding and mastering product quality planning (Bobrek and Sokovic, 2005). Yang (2006) tries to develop an innovative and comprehensive quality management system as a useful benchmarking reference for service organization, which is based on sound theoretical and pragmatic considerations. A new methodology based on fuzzy rules (Lau et al., 2009) is presented as a tool to discover the hidden relationships among all the process variables in the development of quality management system.

However, most of the existing methods for quality management system development focus more on "what" should be done rather than on "how" to do it. As a result, the traditional approaches to developing QMS heavily rely on experience not only about QMS development, but also in the corresponding specific application field. This makes it a challenging task for novice engineer to develop a high quality QMS and for an experienced engineer to work on a new area. An operational methodology becomes necessary for the rapid development of quality management systems.

This paper aims to introduce a design methodology – Environment-Based Design (EBD) to show how it can be applied to develop a quality management system efficiently and effectively. The EBD is a generic design methodology including three activities: environment analysis, conflict identification and solution generation. In order to develop a quality management system, all related components and requirements about QMS, as well as the relationship between these components should be analysed. Potential conflicts exist between environment components or in the relations between these components. The EBD identifies those potential conflicts and shows how to resolve these conflicts such that the developed QMS can meet or exceed the customers' expectations.

A variety of design theories and methodologies have been proposed in the last several decades, such as general design theory (GDT) (Yoshikawa, 1981), theory of inventive problem-solving (TRIZ) (Altshuller, 1984), the systematic design methodology (Hubka and Eder, 1988, Pahl et al., 1988), axiomatic design (Suh, 1990), total design (Stuart, 1991), decision-based design (Hazelrigg, 1996), formal design theory (Braha and Maimon, 1998), axiomatic theory of design modelling (Zeng, 2002) , adaptable design (Gu et al., 2004), function based design (Tomiyama and Yoshikawa, 1987, Umeda et al., 1990, Umeda and Tomiyama, 1997, Stone and Wood, 2000, Hirtz et al., 2002, Gero and Kannengiesser, 2004), and affordance based design (Maier and Fadel, 2009). Still, a robust methodology is needed to cope with the co-evolution of design problem, design solutions, and design knowledge resulted from the recursive nature of design (Zeng and Cheng, 1991).

The rest of this paper is organized as follows. In Section 2, we introduce the theoretical foundation and procedure of the EBD. A case study is given in Section 3 to show how the EBD works. In this section, the EBD is used to analyse requirements and help to get the final quality manual. In Section 4, we summarize our study, discuss the limitations, and suggest future directions.

2. Environment-Based Design (EBD) Methodology and its Fundamentals

Intuitively, design is a human activity that aims to change an existing environment to a desired one by creating a new artifact into the existing environment. Environment-Based Design (EBD) is such a design methodology that provides step-by-step procedures to guide a designer throughout this environment change process. The underlying principles behind the EBD are that design comes from the environment, serves for the environment, and goes back to the environment. The EBD (Zeng, 2004, Zeng, 2004, Zeng, 2011) was logically derived from the observation above following the axiomatic theory of design modeling (Zeng, 2002). As illustrated in Figure 1, the EBD includes three main activities: environment analysis, conflict identification, and solution generation. These three steps work together progressively and simultaneously to generate and refine the design specifications and design solutions.

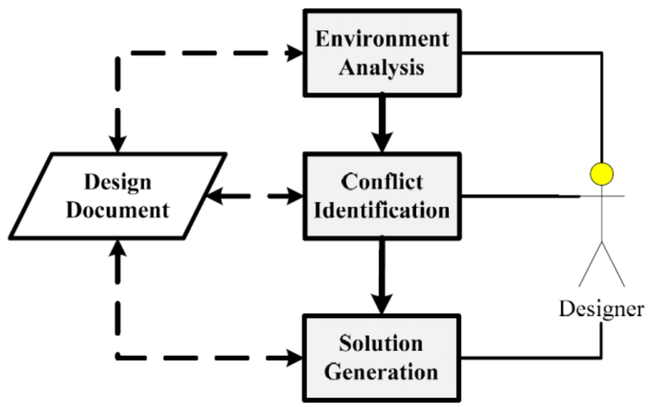

Fig. 1 Environment-Based Design: Process Flow (Zeng, 2004, Zeng, 2011).

This section will give an overview of the EBD methodology. Three activities of the EBD will be explained, followed by introduction of other strategies related to the EBD.

2.1. Introduction to EBD

2.1.1. Environment Analysis

Environment is a compound object including its components and the relationships between those components. Since all product requirements come from the relevant environment, clearly and correctly identifying environment components is critical for a successful design. The objective of environment analysis is to identify the environment in which the desired product is to work and is to be derived from (Zeng, 2004, Zeng, 2011). From the environment implied in a design problem described by the customers, the designer will introduce extra environment components that are relevant to the design problem at hands. Results from this analysis constitute an environment system.

In the environment analysis section, by using Recursive Object Model (ROM) (Zeng, 2008) and question asking strategy (Wang and Zeng, 2009), the whole environment system will be broken down into sub-systems, and each sub-system will be decomposed into smaller components until these components are proper for defining the current environment system.

2.1.2. Conflict Identification

Conflicts are considered as the driving force in the EBD process (Zeng, 2004, Zeng, 2011). From the updated ROM diagram that is developed in environment analysis, potential conflicts may be identified between environment components, as well as in the relations between these components. As shown in Figure 2, there are three forms of conflicts in a ROM diagram: conflict between two objects, conflict between two constraint relations, and conflict between two predicate relations. Design conflicts can be identified by iteratively applying the three rules (see Table 1) to the ROM diagram for a design together with the semantics of the constrains or predicates.

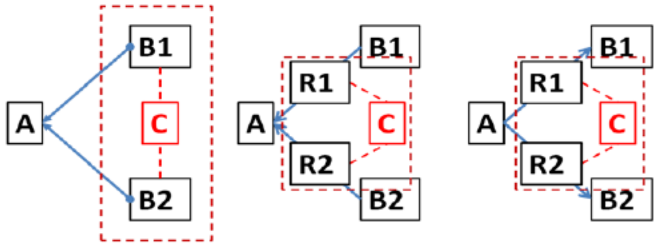

Fig. 2 Three Rules for Conflict Identification from a ROM Diagram.

Table 1 Rules for identifying potential conflicts

Rule 1:	If an object has multiple constraints, then potential conflict exists between any pair of constraining objects
Rule 2:	If an object has multiple predicate relations from other objects, then potential conflict exists between a pair of those predicate relations
Rule 3:	If an object has multiple predicate relations to other objects, then potential conflict exists between a pair of those predicate relations

2.1.3. Solution Generation

Before generating solutions to identified conflicts, the designer should analyze them first to identify the root conflicts. The principle is to establish dependences among potential conflicts as one conflict may be resulted from others. The root conflicts are those that have direct and/or indirect influence on the other conflicts, resolving a critical conflict may eliminate some conflicts that depend on it. Effective solutions can be generated in this manner. With the generated solutions, the ROM diagram, which represents the original design problem, is updated again. Repeat the process until no more undesired conflicts exist.

In generating design solutions, a design process was divided into two parts: atomic design and the recursive resolution of complex design problem (Zeng and Cheng, 1991). Atomic design is where knowledge is available or can be systematically discovered to resolve a conflict. Hence, it depends on the designer's experience and background. Obviously, an experienced designer can have a more complex atomic design than a novice. Recursive resolution of a complex design problem can be conducted through environment decomposition, which starts with the identified root conflict.

2.2. Foundation for Applying EBD

2.2.1. Recursive Object Model (ROM)

As shown in the last subsection, environment structure can be used to represent design mathematically throughout the design process. A critical component in the structure operation is the interaction operation. To facilitate the application of the structure operation, the Recursive Object Model (ROM) is proposed to represent the information appeared in design (Zeng, 2008). The ROM includes two kinds of objects, which are primitive and compound objects, and three kinds of relations: constraint, predicate and connection. Table 2 shows the graphic symbols in the ROM.

Table 2 Types of symbols in ROM (Zeng, 2008)

Type	ROM symbols	Description
Object	O	Everything in the universe is an object.
Compound Object	O	It is an object that includes at least two objects in it.
Constraint Relation	ξ	It is a descriptive, limiting, or particularizing relation of one object to another.
Connection Relation	ι	It is to connect two objects that do not constrain each other.
Predicate Relation	ρ	It describes an act of an object on another or that describes the states of an object.

The ROM is a fundamental tool to the EBD. In environment analysis, designers transform original design problem and requirements described in natural language into a ROM diagram. The transformation enables the designer to define and understand the design problem more clearly. In conflict identification, a ROM diagram can show the relations between environment components intuitively, which can be used to identify the root conflict.

2.2.2. Question Asking Approach

Product requirements are descriptions of the desired solution to a design problem. In engineering design, just as in all other design problems, the efficient, precise, and complete specification of design requirements is critical if designers are to deliver a quality design solution within a reasonable range of cost and time (Wang and Zeng, 2009). Therefore, another main tool used in the EBD is question asking approach. How to ask proper questions is critical for collecting right product requirements and having a correct understanding of current system.

There are two types of questions should be asked based on the developed ROM diagram in environment analysis. The first is generic question for the clarification and extension of the meaning of the design problem whereas the second is domain specific question for implicit design information related to the current problem (Wang and Zeng, 2009). The generic questions are based on linguistic analysis of the description of a design problem. They help designer to better understand the design problem. The domain specific questions are based on the life cycle of design product. The purpose of asking domain specific questions is to collect information that would have significant influence on the design problem.

2.2.3. Classification of Product Environment

In order to further verify the completeness of the extracted environment components and their relations, a roadmap was proposed as guidance for requirements modeling (Chen and Zeng, 2006). In this roadmap, requirements (structural or performance) were categorized by two criteria in terms of different partitions of product environment. One criterion classifies the product requirements by partitioning product environment in terms of the product life cycle whereas the other classifies them by partitioning the product environment into natural, built, and human environments (Zeng, 2011). For the case of manufacturing industry, Chen and Zeng (2006) divided the life cycle into seven kinds of events, which were design, manufacture, sales, transportation, use, maintenance, and recycling. The requirements were fit into the seven events. At any time point of product life, one or some of these seven events might occur simultaneously or alternatively (Chen and Zeng, 2006). On the other hand, as illustrated in Figure 3, they classified the product requirements into three environments: natural environment, human environment and built environment. In this pyramid-like model, requirements at the lower levels have higher priority in the development of a design solution while those products meeting the requirements at the highest level are said to be called high usability products (Zeng, 2004). They pertain to the purposes of the human use of the product (Wang and Zeng, 2009); the lowest level of product requirements comes from the natural environment; and the rest are the result of the built environment. Although product life cycle varies from product to product, by following the roadmap, the implicit requirements can be found, which gives the designer a very detailed "whole picture" about the design problem.

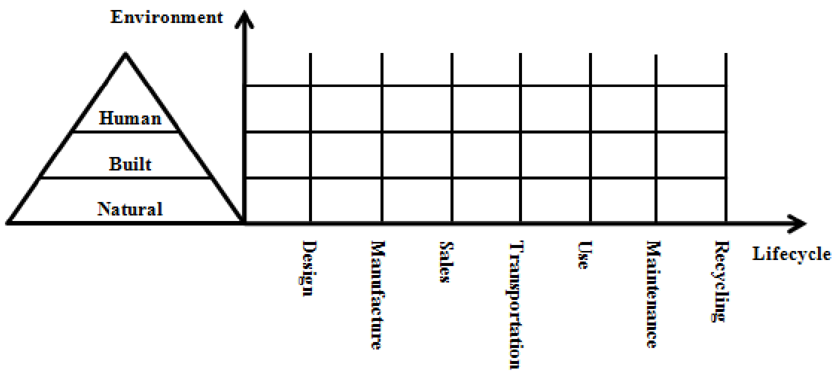

Fig. 3 Roadmap for Product Environment Classification.

3. Case Study: Development of a Quality Manual for Environment Monitoring System in a City

3.1. Background

City of Edmonton, Alberta, Canada, runs a monitoring program to monitor and report the performance of the city's drainage system (Edmonton, 2004). Under the obligation of ISO 9001 and ISO 14001, the city's monitoring group (the customer, hereafter) decided to develop and implement a quality management manual to provide higher quality and more efficient services with current available resources.

In the beginning of the project, the university research team was not sure about what the customer exactly wanted and what should be included in the final manual. The sample quality manuals provided by the customer all have different contents. After having failed to produce a manual that satisfies the customer by following a traditional quality management approach, the university research team adopted the EBD methodology by viewing the development of quality manual as a design problem. It must be indicated that the two processes were conducted by two different individual students, respectively, with a small amount of overlapping between their works.

In conducting environment analysis, a great amount of documents from the customer are organized and digested for the design purpose. Other necessary information is solicited through questions generated by the EBD questioning algorithms. Conflicts in the existing environment monitoring system are identified based on the information such as the characteristics of the drainage system and the ongoing business processes. Solutions are then produced to resolve the conflicts. This process clarified the questions regarding what must be included in the quality manual and what must be implemented to enhance the existing environment monitoring process. The customer is thus satisfied with the project results.

The objective of this design problem can be summarized as follows:

"Develop a quality manual for current monitoring system to meet quality requirements and to provide efficient services"

3.2. Environment Analysis

The ROM diagram of this objective is drawn as in Figure 4. According to the ROM diagram, it is clear that the component "manual" has the most undefined constraint relations, which means that the "manual" is the most important component. Based on the question asking strategy mentioned before, the generic questions about objects constraining the critical component "manual" should be further defined firstly. So questions about compound objects "monitoring system", "quality requirements", "efficient service" and "quality manual" should be asked now. For example, we start with object "quality requirements", asking generic questions and answer them: "what kinds of quality requirements should be met?" The answer is ISO 9001 and ISO 24511. Then, we ask questions about ISO 9001 and ISO 24511: "What is the related information in ISO24511?" "What are the requirements based on ISO 9001?" The ROM diagram can be extended based on the answers of these questions.

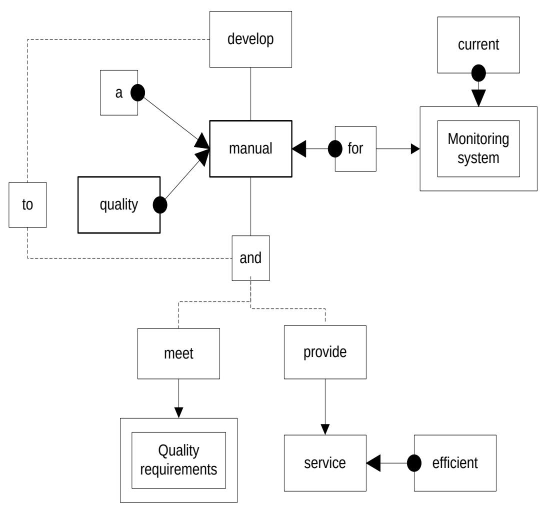

Fig. 4 ROM of Requirement Description.

After finishing question asking for environment components, we should ask questions about the relation objects: "meet" and "provide". We take "meet" as an example, question like "how to meet" can be asked. To answer this question, the content of quality requirements should be analysed. ISO 9001 asks the scope, the procedure and the interaction of QMS; ISO 24511 requires defining the proper sequence of activities and clear operation instructions. In our case, defining proper sequence and giving clear instruction are the key points to meet quality requirements. Table 3 shows all the generic questions, specific question and answers of these questions.

Table 3 Generic and specific questions.

Generic Question	Answer
What kinds of quality standards should be met?	ISO 24511, ISO 9001 …
What is the related information in ISO24511?	"The wastewater utility should define the sequence of all essential operations required for the proper performance of its tasks, processes and activities… More detailed working instructions (such as standard operating procedures and operation and maintenance manuals) should be prepared whenever required, in order to ensure the proper and expert handling of individual activities, adhering to applicable national or generally accepted requirements or practices" (ISO24511, 2008).
What are the requirements based on ISO 9001?	According ISO 9001, a quality manual should include the scope of the quality management system, including details of and justification for any exclusions; the documented procedures established for the quality management system, or reference to them; and a description of the interaction between the processes of the quality management system (ISO9001, 2000).
What does efficient mean?	Performing or functioning in the best possible manner with the least waste of time and effort; satisfactory and economical to use.
What are the characteristics of efficient service?	Less time consuming, low cost, low error rate, high data quality…
What is the environmental monitoring program?	The city of XYZ has a drainage monitoring program under the Environmental Monitoring group which consists of performing several processes for the maintenance and monitoring of different parameters of the drainage systems. People install equipments to different sites for meeting customers' monitoring requirements.
What kinds of objects are included in the monitoring system?	People, device, information system, software.
What is the current situation of monitoring system?	There is no quality manual in current monitoring system. The document management is not good. Technologists just follow their own procedure based on experience, some operations are not proper. The software popularization is not good, so most operations depend on human being. It is hard to avoid human error, time consuming and high cost.
How to meet these quality requirements?	According to the quality standards, it is better to define the proper operation sequences of monitoring activities and to give clear instruction of each activity.
How to provide efficient service?	Reduce the operation time, ensure the quality of data …
Specific Question	**Answer**
What is the lifecycle of our manual?	In our case, the lifecycle of manual includes design, communication, use, and maintenance.

When finishing all of the generic questions about important objects, the specific question about "manual" can be generated. Complying with the product requirements classification roadmap mentioned in the previous section, since the quality manual is specialized for the monitoring group, the product life cycle of our manual includes four stages: design, communication, use and maintenance. For each stage, the related requirements and components are further classified into built environment, human environment and natural environment. Then, relations between these components are analysed. The details are shown in Table 4.

Based on the analysis carried out so far, the ROM diagram can be updated as shown in Figure 5. This new ROM diagram gives a clear map of the quality management manual for monitoring group. It shows the objective of this manual - giving operation instructions and defining the sequence of operations that involves different components such as people, devices and information system as well as monitoring activities, in order to ensure individual performance and adhere to practice or quality requirements.

Table 4 Requirement classification.

Environment Lifecycle	Built Environment	Human Environment	Natural Environment
Design	quality requirement, cost, time, interface, basic function	designer, consultant	N/A
Transportation	Time, transportation software	N/A	N/A
Use	information system, equipment	technologist, contractor	N/A
Maintenance	warranty time, maintenance activities	designer, technologist	N/A

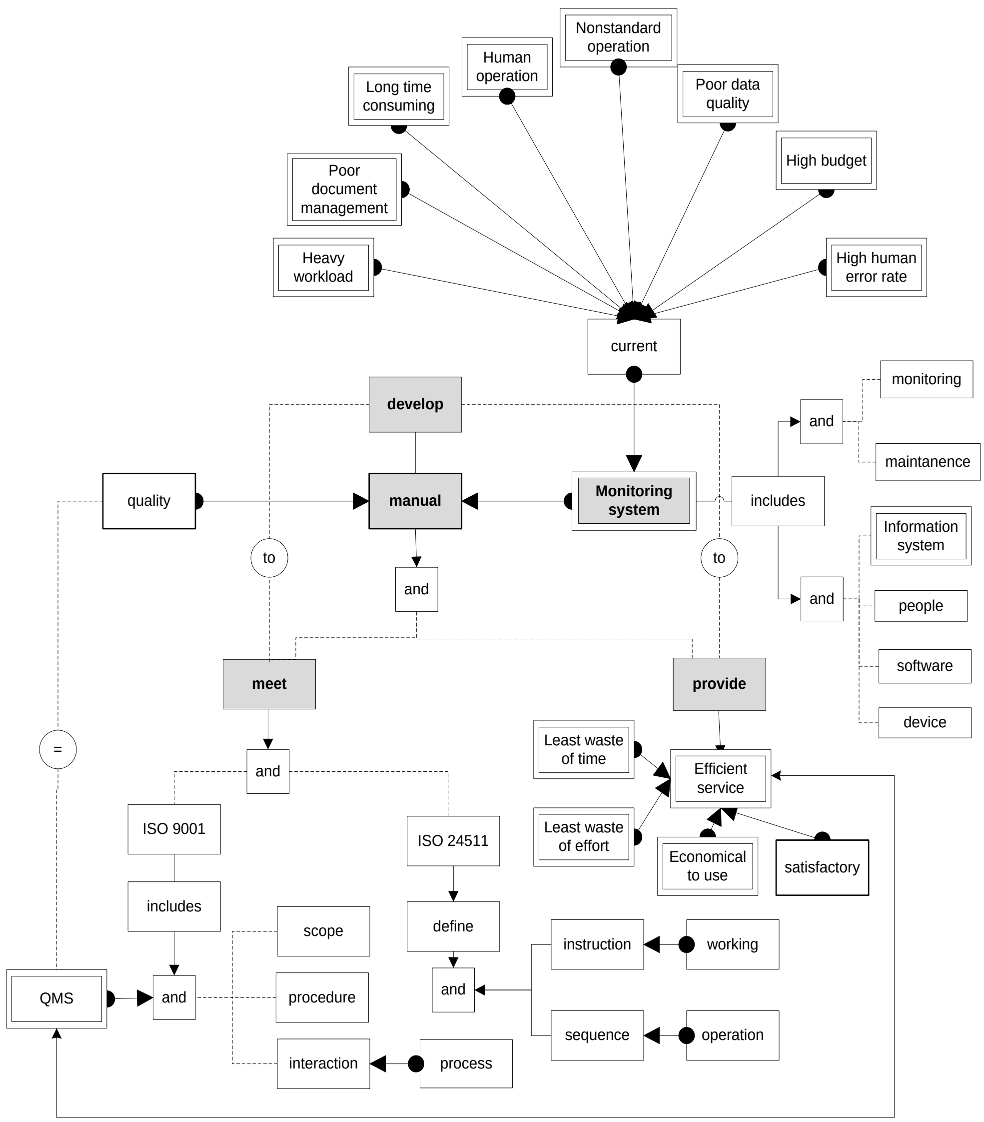

Fig. 5 Updated ROM.

3.3. Conflict Identification

From the developed environment system which includes objects and their relations, there will be conflicts or potential conflicts between the objects or between their relations. According to Figure 5, it is obvious that the relations between these environment components are interdependent, which means these are conflicts in current system. Several conflicts are identified based on the relations between environment components shown in Table 5. For example, workload issue exists in current monitoring system; technologists complain that their workload is too heavy. On the other hand, the object of system improvement requests economical using. That means the workload issue should be solved to meet new quality requirements. Since both "heavy workload" and "economical using" constraint "monitoring system", according to Figure 2, we can get Conflict 3.

Table 5 Conflicts

#	Significant Conflicts	
c1	High human error rate	Least waste of time; least waste of effort.
c2	High cost	Economical to use; satisfactory.
c3	Heavy workload	Economical to use.
c4	Long time consuming	Least waste of time; least waste of effort.
c5	Poor document management	Least waste of time; least waste of effort; economical to use.
c6	Nonstandard operations	Least waste of time; least waste of effort; economical to use.
c7	Poor data quality	Least waste of time; least waste of effort; economical to use; satisfactory.
c8	Too many human operations	Least waste of time; least waste of effort.
c9	No improve or warranty activities	Economical to use; satisfactory.
c10	No defined efficient sequence of operations	Economical to use; satisfactory.

Before starting to resolve conflicts, these conflicts should be analysed firstly. The root conflicts should be identified based on the dependences among conflicts as one conflict can be resulted from others. In such a way, handling a root conflict first may eliminate other depending conflicts. Directed graph is used to represent the relations between conflicts in Figure 6. For example, high human error could increase the operation cost since some operations need double check. Also, human error is an important factor to cause poor data quality. Therefore, high human error can cause high cost and poor data quality, that means c1 can lead to c2 and c7, c1 is the root conflict of c2 and c7. Once c1 is solved, conflicts c2 and c7 will be eliminated correspondingly.

According to graph theory, adjacency matrix can represent the directed graph with n vertices using an n*n matrix, where the entry value at (i, j) is '1' if there is an edge from vertex i to vertex j; otherwise the entry is '0' (Shukla, 2009). Every entry value (i ,n_j) at column n_j shows whether conflict n_j can be represented by conflict c_i. Taking the first column as an example, the value '1' at the 3rd row, 6th row, 8th row, and 10th row means c1 can be lead from c3, c6, c8 and c10.

Table 6 is the adjacency matrix that shows the conflict dependency relations in Figure 6. From this table, it is clear that no conflicts can lead to c8, c9 and c10 since the entry values of these columns are all zero, while all the other conflicts can be represented by these three conflicts. Although c5 cannot lead to other conflicts as well as it cannot be represented by other conflicts, which means c5 is also a root conflict. Therefore, c5, c8, c9, c10 are the root conflicts for the monitoring system. Once we solve these four conflicts, the other conflicts will be eliminated or changed.

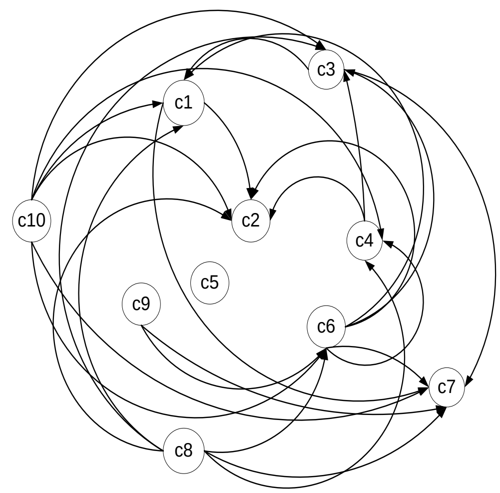

Fig. 6 Directed Graph - Dependences among Conflicts.

Table 6 Adjacency matrix.

Conflicts	c1	c2	c3	c4	c5	c6	c7	c8	c9	c10
c1	0	1	0	0	0	0	1	0	0	0
c2	0	0	0	0	0	0	0	0	0	0
c3	1	0	0	0	0	0	1	0	0	0
c4	0	1	1	0	0	0	0	0	0	0
c5	0	0	0	0	0	0	0	0	0	0
c6	1	1	1	1	0	0	1	0	0	0
c7	0	0	0	0	0	0	0	0	0	0
c8	1	1	1	1	0	1	1	0	0	0
c9	0	0	0	0	0	1	1	0	0	0
c10	1	1	1	1	0	1	1	0	0	0

3.4. Solution Generation

Based on the previous analysis, it is easy to know what should be included in the quality manual and what the manual should focus on:

- Solving the problems caused by human operation and eliminating the unnecessary human operations;
- Defining the efficient sequence of monitoring operations, developing improvement activities and managing documents efficiently.

EBD will be used once again in solution generation, in order to analyse the current monitoring system to get the final quality manual.

3.4.1. Environment Analysis for Monitoring System

Monitoring System provides information for assessment and control of existing drainage system performance, as well provides the monitoring report to meet the requirements of City Environment Department and agreements with organizations outside of the city (Edmonton, 2004). It includes many environment components as shown in Figure 5: people, device, information system and software. The detailed information about these components is described in Table 7.

After analysing all the important components, the relations between these components can be identified in Table 8, where the potential conflicts may exist. Also, this relationship analysis can be helpful to understand the monitoring system clearly for future manual.

Table 7 Environment components in monitoring system.

	Component	Description
Built Environment	Drainage system	The drainage system is responsible for planning, building, operating, and maintaining the pipes, tunnels, pump stations, storm water management facilities that make up the city's drainage network.
	WISIK system	The WISKI Application system is an information system used to monitor and evaluate the effectiveness of city's existing and future sewer systems using accurate and timely monitoring data.
	GIS system	The GIS System can provide site information help select candidate manholes; it also can help identify the potential data quality issues and maintenance cost.
	Equipment	The equipment includes velocity sensors, pipes, bands, probe and meter hooks.
Human Environment	Employee	The field technologists mainly focus on the field practical work and coordinate contractor resources to install, replace and maintain flow monitors; Office technologists issue site installation request, collect site information for requested locations and negotiate with requestors for alternative sites if needed. They also review graphs for problems at the site; circulate graphs for review by senior staff; notify field monitoring staff of site problems; mark incorrect data as bad; store data in database and prepare the final report for customers.
	Contractor	Contractors' work scope include: installing temporary flow monitors; providing maintenance as requested; removing temporary flow monitors; completing two flow monitor verifications; securely fastening flow monitors and sensors; securing the site as required, including the obtaining of permits and allowable times for street/lane closures from Transportation and Streets as needed; and so on.
	Customer	Different customers have different requirements. Some of them need the raw data of drainage system to analyze the performance of sewer system; some of them want to use monitoring data to generate a computer model for data checking; some of them just need the annual report that describe the performance of the drainage system for the whole year.
Natural Environment	Site	The condition of site determines the kind of equipment, the installing location of equipment, and the type of monitoring data and so on.

3.4.2. Conflict Identification for Monitoring System

According to the component relation analysis and the operation process analysis, a critical conflict about human operation can be found in data quality assurance and quality control (QA/QC) process. It means that the human operation in QA/QC is the key to solve the conflicts related to human operation. In the current monitoring system, QA/QC are done manually and mostly based on the technologists' experience. On the one hand, the manual checking process overwhelms technologists with heavy workload, thereby introducing human errors and leading to poor data quality. On the other hand, some data problems cannot be identified without comprehensive data analysis. Therefore, if some other technologies/techniques can be used to replace human operation and to eliminate unnecessary operations in the QA/QC process, the problems caused by human operation can be solved and the data quality will be improved.

Table 8 Relations between environment components.

Monitoring program		Built				Human			Natural
		Equipment	WISKI System	GIS System	Drainage System	Employee	Customer	Contractor	Site
Built	Equipment		Transfer information through	N/A	Measure	Selected & Used by	N/A	Installed by	Stay in
	WISKI System	Transfer & Save data of		Transfer & Save data of	Transfer & Save data of	Transfer information to	Transfer information to	Transfer information to	N/A
	GIS System	N/A	Transfer information through		N/A	Used by	N/A	N/A	Guide the selection of
	Drainage System	Measured by	Transfer information through	N/A		Monitored by/Working place	Managed by	Working place	Offers
Human	Employee	Select & Use	Transfer information through	Use	Monitor & Work in		Work for	Request	Select
	Customer	N/A	Transfer information through	N/A	Manage	Request		N/A	N/A
	Contractor	Install	Transfer information through	N/A	Work in	Obey	N/A		Work in
Natural	Site	Hold	N/A	Selected based on	Belong to	Selected by	N/A	Working place	

3.4.3. Solution Generation for Monitoring System

Based on the property of conflicts, we are trying to use a computer program instead of human beings for the QA/QC process. The interface of this program is shown as Figure 7. Three algorithms with computer implementations are taken with regard to the quality and efficiency of data assurance. The computer program is implemented by dealing with the following three issues: data rationality and effectiveness check, data drifting check, and data sudden change check. There are many advantages by using automatic computer program in the QA/QC process, i.e., enhancing quality and accuracy of data assurance, improving the efficiency of data quality assurance and avoiding human errors by relieving technologists of a heavy workload.

3.4.4. Quality Manual for Monitoring Group

After checking each monitoring activity and analyzing the relations between these performances based on Table 8, the sequence of activities can be adjusted and redefined in a logical way. Therefore, the correct sequence of all monitoring performance can be generated as shown in Figure 8, which informs the monitoring technologists and contractors about what should be done firstly and what should be done after some specific activities. It helps construct the standard operation and ensure the effectiveness and efficiency of monitoring operation.

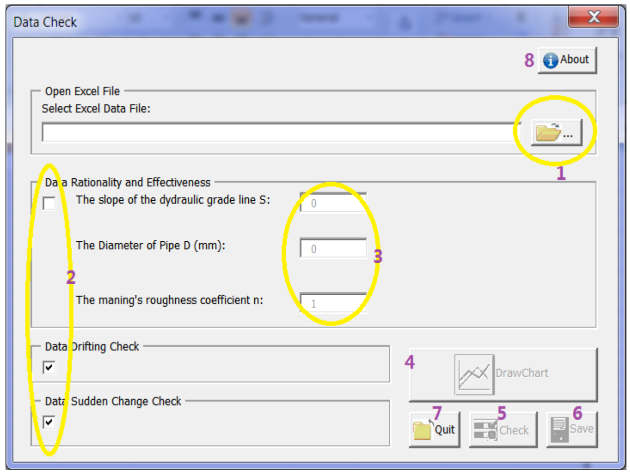

Fig. 7 Interface for Data Checking (Liu, 2011).

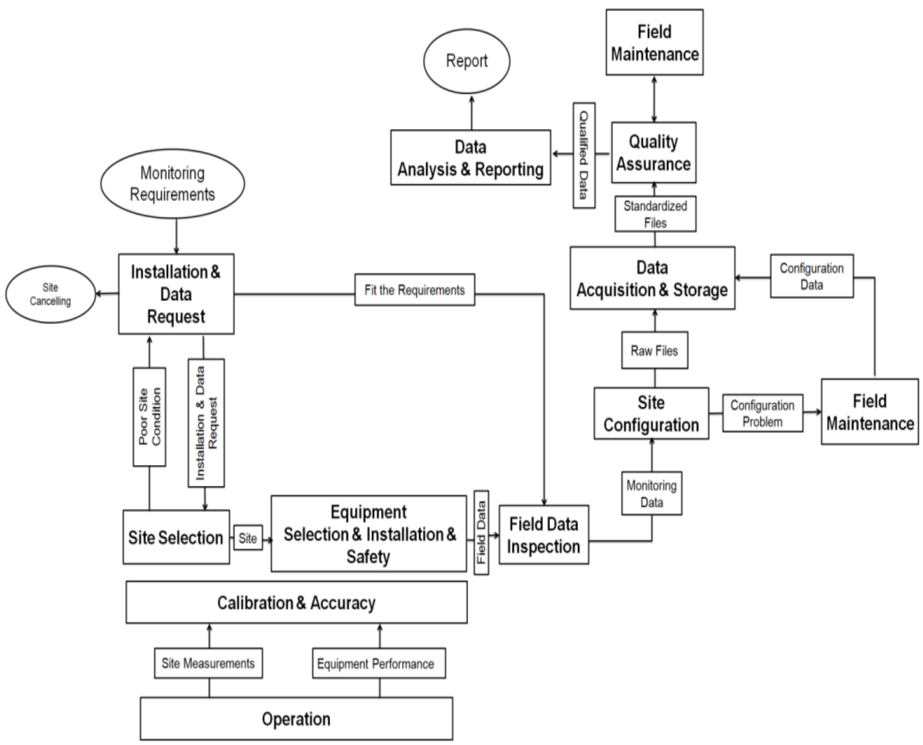

Fig. 8 Sequence of Monitoring Activities (Sun et al., 2010).

The quality standards indicate the opportunities and requirements for improving the monitoring system. According to the understanding of ISO standards, Total Quality Management (TQM), and other related quality methodologies, a template of ideal quality requirements for a quality management system can be generated. Since now we already have the correct sequence of working activities, in order to ensure individual performance and adhere to practice or quality requirements, the ideal template (Sun et al., 2010) of quality requirements can help improve the quality manual. On the one hand, the current operation state can be compared with the quality requirements to improve the operation instructions. On the other hand, in the quality manual, proper items from the quality requirement template can be chosen and be followed. This can make sure that the manual not only meets the quality requirements, but also has enough information to support the operation instruction.

Table 9 Sample manual - manual for quality assurance.

<table>
<tr><td colspan="3">Activity 10: Quality Assurance</td></tr>
<tr><td colspan="2">Predecessors: Data Acquisition and Storage</td><td>Successors: Data Analysis and Reporting</td></tr>
<tr><td rowspan="8">Operational Manual</td><td colspan="2">1. Check the data</td></tr>
<tr><td colspan="2">2. Draw the graphs</td></tr>
<tr><td colspan="2">3. Review graphs for problems at sites</td></tr>
<tr><td colspan="2">4. Circulate graphs for review by sensor staff</td></tr>
<tr><td colspan="2">5. Notify field monitoring staff of site problem</td></tr>
<tr><td colspan="2">6. Mark incorrect data as bad</td></tr>
<tr><td colspan="2">7.Store data in database</td></tr>
<tr><td colspan="2">8. Data repairing and finalization</td></tr>
<tr><td rowspan="4">Quality Audit</td><td>Audit duration</td><td>one day to three days</td></tr>
<tr><td>Audit procedure</td><td>check and record each procedure</td></tr>
<tr><td>Audit people</td><td>Office Work technologists</td></tr>
<tr><td>Audit report</td><td>N/A</td></tr>
<tr><td rowspan="2">Non-conformance and possible actions</td><td colspan="2">QA/QC process depend on technologists' experience</td></tr>
<tr><td colspan="2">Use computer program instead of human to operate the QA/QC process</td></tr>
<tr><td>Continuous Improvement</td><td colspan="2">Since we use computer program to replace human operation in QA/QC process, continuous program debug should be considered.</td></tr>
</table>

Table 9 gives an example to show the main contents in our developed quality manual. All monitoring performances have the same standard documents control process. However, other instructions are different based on their special characteristics. The instruction may include operational manual, control of documents, quality record, quality audit, control of non-conformance, corrective and preventive action, and continuous improvement. It can be seen from the table that the structure of the QMS systems generated from the manual would not be much different from the one generated by a traditional quality management methodology. However, since the process is more naturally related to the concerned situation, the content under each category could be greatly different.

4. Conclusion

The Environment Based Design (EBD) methodology includes three interdependent design activities: environment analysis, conflict identification, and solution generation. This paper presents a case study to show how the EBD methodology can be applied to real industrial problems.

This case study is from an industrial project, which aims to create a quality manual that guides the development of quality management systems (QMS) in an environment monitoring group in a city. The content of the manual was not precisely defined in the beginning. The EBD was adopted to accomplish this task after a failed endeavour following a widely accepted quality management methodology. It was found from this project that the EBD is able to clarify the goals of the project step by step and to guide the project members to follow the right path. The final deliverable turned out to be a quality manual together with a data processing tool, which have addressed the customer's real concerns.

In applying the EBD, the environment analysis activity clarifies the definitions of key components such as manual, drainage system, environment monitoring, and quality standards. Following those definitions, the structure of the manual was determined based on the right sequence of monitoring activities identified through analysing the main environment components and the relations among them. The conflict identification activity then finds the incompatibility and inconsistency among the relations implied in the environment system. Finally, the quality manual was developed by resolving a few major conflicts in the current system.

This paper also shows the concrete procedures for the EBD to be applied to other industrial projects.

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7. Authors’ Biographies

Xuan Sun was a Master student of Quality Systems Engineering at Concordia University. She received her diploma in Industrial Engineering in China. Her research interests are improvement of quality management system, design methodology development and system optimization.

Dr. Yong Zeng is Canada Research Chair (Tier II) in design science (2004-2014) and a professor in the Concordia Institute for Information Systems Engineering at Concordia University, Montreal, Canada. Prior to joining in Concordia in August 2003, he was a research associate in the Integrated Manufacturing Technologies Institute at the National Research Council of Canada for two years after he received his Ph.D. from Department of Mechanical and Manufacturing Engineering at the University of Calgary in 2001. He got his first PhD degree and Master’s degree from Research Institute of Engineering Mechanics at Dalian University of Technology in 1989 and 1992, respectively. He received his Bachelor’s degree in Structural Engineering from PLA Institute of Logistics Engineering, Chongqing. He was a lecturer and then an Associate Professor at PLA Institute of Logistics Engineering between 1992 and 1996. Zeng’s research interest is in understanding and improving product design activities, especially creative design activities. Specific topics of his research include the science of design, methodology for innovative and creative design, computer-aided product conceptual design, design cognition and semantics, as well as geometric modeling for product development. He has been developing formal and experimental approaches to design research. All of his research has led to a new design theory and methodology – Environment Based Design (EBD). He collaborates with aerospace companies, pharmaceutical companies, software development companies and municipality for the applications of his research results.

Dr. Fayi Zhou is a general supervisor for the Environmental Planning group with the City of Edmonton in Drainage Services Branch. He has been an adjunct associate professor with Concordia University since 2009. Dr. Zhou received his PhD degree in Civil & Environmental Engineering from the University of Alberta (2000), and his Bachelor (1984) and Master’s degrees (1987) in Civil and Water Resources Engineering from Dalian University of Technology (formerly Dalian Institute of Technology) in China. He has over 25 years of experience in water resources and environmental engineering, covering the project management, planning, design and construction. His is specialized in computational flow mechanics. He is also a certified project management professional (PMP) with the Project Management Institute. In the City of Edmonton, Dr. Zhou leads the research and development of various environmental initiatives such as Low Impact Development, Zero-Discharge, Stormwater Quality Management, and public education. Prior to his current employment, he was a senior research fellow at the St. Anthony Falls Hydraulic Laboratory at the University of Minnesota. He has also worked for international consultant firms CH2MHILL and AMEC. Dr. Zhou has published over fifty papers in peered reviewed journals and conference proceedings. He is a reviewer of Journal of Hydraulics (ASCE), International Journal of Hydraulic Research (IJHR), Journal of Computation Engineering (IJCES), and Canadian Journal of Civil Engineering.