

Quality Management of Drainage System Monitoring Process:
Design Perspective

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ABSTRACT

Quality Management of Drainage System Monitoring Process: Design Perspective

Yu Bing Hu

The Drainage Services branch of the City of Edmonton is responsible for planning, building, operating and maintaining over \$8.1 billion of the drainage infrastructure. The environmental monitoring group within the Drainage Services branch has the responsibility of understanding the hydraulic performance of the sewerage and drainage facilities, and assessing how that performance measures up to the goals and objectives of Drainage Services. The Monitoring Group provides monitoring data and reports to the clients. The overall product quality consists of data quality and service quality, which relies on the performance of three major components: staff, device and program. Achieving data retrieval proficiency from monitoring sites and providing an acceptable level of service are of critical importance for the success of the Environmental Monitoring group in Drainage Services Branch.

The objective of this thesis is to develop a framework for the environmental monitoring group of the City of Edmonton to establish a Total Quality Management System. It is hoped that, with the implementation of this TQM system, the monitoring group can improve the quality of services, especially in the data integrity, correctness, and completeness. The development of the framework for TQM of the drainage monitoring system is accomplished by applying the methodology of environment-based design

(EBD). EBD is the theoretical background for the whole project. It helps to present Recursive Object Model (ROM) diagram and elicit the complete requirements of ideal monitoring system, and then design the quality management system based on the product requirements.

In this thesis, the current monitoring process and practices are analyzed, including detailed discussion of the business processes, functional activities, and Operating processes of the Environmental Monitoring Group. Then the ideal process requirement analysis is performed by applying the Environmental Based Design (EBD) model in general and discusses the advantage of this method, presents ROM and the completed requirements. Next, the quality evaluation system is accomplished by setting up the quality standard or performance requirement for each segment of the management of the monitoring process, which helps to evaluate the group performance. Furthermore, the gap analysis is conducted, which presents the gap between the as-is and the to-be status of the monitoring group's quality management performance. Finally, the improvement recommendation is made and the future studies are proposed at the end of the present thesis.

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Chapter 1

Introduction

1.1 Motivation

Municipal drainage systems collect, treat, and dispose storm water and wastewater in order to assure a safe environment and public health. The Drainage Services branch of the City of Edmonton is responsible for planning, building, operating and maintaining over \$8.1 billion of infrastructure, including a 4939 kilometer long wastewater and storm water transportation network and a state-of-art tertiary wastewater treatment plant. As of 2005, this network consisted of 2083km of storm pipes, 1902km of sanitary pipes, and 937km of combined pipes, and 17km of foundation drains. The Drainage Services branch also operates over 79 pumping stations, 56 wet storm management facilities, 54 dry storm management facilities, and 43 peak storage units.

The Environmental Monitoring group is a part of the Drainage Planning section of Drainage Services branch of the City of Edmonton. It is responsible for monitoring and evaluating City wide drainage system, including sewer and storm trunks, pump stations, storm water management ponds, outfalls, and wastewater treatment plant's influents and effluents. To provide efficient and affordable drainage services to the citizens of the City of Edmonton, the environmental monitoring group monitors and evaluates the effectiveness of Edmonton's existing and future sewer systems using accurate, timely monitoring data and computer models.

Achieving monitored data quality and providing high quality services to stakeholders are of critical importance for the success of the Environmental Monitoring group. And it is essential to implement a sound quality management program.

1.2 Objective

The research objective is to improve the quality of drainage system monitoring services in the City of Edmonton by developing management strategies and procedures based on quality management theory and techniques. There is a strong need of a solid quality management strategy for the system monitoring program to provide accurate and timely rainfall and flow data for the purpose of planning, design and construction of Edmonton's drainage system.

The objective of this thesis is to develop a framework for the environmental monitoring group of the City of Edmonton to establish a Total Quality Management System to elevate the service performance through improved service efficiency and data accuracy.

1.3 Challenge

Currently, the considerable design methodologies for public service sector's quality management are deficient. A systematic method for designing service processes along with the quality management requirements has yet to be formalized in the design literature, whereas the relevant efforts are limited (Fantechi, Gnesi et al., 1994; Miles Osborne, 1996; Gnesi, Lami et al., 2005).

1.4 Approach

In this paper, we introduce the procedure of implementing EBD (Zeng, 2004) to Process Design, and discuss generically how to perform quality control and quality assurance

management in public service practice. The design of Quality Management for Drainage Service Monitoring System of City Edmonton is a case study.

The proposed approach in the present thesis is characterized in the following list:

- 1) Analyzes the current monitoring process and practices, including detailed discussion of the business processes, functional activities, and operating processes of current practice.
- 2) Performs the ideal process requirement analysis by applying the EBD, presents ROM (Zeng, 2007) and generates the completed requirements that fulfill the product objective.
- 3) Initiates the quality evaluation system by setting up the quality standard or performance requirement for each segment of the monitoring process, which helps to evaluate the group performance in quality point of view.
- 4) Presents the improvement recommendations from the above analyses.
- 5) Advises directions of the future effort

1.5 Thesis Organization

This thesis has seven chapters.

Chapter 1, Introduction, presents the background of the study, the objectives and the overview of the thesis.

Chapter 2, Literature Review, introduces and evaluates what have been done for the objective problem and what need to be done to develop a quality management system for a flow drainage system monitoring program.

Chapter 3, Theoretical Foundation: Environment Based Design describes the Environmental Based Design (EBD) model in general. The advantage of this method is discussed. The recursive object model (ROM) and the requirement analysis are presented.

Chapter 4, Environment Analysis, presents the as-is and to-be status of the target system.

Chapter 5, Conflict Identification, presents the analysis and identification of the gaps between the as-is and to-be status.

Chapter 6, Concept Generation, presents specific recommendations for implementing the quality management system. The service quality standards, performance features, and control parameters for the monitoring process management are discussed.

Chapter 7, Conclusion and Future Work, summarizes the main research results based on the present thesis, and points out future research directions.

Chapter 2

Literature Review

2.1 Quality Management

In today's highly competitive world, quality is the central issue. There are many definitions of quality; however, they all accept the notion that quality is defined by the customer (Gryna, Chua et al., 2007). Of all the management functions that must operate in any organization—budgeting, procurement, human resources, the services themselves, and quality management—it is the quality management that most needs to demonstrate what it means to engage in continuous improvement (Juran and Godfrey, 1998). Quality management is a body of practices defined by both quality theorists and practitioners (Gryna, Chua et al., 2007).

The National Association of Healthcare Quality claimed that Quality management is, first of all, a management function rather than a planning, policy or design function, or a direct service to consumers. The organization defines quality management as:

“A planned, systematic approach to the monitoring, analysis, and correction and improvement of performance, which increases the likelihood of desired outcomes by continuously improving the quality of care and services provided” (DHFS., Healthcare. et al., 2006).

Now quality is not only an order winning criteria but also is an order qualifier for many companies. Total quality management (TQM) has been widely accepted as ways and means for achieving excellence in quality in this new millennium by many companies around the world (Bandyopadhyay, 2003).

TQM emphasizes on customer focus. Product quality is commonly defined as the product's fitness for its intended use which means how well the product meets the needs and expectations of its customers. Again different customers have different needs and expectations. Therefore a product must be designed to meet the needs and expectations of its target customers (Bandyopadhyay, 2003).

2.2 Quality Management System

The importance of assuring quality requires that quality not be dealt with on an ad hoc basis. Only a properly implemented quality management system (QMS) within an organization and across its supply chain can provide protection from short-term actions that do not serve long-term goals. For many firms, obtaining acceptable levels of quality comes with the registration of a QMS for itself and its suppliers (Sroufe and Curkovic, 2008).

Quality Management System (QMS) can be defined as a set of policies, processes and procedures required for planning and execution (production / development / service) in the core business area of an organization. QMS integrates the various internal processes within the organization and intends to provide a process approach for project execution. QMS enables the organizations to identify, measure, control and improve the various core business processes that will ultimately lead to improved business performance (Wikipedia, 2008) .

Nortel built its Quality Management System upon “a process framework that requires key decision points and accountabilities for success at every critical phase in a product's life cycle. These decision points are based on clearly articulated customer requirements, well defined metrics, and rigorous quality reviews. Also parts of this framework are Nortel's

own network vision and renowned product innovation, thorough product design and testing, supplier quality assurance, as well as regulatory, competitive and regional considerations that are critical to ensuring satisfaction for the customers.”(Nortel, 2008)

This research is about to ensure the performance of a public service sector by applying a Total Quality Management (TQM) strategy. TQM is a philosophy and system for continuously improving the services or products offered to customers (Fitzgerald, 2004). Total quality management is a management approach aimed at creating an organization that is characterized by continuous improvement and meeting and exceeding customers' expectations (Zultner 1993). Briefly stated, TQM or quality management practice, dictates that an organization should have a comprehensive master plan for continuously improving quality. Kaynak (2003) identified multiple relationships among TQM practices and performance and then found significant positive relationships by examining the direct and indirect effects of these practices on various performance levels (Sroufe and Curkovic, 2008).

TQM is a strategic, long-term set of practices that make it possible for management to introduce continuous improvement initiatives across all functions. Its quality practices integrate various techniques and management principles. The ultimate aim is the implementation of quality practices in all activities throughout the organization(Gryna, Chua et al., 2007). It shows that companies who fully integrate a QMS can reap significant benefits internally and externally in terms of quality assurance(Sroufe and Curkovic, 2008). However, while TQM has been heavily used in manufacturing, its applications in service organizations in general, and information systems in particular, have been limited(Stylianou, Kumar et al., 1997).

The TQMS includes both Quality Control (QC) and Quality Assurance (QA) programs. Quality control is largely directed at meeting goals and preventing adverse change, i.e., holding the status quo. The control process addresses sporadic quality problems. QC process involves observing actual performance, comparing it with some standard, and then taking action if the observed performance is significantly different from the standard (Gryna, Chua et al., 2007). Quality assurance (QA) covers all activities, including design, development, production, installation, servicing, and documentation (Deming, 1981, 1986; Garvin, 1983, 1984, 1986, 1987), and is important to the competitive capabilities of any organization. (2-QM-3) QA includes the regulation of the quality of raw materials, assemblies, products, and components; services related to production; and management, production, and inspection processes. The main goal of QA is to ensure that products fulfill or exceed customer expectations. One approach to QA is through the development of a formal QMS, and for many firms this has meant ISO 9000:2000 registration. However, the decision to obtain ISO registration is not always straightforward since many issues still surround the quality standard (Sroufe and Curkovic, 2008).

Standards Council of Canada accredits certification bodies that assess and certify quality management systems to the international standard ISO 9001. It claims that “A quality management system defines and establishes an organization's quality policy, objectives and procedures. Quality management system standards do not provide specific quality indicators or describe ways of achieving them, since these will be different in every situation. Instead, they provide generic frameworks and general principles that can be applied to any organization of any size, in any industry.” (Council, 2008)

In the new ISO 9000:2000 standards, the International Organization for Standardization (ISO) provides what is regarded as the most prevalent approach to developing a QMS. To date, over half a million organizations in over 150 countries have achieved quality registration through ISO standards.(Sroufe and Curkovic, 2008)

Praxiom Research Group Limited has tried to identify 22 QMS processes that make up a complete ISO 9001 2000 Quality Management System.

- | | |
|-------------------------------------|--------------------------------------|
| 1. Quality Management Process | 12. Internal Communications Process |
| 2. Resource Management Process | 13. Document Control Process |
| 3. Regulatory Research Process | 14. Record Keeping Process |
| 4. Market Research Process | 15. Planning Process |
| 5. Product Design Process | 16. Training Process |
| 6. Purchasing Process | 17. Internal Audit Process |
| 7. Production Process | 18. Management Review Process |
| 8. Service Provision Process | 19. Monitoring and Measuring Process |
| 9. Product Protection Process | 20.Nonconformance Management Process |
| 10. Customer Needs Assessment | 21. Continuel Improvement Process |
| 11. Customer Communications Process | 22. General Systemic Process |

Despite the international acceptance of ISO 9000:2000, this standard is still subject to controversy for individual firms and supply chains. A widespread criticism of the program is that it is not connected directly enough to product quality (Wayhan et al., 2002; Naveh and Marcus, 2004). For example, a registered company can still have

substandard processes and products because registration does not tell a company how to design more efficient and reliable products.

When registration is used as a requirement for a supply base, buyers like to think that registered suppliers will have a leg up on the competition, but this may not be the case. Basically, the ISO quality standards ensure only that a quality system exists but cannot guarantee its functionality within a particular firm or supply chain (Curkovic and Handfield, 1996; Gotzamani, 2005).

Other important criticisms include the idea that registration will not ensure improved firm performance. There is also uncertainty as to the amount of resources necessary to implement a QMS and whether these resources actually improve quality assurance. Mixed results from research on quality initiatives show that organizations achieved a distinct operating advantage when they used the ISO standards in daily practice and when these standards served as a catalyst for change (Naveh and Marcus, 2004). Doing so does not necessarily lead to improved business performance (Sroufe and Curkovic, 2008).

2.3 Quality Management System Design

Previous studies show that implementation of quality practices does in fact improve business performance. Meanwhile there are practices as well of quality management systems design, such as customer oriented design of quality management systems, a preliminary design for an integrated quality management system.

While the importance of quality received much attention in the world during the 1980s, formal attempts to develop quality management systems and audits of these systems did

not come about until the International Organization for Standardization and the British Standards Institute became involved.

The International Organization for Standardization was established in 1947 to develop common international standards in many areas. In 1979, the British Standards Institute introduced a new set of standards aimed at promoting quality of goods and services provided by United Kingdom industries. ISO 9000:2000 is the most recently approved revision of the standard. Some of the most significant aspects of the revised standard include its emphasis on using a process-related structure, using information from the system to facilitate quality improvement, and including customer satisfaction in improvement activities. Registration to the standard required that an organization have a documented, verifiable quality system in place to ensure that it consistently produced what it said it would produce.

Although ISO 9000:2000 addressed several criticisms of the previous version, it is still met with uncertainty. Most of this uncertainty is related to perceived weaknesses in its ability to deliver real benefits and a continued overemphasis on bureaucratic processes and documentation. Other criticisms generally point to misapplication or extension of its use in companies and the effect this can have on organizational resources and culture. While the criticism focuses on the standard, the problems typically arise from the failure of organizations to understand the underlying philosophy of the standard and the idea that this is a process-driven, systematic approach to QA. Lack of internal enthusiasm and motivation can hinder the impact of ISO 9000 on performance. Meeting registration requirements may have no impact on performance. Terziovski et al. (1997) found that

ISO 9000 registration has not been shown to have a significantly positive effect on organizational performance in the presence of a QMS (Helfert and Herrmann, 2008).

Several systems analysis and design methodologies have been proposed in the computer science and management information systems literature. These include structured systems analysis and design (Yourdon and Constantine, 1979), information engineering (Inmon, 1988), and object-oriented analysis and design (Coad and Yourdon, 1991). These methodologies typically start with an unstructured problem specification and produce a detailed design specification, usually through a process of stepwise refinement. The primary focus of these methodologies is on data and process modeling. These approaches share the following process:

a) Start with an unstructured problem.

Model characteristics of the problem (usually, the data and processing requirements) in a broad sense using constructs that is methodology-dependent. Refine the model in steps by adding details until a sufficiently detailed problem description is obtained. For example, one might start with a context-level data-flow diagram and refine it to obtain more detailed lower level diagrams. Entity Relationship diagrams (may be used to provide detailed description of data stores in lower level diagrams).

b) Make design decisions and implement the system using a particular technology (for example, object-oriented programming).

c) Develop and implement the system.

The quality of the final system is often evaluated by the users based on factors such as ease of use, response time, availability and understandability of on-line help, and others.

The system is considered to be of high or poor quality based on such user-oriented factors, as well as other more technical factors.

Careful attention to details and user involvement in the development process increase the potential for, but do not guarantee, a high-quality system. It is important to realize that the systems development process described above do not explicitly recognize all the stakeholders (customers), nor does it document their quality attributes. It also makes no provisions for ensuring that those quality characteristics are properly and systematically considered throughout the various stages of the development process. It is possible that some customer requirements such as ease of use, maintenance, and security are not captured in data and process modeling. It may also be the case that quality features related to hardware or support services and other customer requirements are either not explicitly considered or they vanish in the stepwise refinement process, which typically emphasizes software (Stylianou, Kumar et al., 1997).

2.4 Quality Management Information System

In order to carry out all processes involved in total quality management effectively starting from product design to delivery of the product to customers just in time, a large number of data must be collected, stored, processed, analyzed and retrieved (Nookabadi and Middle, 2008) . Proper and speedy collection, processing, storage and retrieval of data using a total quality management information system are critical to the success of TQM in an organization (Mahdavi, Shirazi et al., 2008).

The total Quality Management Information System (TQMIS) is designed as a Database Management System (DBMS) for regularly collecting, storing, retrieving, and manipulating quality related data for effectively implementing total quality management

across the organization. In order to design and develop a realistic Total Quality Management Information System (TQMIS), 300 Michigan auto parts manufacturers were surveyed by Central Michigan University and their Quality manager were asked to identify the critical data bases needed for successfully implementing TQM in their organization. The results of the survey revealed that the following eleven categories of data are essential for successful TQM implementation: (1) quality Policies, (2) quality Procedures, (3) quality Instructions,(4) customers needs & expectations, (5) customer satisfactions and complaints, (6) design specifications and tolerances, (4) engineering & processing instructions, (7) inspection & quality control data, (8) repair & preventive maintenance schedules, (9) employees training & development schedules,, (10) production planning & scheduling data, (11) marketing & sales data. For regularly storing, updating, retrieving, and manipulating these critical data a total quality management information system (TQMIS) must be designed developed and installed for successful implementation of TQM (Chin, Kim et al., 2004).

2.5 Quality Management in Flow Monitoring

Flow monitoring has been a practice in engineering society for a long time. While most of the quality management systems implemented in flow monitoring service field are still limited to the water quality monitoring, there are different quality assurance and control policies and plans developed for each individual program.

In 1999, the Water Management Branch of the Province of British Columbia prepared an automated water quality monitoring field manual, which addresses the minimum requirements for the establishing and operating a reliable automated water quality monitoring program, to aid field staff in developing an automated monitoring station and

collecting reliable and representative data. The challenge associated with automated monitoring programs is to collect data that consistently represent environmental conditions. This requires clear planning and the field staff to have a full understanding of the equipment and the necessary protocols for data collection, and quality assurance and quality control. To meet the challenge, the manual has been developed and organized to present the basics of implementing and maintaining an automated monitoring station(White and II, 1999).

The procedures outlined in this field manual provide the standards to ensure quality and consistency in automated data collection, yet associated subjects such as sample containers, preservation techniques, safety measures, etc. are only briefly discussed in this manual. Though the procedures presented are acceptable ones, it need be emphasized that experienced professional judgment is a necessary component of method choice and application.

In 2000, the South Florida Water Management District (SFWMD), together with the United States Army Corps of Engineers (USACE), began implementation of the Comprehensive Everglades Restoration Plan (CERP)(District and Engineers, 2000) . In order to successfully implement the CERP, the region-wide operating standards for data collection and quality assurance protocols for a variety of data types that relate to the hydrologic system were established. These protocols provide guidelines for an efficient and effective analysis of data collected by the various agencies. Standardized protocols ensure that data are collected with similar accuracy and processing standards across agencies. In addition, these protocols provide guidance, with respect to accuracy and precision, to those involved with establishing new monitoring stations.

The scope of this document is to provide general minimum requirements for the accuracy and precision that should be met in the collection of hydro meteorological and hydraulic data. Guidelines are provided for the accuracy and precision requirements for measuring and monitoring rainfall, evaporation and evapotranspiration, water stage, and flow as well as for estimating flow through control structures and data management.

A special emphasis has been placed on direct measurements of discharge and velocity with state-of-the-art acoustic instrumentation. References to existing industry guidelines, standards and published documents covering the most relevant aspects of field flow measurements including protocols and procedures for data collection, instrument calibration, quality assurance, and measurement uncertainty are provided in the sections on water level and flow measurements (District and Engineers, 2000).

By this quality assurance practice for hydraulic monitoring, the accuracy and precision requirements have been specified for the monitoring activities, such as water level measurements, data collection frequency, rain Gauge type, siting, inspection and maintenance, computed evaporation and evapotranspiration values, etc. However, the procedures for calibrating and using the various instruments that may be deployed to actually measure, record and transmit hydro meteorological data are not included in this document. There is also weak on some other management functions, like process management and performance evaluation.

In 2005, Michigan Department of Environmental Quality of Surface Water Quality division distributed the "Quality Assurance Project Plan for Best Management Practice Water Quality Sampling" (Kieser and Boyer, 2005). The objective of the project was to provide a plan to implement desired goals for water quality improvements and protection,

as well as a consistent venue to communicate, adapt and revise the overall plan as new information is obtained and milestones completed. A Steering Committee directs the course and direction of these efforts with the basis of communications maintained through an independent internet website dedicated solely to this project and future related efforts (Kieser and Boyer, 2005).

To establish a quantitative measure of accuracy and representativeness, the Quality Assurance Management (QAM) reviews field notes, field measured parameters, and rainfall rates to verify that cross-sectional velocity measurements and field measured parameters recorded during grab sampling verify the presence, intensity, and any variation in the field-measured condition and rate of storm water runoff. For all storms sampled, the QAM compares the runoff condition and hydrograph to the size of storm and resultant composite sample results from the laboratory. To establish a qualitative measure of comparability, the QAM records any deviation from standard sample collection and handling methods noted in field notes. The QAM reviews chain of custody documentation and laboratory results to note any deviation from standard sample preparation, analytical procedures, holding times, stability issues, and QA protocols established in the standardized methods for total phosphorus and total suspended solids analysis (Kieser and Boyer, 2005).

The quality assurance project plan focuses on short and long-term goals to improve water quality, incorporating stakeholders' needs and expressed desires in a flexible framework. The plan also serves as a template for established jurisdictions to adopt short-term and long-term goals that accommodate existing infrastructure and established community visions, as well as allow growing areas of these watersheds to enact new policies and

practices, which better address water quality protection (Kieser and Boyer, 2005). On the other hand, the QAPP doesn't cover the quality management elements from the system point of view. It just set up the basic standard and field measured parameters.

In September 2006, the Division of Watershed Management of the Massachusetts Department of Environmental Protection developed the Massachusetts volunteer coastal monitoring general quality assurance project plan for water quality monitoring, wetland biological assessments, and marine introduced species monitoring. The quality assurance project plan (QAPP) outlines the procedures a monitoring project will use to ensure that the samples participants collect and analyze, the data they store and manage, and the reports they write are of high enough quality to meet project needs (EPA, 1996). It contains baseline requirements to be met for data collection projects, as well as common objectives, parameters, methods and approaches for river, lake, wetland, and coastal chemical and biological monitoring (Schoen and Warren, 2006).

The general QAPP was designed to be adopted as the project QAPP by any group performing these types of monitoring activities. If not adopted, an individual project QAPP is typically required and the General QAPP may be useful as a template for a project-specific QAPP (Schoen and Warren, 2006).

Due to the differences among flow monitoring programs, it is difficult to develop and implement a universal and standardized quality management system for all flow monitoring activities and programs. In addition, the quality management systems of many large companies have evolved by default rather than by design, since there is neither considerable design methodology for public service sector's quality system nor a systematic method for designing service processes. In addition, the quality management

requirements haven't yet to be formalized in the design literature. Currently, the environment based design (EBD) methodology is a functional tool to fill in this gap.

Chapter 3

Theoretical Foundations






3.1 Axiomatic Theory of Design Modeling

Zeng has proposed an axiomatic theory as the logic tool to represent and to reason about object structures (Zeng, 2002). This is also the basic theoretical foundation for the present thesis. This axiomatic theory gives the designer a logical approach to human thought after defining axioms dealing with objects. The basic concept rests on two definitions of axioms: 1) everything in the universe is an object; 2) there are relations between objects.

3.2 Recursive Object Model (ROM): introduction

The Recursive Object Model (ROM) (Zeng, 2007) is a part of a general design theory - Environment-Based Design (EBD) (Zeng and Cheng, 1991; Zeng, 2002; Zeng, 2003; Zeng, 2004). In the context of this research, the ROM provides an intermediate medium between natural language and structured modeling language. The ROM theory treats each word in a sentence as an object and considers that every object may have one or more relations to other objects. Furthermore, each sentence also forms an object and has a relation to other sentences in the text. Table 1 shows the elements of ROM.

Table 1 Elements of Recursive Object Model (ROM) (Zeng, 2007)

Type		Graphic Representation	Definition
Object	Object		Everything in the universe is an object.
	Compound Object		It is an object that includes at least two other objects in it.
Relations	Constraint		It is a descriptive, limiting, or particularizing relation of one object to another.
	Connection		It is to connect two objects that do not constrain each other.
	Predicate		It describes the act of an object on another or that describes the states of an object.

3.3 Formalization of Design Requirements

Since the ROM diagram forms a graphic representation of natural language, it can be used to store the semantic information of the design requirements. However, an ROM diagram performs only a linguistic analysis of the requirements text; it lacks the method for extracting modeling information from the diagram. Zeng has proposed a general methodology for the process to formalize design requirement. The input of the process is the design requirements text and the output is the formulation of these requirements.

In the formalization process, Zeng defines Ω as the structure of the engineering system, E as its environment, and S as the product. The engineering system is then decomposed into the following formula:

A key concept used in EBD is the structure operation, denoted by \oplus , which can be defined as the union (\cup) of an object and the interaction (\otimes) of the object with itself.

$$\oplus O = O \cup (O \otimes O), \quad (1)$$

$\oplus O$ is the structure of an object O.

Based on the structure operation, a product system can be defined as the structure of an object (Ω) including both a product (S) and its environment (E).

$$\Omega \text{ including, } \forall S [E \cap S = \Phi], \quad (2)$$

where Φ is the object that is included in any object, which equals to the intersection of E and S, and \forall stands for “all” .

the product system ($\oplus \Omega$) can then be expanded as follows:

$$\oplus \Omega = \oplus (E \cup S) = (\oplus E) \cup (\oplus S) \cup (E \otimes S) \cup (S \otimes E), \quad (3)$$

where $\oplus E$ and $\oplus S$ are structures of the environment and product, respectively; $E \otimes S$ and $S \otimes E$ are the interactions between environment and product. Figure 1 illustrates the engineering system.

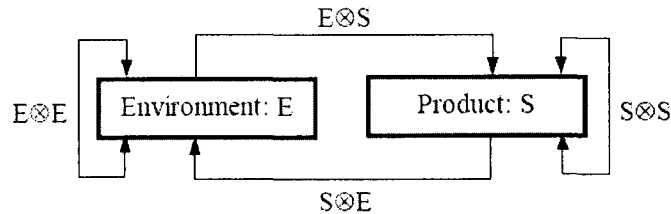


Figure 1 Engineering System(Zeng, 2004).

Figure 2 shows that in the design process, any previously generated design concept can be indeed seen as an environment component for the succeeding design. As a result, a new state of design can be defined as the structure of the old environment (E_i) and the newly generated design concept (S_i), which is a partial design solution.

$$\begin{aligned} \oplus E_{i+1} &= \oplus(E_i \cup S_i) \\ &= (\oplus E_i) \cup (\oplus S_i) \cup (E_i \otimes S_i) \cup (S_i \otimes E_i). \end{aligned} \tag{4}$$

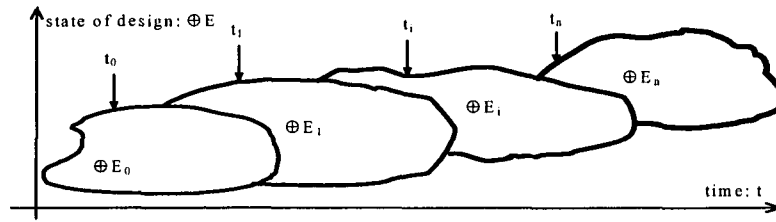


Figure 2 Evolution of Design Process (Zeng, 2004).

By using linguistic analysis in the formalization process, the formula of the engineering system is derived from the natural language requirement. Figure 3 shows the formalization process for the requirements.

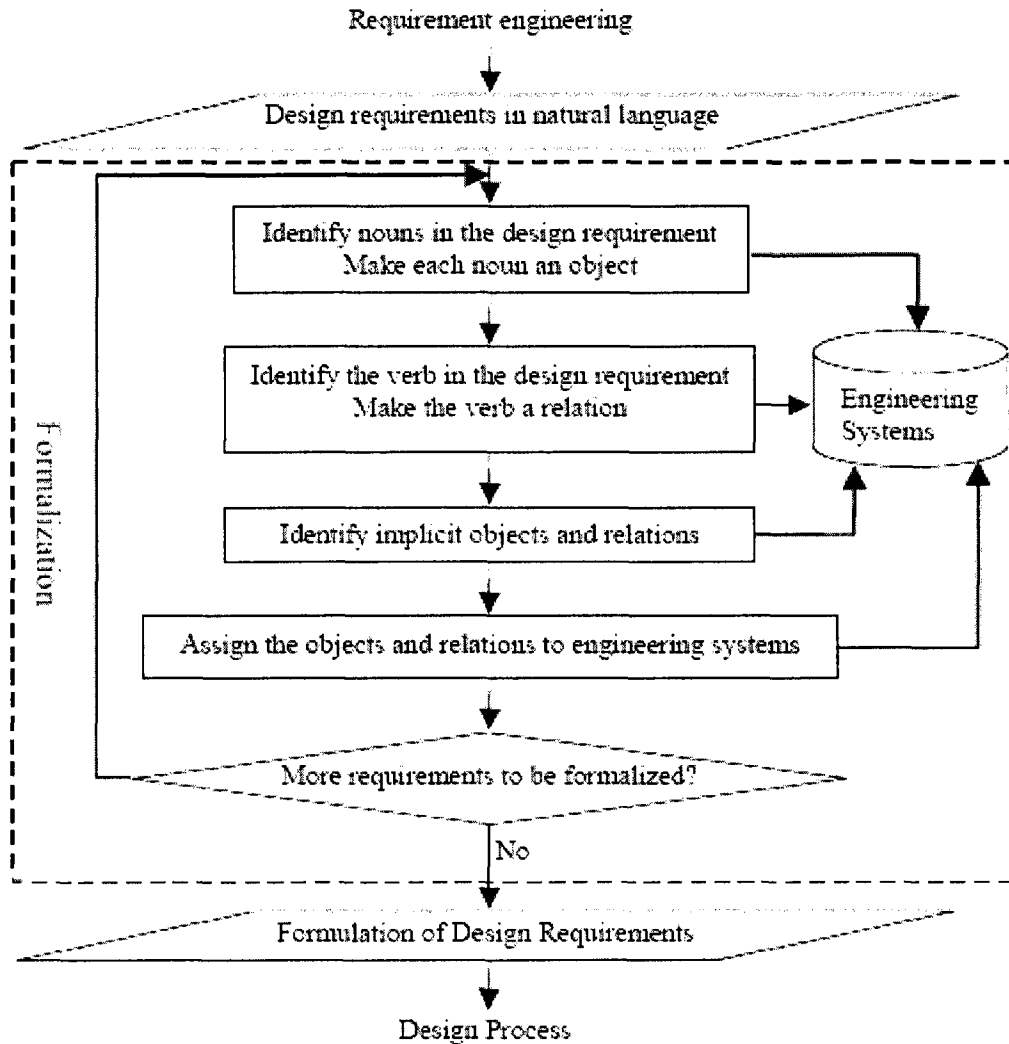


Figure 3 Formalization Process of Design Requirements(Zeng, 2003).

3.4 Environment Based Design (EBD)

The work introduced in this thesis uses a new design methodology - environment based design (EBD) proposed by Dr. Zeng. Different from traditional design methodologies, environment-based design theory was logically derived from the axiomatic theory of design modeling, which was founded on the recursive logic of design. The EBD is a prescriptive model of design (which is a design methodology) that guides designers from the gathering of customer requirements throughout the generation and evaluation of

design concepts. It is also a descriptive model of the natural design process that illustrates how designers conduct a design task. In this thesis, we introduce the procedure of implementing EBD (Zeng, 2004) to quality management system design, and discuss generically how to perform quality control and quality assurance management in public service industry. The design of Quality Management for Drainage Service Monitoring System of City Edmonton is a case study.

First of all, we analyzed the current monitoring process and practices, including detailed discussion of the business processes, functional activities, and operating processes of the Environmental Monitoring Group. Then we performed the ideal process requirement analysis by applying the Environmental Based Design (EBD), presents ROM (Zeng, 2007) and the completed requirements. Next, we accomplished the gap analysis, which presents the gap between the as-is and the to-be status of the monitoring group's quality management performance. The next thing that we show is the quality evaluation system by setting up the quality standard or performance requirement for each segment of the management of the monitoring process, which helps to evaluate the group performance in quality point of view. Finally, we generate the improvement recommendation from the above analyses; summarize the main research result based on the presented case, and point out directions of the future effort.

As is illustrated in Figure 4, the environment-based design includes three main stages: environment analysis, conflict identification, and concept generation.

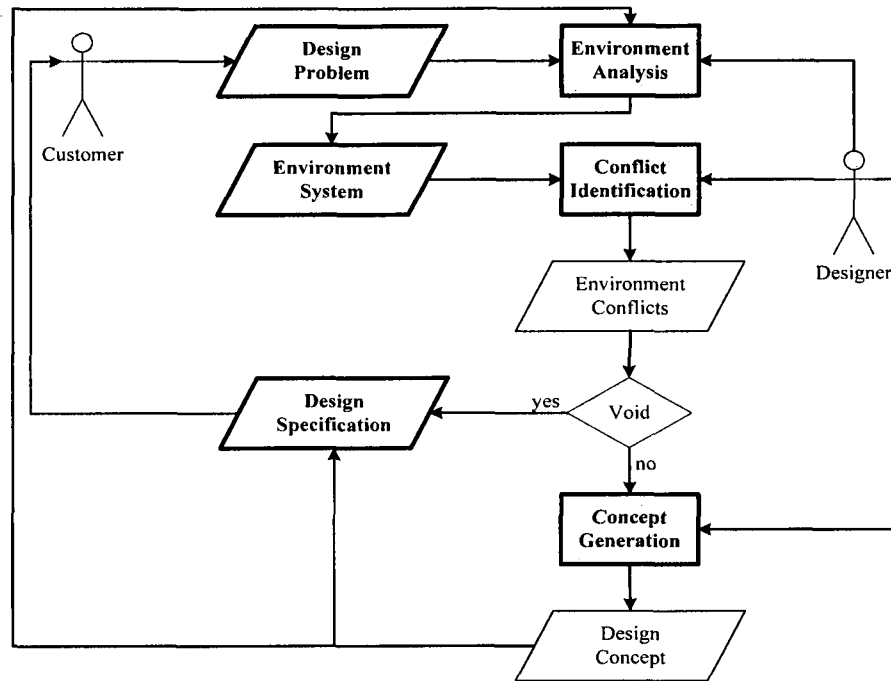


Figure 4 Environment-based design: Process Flow(Zeng, 2004).

Environmental analysis - The objective of environment analysis is to find out the key environment components, in which the product works, and the relationships between the environment components. From the environment implied in the design problem described by the customers, the designer will introduce extra environment components that are relevant to the design problem at hands. The results from this analysis constitute an environment system. One of the key methods for environment analysis is linguistic analysis.

Conflicts identification - Following the environment analysis, conflicts should be identified among the relations between environment components.

Concept generation - At the third stage of EBD, a set of key environment conflicts will be chosen to be resolved by generating some design concepts. This process continues until no more unacceptable environment conflicts exist.

The above three stages work together to ensure progressively and simultaneously generate and refine the design specifications and design solutions.

3.5 EBD Question Asking Approach

How to ask proper questions is critical for collecting right product requirements. These questions can help gather precise and complete requirements for the product to be designed.

3.5.1 Procedures for eliciting product requirements

Zeng and Wang (Wang and Zeng, 2007) have proposed a generic inquiry process for eliciting product requirements, which is shown in Figure 5. The process can be divided into the eight steps as follows.

Step 1: Create ROM diagram.

Designer transforms the original design problem described by natural language into a ROM diagram using a ROM analysis tool. This will enable the designer to understand the design problem more clearly.

Step 2: Generate generic questions.

In this step, designer analyzes each object in the ROM diagram to find out the objects that need to be identified or clarified further and generates some candidate questions based on a set of predefined rules and question template. Then these questions will be chosen to ask. These questions will help customers to understand and to clarify their real intent.

Step 3: Collect answers.

Designer collects the answers to the questions which are generated from Step 2 by looking up dictionary or knowledge base, searching on internet, or collecting from the customer.

Step 4: Repeat Step 1 to 4 until no more generic questions can be asked.

The answers collected in Step 3 are analyzed iteratively as new ROM diagrams at Step 1. Then these new ROM diagrams are identified or clarified by asking questions at Step 2. Thereafter, ROM diagrams are merged into the original ROM diagram in the ROM tool based on a set of predefined rules. At the end of the step, the explicit design problem description is extended further. The recursive process will be shown more clearly in the algorithmic description of the procedures.

Step 5: Generate domain specific questions.

The explicit design problem description above may not exactly and completely define the design problem. Designer needs to elicit more implicit environment information about the design problem. In this step, designer analyzes the relationships between the objects in the updated ROM diagram and generates a set of questions that should be answered at each stage of the design. Meanwhile the sequence for asking these questions should be determined automatically or manually based on a set of predefined rules.

Step 6: Collect answers to the questions generated in Step 5.

This step is similar to Step 3.

Step 7: Repeat Step 1 to 6 until no more domain questions can be asked.

To collect complete domain dependent product requirements and to analyze the implicit domain dependent product requirements iteratively in Step 1 to 7 may ensure that the domain dependent product requirements are accurate.

Step 8: Output the updated design problem description.

Generic Inquiry Process

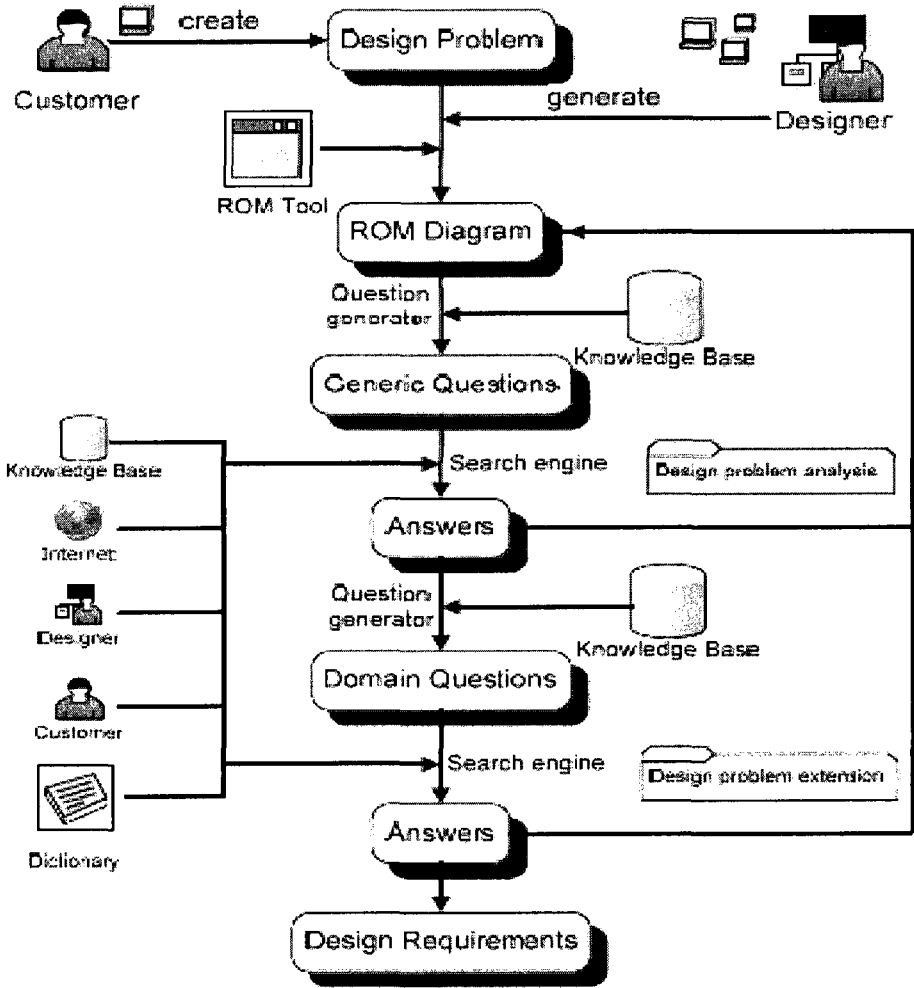


Figure 5 Requirements Elicitation: Generic Inquiry Process (Zeng, 2004; Wang and Zeng, 2007).

3.5.2 Identification of latent requirements

Based on the product life cycle and the requirements classification that shows in Figure 6 (Chen and Zeng, 2006), a question for product life cycle is first asked to identify the related stages in which the product is involved. Then for each stage, questions are generated in terms of environment components on their requirement level.

In summary, a complete list of product requirements can be defined from two perspectives: one is based on the partition of environment in terms of the product lifecycle whereas the other is the partition of the environment into human environment, natural environment, and built environment.

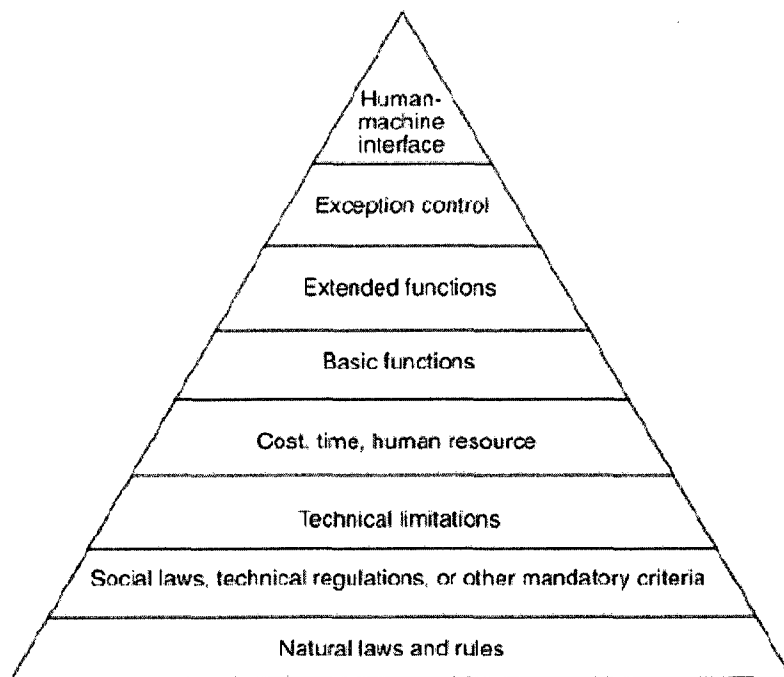


Figure 6 Eight Levels of Requirements (Zeng, 2004).

3.6 Advantage of EBD method

Environment-based design model is based on axiomatic theory of design modeling. The foundation of this theory is two axioms: 1) everything in the universe is an object; 2)

there are relations between objects. By analyzing the relations between objects, we can construct product system that comprises product and environment. All design problems can be considered as the conflict between the environment and the product. To design a product is to find a physical representation that can solve this conflict.

Environment-based design model provides a robust tool that can help designers quickly understand a design problem and find a solution to it. This model can be applied not only to redesign problems but also to inventive design problems.

The application of the EBD method to the drainage monitoring quality management system will be performed in later chapters to analysis the research case and generate the complete process requirements.

Chapter 4

Environment Analysis

4.1 Process overview

To operate and maintain the existing drainage infrastructure, as well as plan for future development of the City of Edmonton's drainage system, improve the practice and bring in the quality inputs, a thorough understanding and ongoing evaluation of the drainage system is required.

The Drainage Services branch of the City of Edmonton is responsible for planning, building, operating and maintaining over \$8.1 billion of infrastructure, including a 4939 kilometer long wastewater and storm water transportation network which consists of 2083km of storm pipe, 1902km of sanitary pipes, 937km of combined pipe, and 17km of foundation drain. The Drainage Services also operates over 79 pumping stations, 56 wet storm management facilities, 54 dry storm management facilities, and 43 peak storage units.

Since 1991, there are 527 flow sites (to the end of March 2007) that have been monitored either permanently or temporarily. Permanent sites are generally used to collect data for license requirements, to understand flow volumes discharged to the river and treatment plant, or for billing sites that discharge into/out of Edmonton's wastewater treatment plant. Temporary sites are usually sites which information is requested for such things as calibrating a model or determining the capacity of a system for extra follow. Table 2 shows the components of the total of 527 flow monitoring sites. Table 3 illustrates the monitoring site statistics for the period of 2002-2006.

Table 2 Distribution of Total Flow Monitoring Sites

Monitoring Sites	CSO	Combined	Sanitary	Storm	Storm Outfall	Total
Number	18	141	231	118	19	527

Table 3 Monitoring Site Statistics (2002-2006) (Edmonton, 2006)

	2002	2003	2004	2005	2006
Permanent Flow Site	59	63	73	79	92
Temporary Flow Site	51	43	59	60	52
Storage Tank	32	28	28	27	17
Pump Station	18	29	29	30	33
Rain Gauge	23	23	23	27	28
Interconnection	174	153	223	223	222
(%) Overall Proficiency	80.9	83.1	92.7	92.7	97.9

(The Overall Proficiency: the percentage of time the monitors were on-line and collecting good data.)

Through this extensive monitoring effort, the City has developed a rich database of the flow and rainfall used to understand the system performance, to calibrate computer models, and to report to stakeholders regarding the combined sewer overflow and severe storm events. (Stantec, 2004; Edmonton, 2006)

4.2 Monitoring Processes and System

As the flow monitoring program keeps growing and the environmental regulation becomes more stringent, there is a need to conduct a thorough study to review the system monitoring process.

A well developed drainage system monitoring program provides good quality data for developing and calibrating simulation models that are used to plan, design, and upgrade the urban drainage and waste water collection and treatment systems. System monitoring also provides information for assessment and control of existing drainage system performance such as combined sewer overflows (CSO) to the rivers, interconnections (where sanitary or combined sewage can overflow into the storm system), and provides the flow data to meet the requirements of Alberta Environment and agreements with organizations outside of the City.

City of Edmonton has a system monitoring program under the Environmental Monitoring group which consists of:

- Installing, removing and maintaining flow monitors in sewers, culverts, creeks, pump stations and lakes
- Verifying that the devices are working properly at the time of installation
- Collecting data
- Checking the data for quality and site problems
- Storing the data in the database
- Purchasing equipment and making manufacturer software work with City systems
- Installing and maintaining tipping bucket rain gauges
- Purchasing weather radar data and rainfall analysis projects based on that data
- Analyzing data and providing data report to customers
- Post event storm analysis for intensity, return period and aerial extent.

4.2.1 The main activities of Monitoring Process

To better understand the current drainage system monitoring process, it is necessary to list the main monitoring activities. The processes applied in monitoring drainage systems include site selection, instrument selection, calibration, installation, maintenance, as well as data collection and analysis. The main monitoring activities include:

- **Manage Monitoring Locations** – the first step for successful monitoring activities in any sewer system is the identification of suitable locations for the installation of flow meters (or rain gauges). It contains site selection and configuration, which are based on the monitoring requirement and site physical accessibility.
- **Site Installation** – once the site locations are determined, appropriate instrument are to be selected, followed by the meter and logger installation. The measurement devices should be first verified and calibrated in shop and on the field before putting them in operation.
- **Site Maintenance** – monitoring sites need to be regularly maintained to make sure that the access is not blocked; the meter and logger are repaired and operated normally.
- **Data collection** – monitor data are either automatically or manually collected at the set schedule.
- **Data quality checking** – raw data collected should be checked in a regular base to make sure that the meters record correct data and loggers save correct data. Criteria have to be developed to conduct the quality checking.
- **Data transformation** – monitored data, once checked to be correct, will be used to calculate other parameters which have relations with those directly monitored data

(such as the discharge of in sewer pipes are calculated based on the measured velocity and depth). This process is called data transformation.

- Data analysis – statistical and numerical analysis are usually required for monitored and transformed data. For example, the daily, weekly, monthly, quarterly, and annual maximum, average, and minimum flow rates, etc.
- Report generation and submission – monitored data are reported to the stakeholders and customers after the analysis. Such as the CSO data to environmental agencies, rain data for other city departments and consulting firms who are working on city planning and design projects, etc. Report generation and submission are part of responses to customer requests.

4.2.2 Graphical model for the system and environment

Based on the system requirement classification, system flow graph and the analysis of the environment requirement components, the graphical model for the system and environment are described below.

Figure 7 illustrates the relationships between the system and environment. The system consists of the Data Collection Network and the Monitoring System Operations. Data is collected from monitoring sites by various rapturous devices. Database stores data after data downloading and quality checking. The shaded blocks represent the components of Human environment, whereas the others represent the Built Environment components. It shows that there are various interfaces, which means conflicts, between the two main environments.

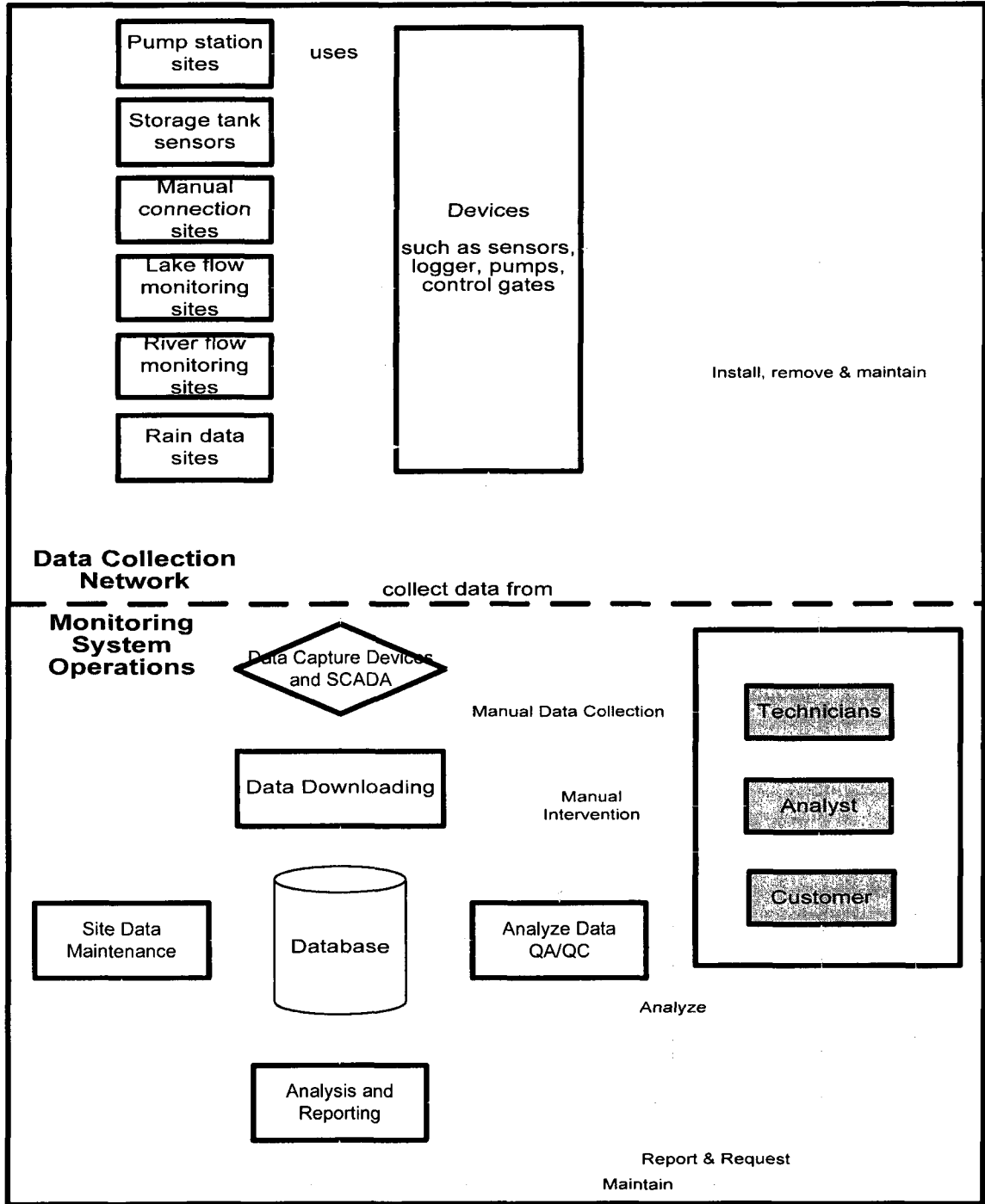


Figure 7 System and Environment Graphical Model (Chan, Jim et al., 2008).

Figure 8 illustrates the drainage monitoring system’s main operation process and components to handle monitoring data. Data has to be converted from raw file to standard

file before it is used to analyzed and reported. People, device and system get involved to the entire process as main components. Each step of the process has its quality assurance and quality control requirements.

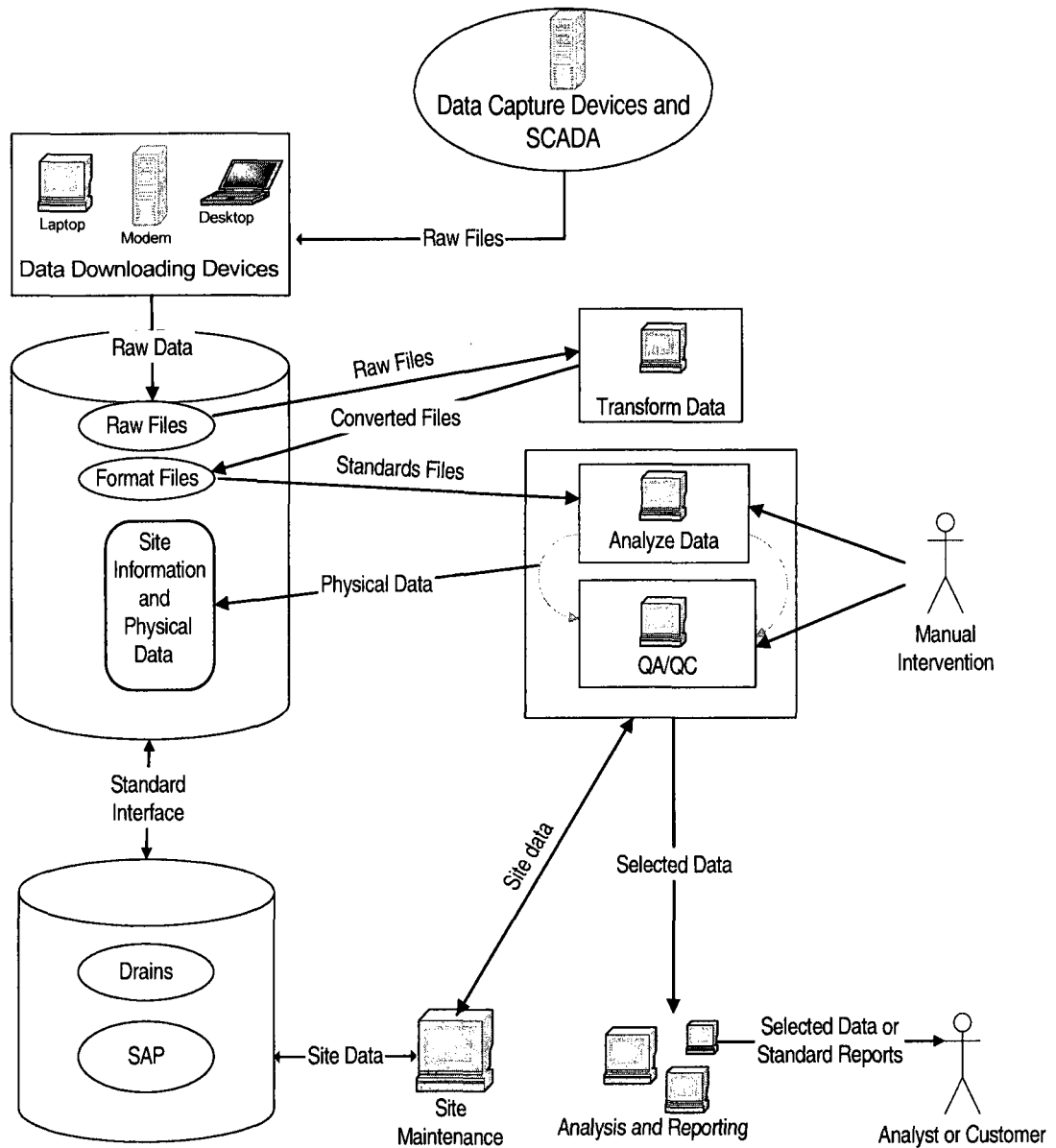


Figure 8 Data Process Flow Graph(Chan, Jim et al., 2008).

4.2.3 Process components and relationships

Based on the above analysis of the design problem, it shows that the quality control opportunities in drainage system monitoring process exist in the connections between the interfaces of the main monitoring components. Thus the drainage system monitoring components need to be listed to elicit the interfaces (conflicts) in the monitoring process for analyzing the completed requirements of the quality management:

A. Human Environment	B. Built Environment	C. Natural Environment	D. Drainage System Monitoring Relationships
A.1. Residence of City Edmonton	B.1. Device	C.1. Whether	R1: Supervise
A.2. Manager	B.1.1 Flow meter	C.1.1 Rain	R2: Operate
A.2.1 Department Manager	B.1.2 Rain gauge	C.1.2 Storm	R3: Request
A.3. Supervisor	B.1.3 Laptop	C.1.3 Snow	R4: Cooperate
A.3.1 Group Supervisor	B.1.4 Desktop	C.1.4 Wind	R5: Check
A.3.2 Monitoring Supervisor	B.1.5 Modem	C.2. Outdoor sites	R6: Use
A.4. Technician A.4.1 Field technician	B.1.6 Removable storage	C.2.1 Fenceless sites	R7: Work
A.4.2 Office technician	B.1.7 Wireless Network	C.2.2 Protected sites	R8: Contact
A.5. Contractor	B.1.8 Hard line cable	C.2.3 on-traffic sites	R9: Set up
A.5.1 Site construction contractor	B.2. Software	C.2.4 off-traffic sites	R10: Install
A.5.2 Device setting up contractor	B.2.1 SHAPES	C.3 Indoor sites	R11: Maintain
A.5.3 Maintenance contractor	B.2.2 SCADA		R12: Supply

A.6. Supplier	B.2.3 SAP		
A.6.1 Device supplier	B.2.4 Micro data base		
A.6.2 Software suppliers	B.2.5 ORACLE		
A.7. Client	B.2.6 DRAINS		
A.7.1 Government Consultant	B.3. Sites		
A.7.2 other City departments	B.3.1 Permanent Flow Site		
A.7.3 other levels of governments	B.3.2 Temporary Flow Site		
	B.3.3 Interconnection site		
	B.3.4 Storage tanks		
	B.3.5 Pump stations		
	B.3.6 Rain gauges sites		
	B.4. Outputs		
	B.4.1 Data		
	B.4.2 Service		
	B.4.3 Document		
	B.5. Working place		
	B.5.1 Office		
	B.5.2 Instrument workshop		

4.3 Process conflicts analysis

Based on the previous process components and relationships analysis, the conflicts in the drainage system monitoring process can be elicited before generating the ideal requirements of the quality management system. As per the previous discussion, conflict means there is the need to be managed, and there is the opportunity to be improved from the quality point of view. In the target monitoring process, there are two main categories of conflicts: environment internal conflicts and external conflicts.

Internal environment conflicts can be divided into human environment conflicts and built environment conflicts. Human environment conflicts exist between supervisors, office technicians, field technicians, device contractors, site contractors, planners, etc. To settle down this type of conflict, there is a need to set up quality management methods which including staff requirements, training procedures, verification procedures, etc. Built environment conflicts exist within the other objective components, such as document, data, device, site, inventory, location, and network. Quality management methods like standard, template, data requirement, data verification procedure need to be set up to deal with this kind of conflict.

Figure 9 illustrates the conflicts that exist in the interfaces between human and built environment components in the target monitoring process.

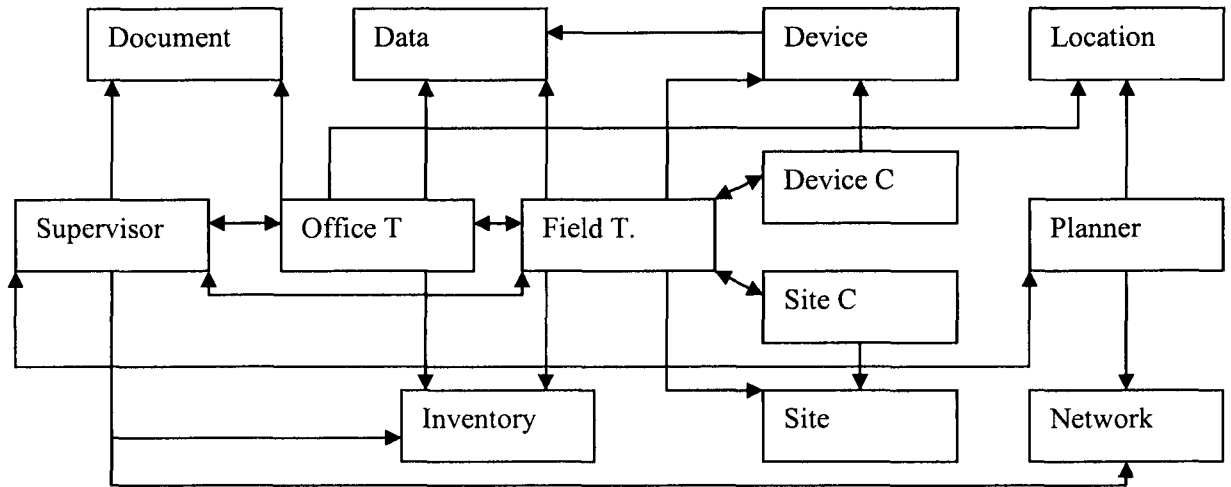


Figure 9 Main Conflicts in Current Practice.

There are also external environment conflicts which exist in the interfaces of different relationships components in the target monitoring process. To handle these conflicts, the quality management methods like operation schedule, operation requirement, operation procedures, and operation logs need to be built.

4.4 Formalization of System Requirement

Based on the previous discussion of the design methodology, EBD will be implemented to analyze the drainage monitoring system in order to generate the requirements of the total quality management system.

4.4.1 Linguistic Model of the System

The research objective is to develop strategy and procedure to formalize quality management system for monitoring process of drainage service for the City of Edmonton, using quality management theory and technique, to ensure a well developed drainage

system monitoring program provides good quality data and to improve the quality of drainage system monitoring services in the City of Edmonton.

4.4.2 Eliciting product requirements

Step 1: Create ROM diagram based on design problem description. The ROM diagram is shown in Figure 10.

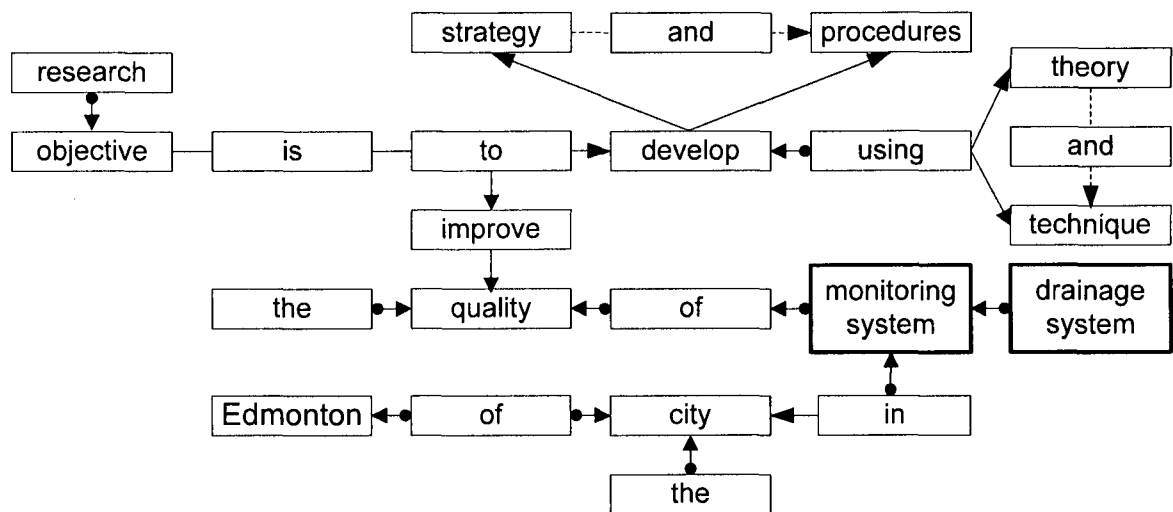


Figure10 ROM Diagram for Step-1

Step 2: Generate generic questions based on ROM diagram.

After analyzing the ROM diagram created in Step 1, some questions asked in this step are listed as followed.

Q1: What's the Quality Control System in general?

Q2: What's the Drainage System of City Edmonton?

Q3: What's the Monitoring process? How to perform the drainage system monitoring?

Who is performing the monitoring? What's the product of the process?

Q4: How could the QC system work on the drainage monitoring system? The connection between the QC system's function and the objective (drainage system monitoring process)

Step 3: Collect answers for the generated questions.

A1: Quality control system is to ensure products and services that are designed and produced to meet or exceed customer requirements.

A2: The Drainage System includes the massive network of pipes, tunnels, pump stations, and storage and treatment facilities.

A3: The drainage systems monitoring process includes site selection, instrument selection, calibration, installation, maintenance, as well as data collection and analysis.

The system monitoring group is performing the monitoring, including devices, programs, and people.

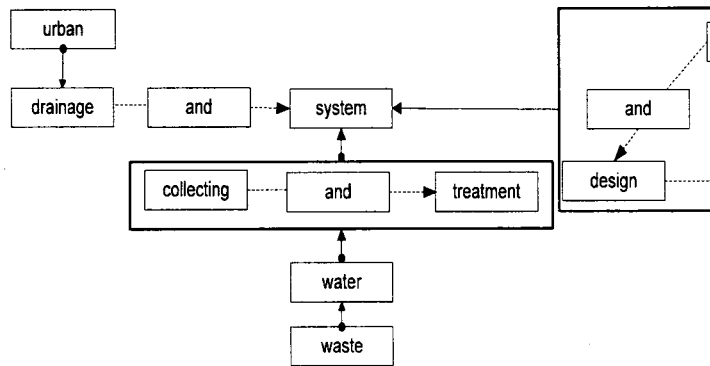
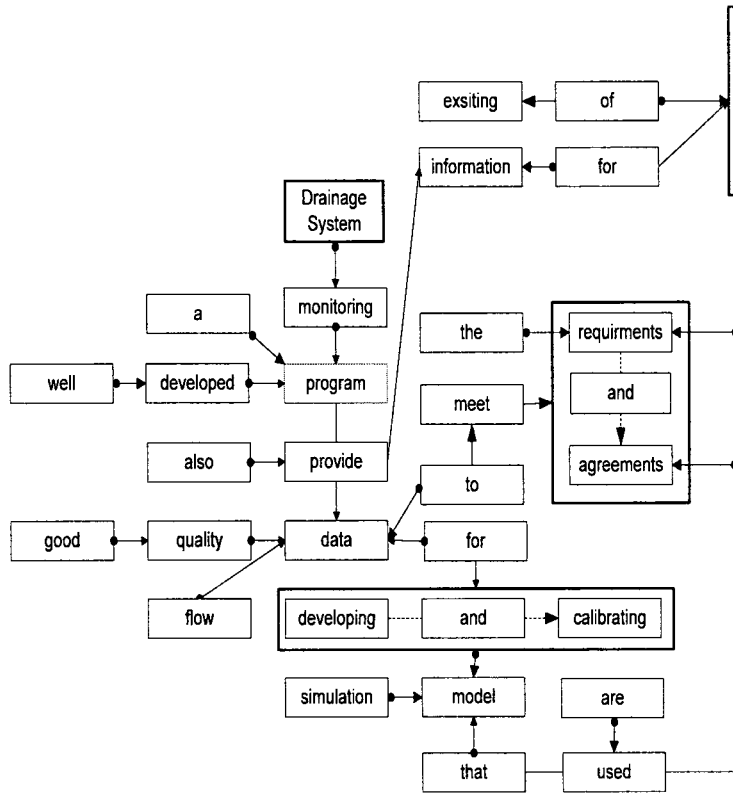
The drainage services branch is responsible for planning, building, operating and maintaining the wastewater and storm water transportation network and a wastewater treatment plant.

The product of the monitoring process is the data report and the service.

A4: The quality control opportunities exist in the connections between the interfaces of the main monitoring components, including devices, programs and people.

Repeat step 1 to 2 to analyze the answers collected in Step 3 until no more questions can be asked.

Step 4: let each answer be gone through from step 1 to step 4. The following details in Figure 11 show the ROM analysis answer.



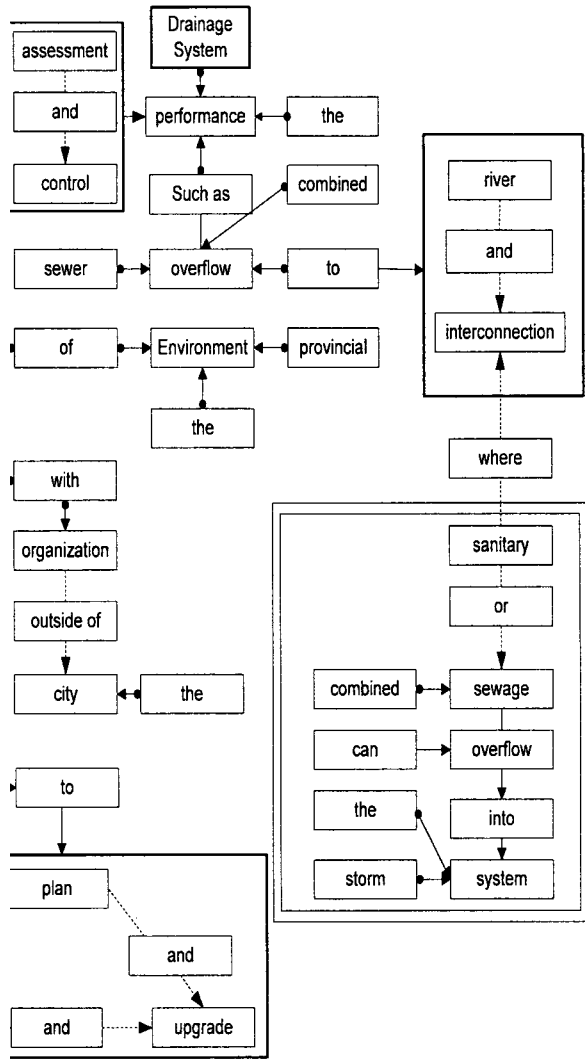


Figure 11ROM Diagram for Generic Questions

Step 5: Generate domain specific questions.

To identify the implicit environment and complete requirements of the design problem based on a set of predefined rules that some questions will be selected to ask. These questions shown below should be answered at each stage of the process design.

Q5: What is the life cycle of the system to be designed?

Q6: What standards should the system conform to?

Q7: Who are the ultimate users of the system?

Q8: Who are the objectives of the system?

Step6: Collect answers for the questions generated in step5.

A5: The life cycle of the system includes generating problem, design, implementing, maintenance, and adjusting.

A6: The system should follow the related quality management standards.

A7: The ultimate users of the system are the drainage monitoring staff.

A8: The objectives of the system are the main monitoring process components.

Step 7: Repeat step 1 to 6 until no more domain questions can be asked.

Q9: What are the related quality management standards?

A9: The related quality management standards include environment management standard, quality management standard for civil works, process safety management standard.

Each answer should be analyzed in ROM diagram from Step 1 to Step 7 and generated ROM diagrams are merged into the previous one. A part of the final ROM diagram is shown as below in Figure 12.

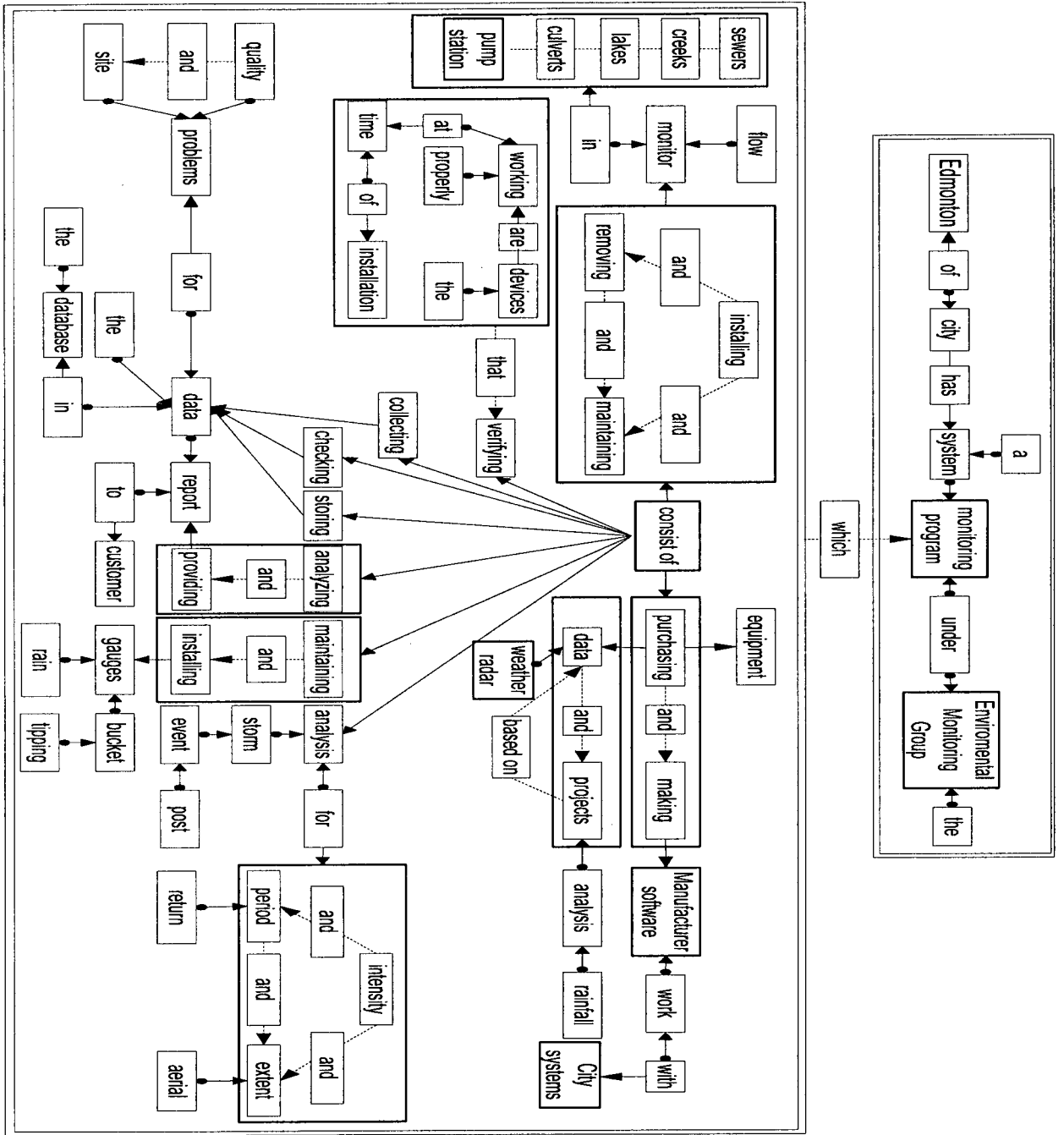


Figure 12 Final ROM (Part).

Step8: Output the updated design problem description

Based on the last ROM diagram generated in the whole generic formalization process, we get a part of final requirements by translating the ROM diagram into natural language. The descriptions are listed as below.

The task is to develop a quality management system for monitoring process of drainage system for City Edmonton. The system is to ensure products and services are designed and produced to meet or exceed customer requirements.

The drainage services branch is responsible for planning, building, operating and maintaining the wastewater and storm water transportation network and a wastewater treatment plant.

The drainage systems monitoring process includes site selection, instrument selection, calibration, installation, maintenance, as well as data collection and analysis.

The product of the monitoring process is the data report and the service. The quality management opportunities exist in the connections between the interfaces of the main monitoring components, including devices, programs and people.

The life cycle of quality management system includes generating problem, design, implementing, maintenance, and adjusting. The system should follow the related quality management standards, which include environment management standard, quality management standard for civil works, process safety management standard. The ultimate users of the system are the drainage monitoring staff.

Chapter 5

Conflict Identification

The City of Edmonton's drainage system is a complicated infrastructure which is constantly developing and holding the significant responsibility for the citizens of the City of Edmonton and its neighborhood municipalities. Contrastingly, the monitoring group within the drainage service branch is a small team taking an immense responsibility of monitoring the performance of the drainage system. Besides, there are limited standard procedures or criteria implemented for many of the system monitoring practices and activities. Work is performed on the basis of individual experience. It is high demanded that the individual experience be transformed into concrete knowledge and rules. To achieve the performance standards and quality control requirements need to be developed and implemented in order to ensure that the monitoring activities be performed more efficiently.

5.1 Gap Analysis

5.1.1 As-Is and To-Be

The drainage monitoring system already exists prior to this project. The current system is illustrated in Figure 13. After the implementation of the quality issues, the aim is to obtain an improved system as in the following figure. Figure 14 illustrates the process. Some issues, such as the quality of the system maintenance & emergency maintenance, will be shown in the corresponding sections.

The future product will not only provide basic functionality as of now, but also create a user and environmental friendly interface to other applications. The updated drainage system monitoring program provides good quality data for developing and calibrating simulation models that are used to plan, design, and upgrade the urban drainage and waste water collection and treatment systems.

The system monitoring group also provides information for assessment and control of existing drainage system performance such as combined sewer overflows (CSO) to the rivers, interconnections (where sanitary or combined sewage can overflow into the storm system), and provides the flow data to meet the requirements of the Alberta Environment and agreements with organizations outside of the City.

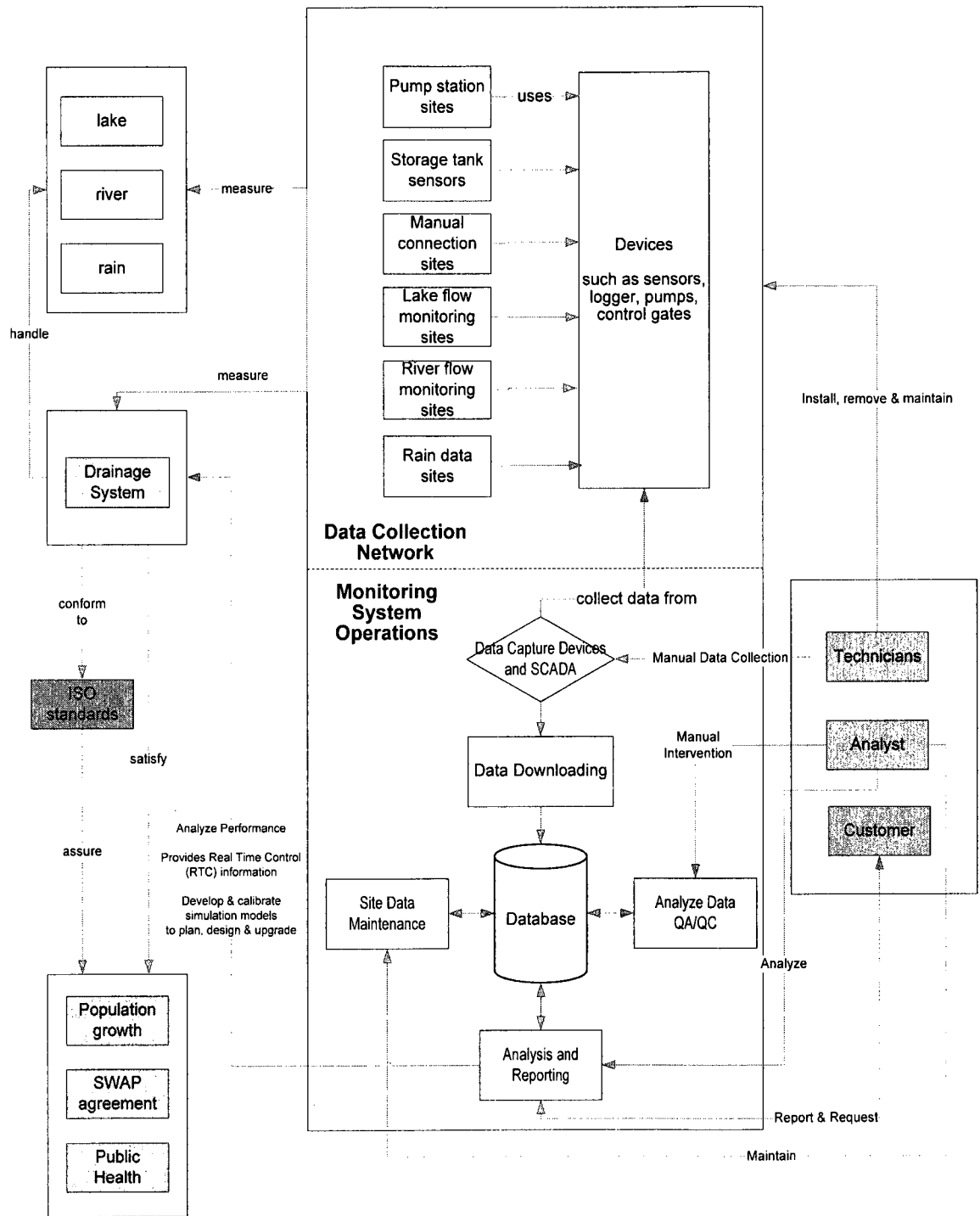


Figure 13 Current State of the Product (As-is) (Chan, Jim et al., 2008)

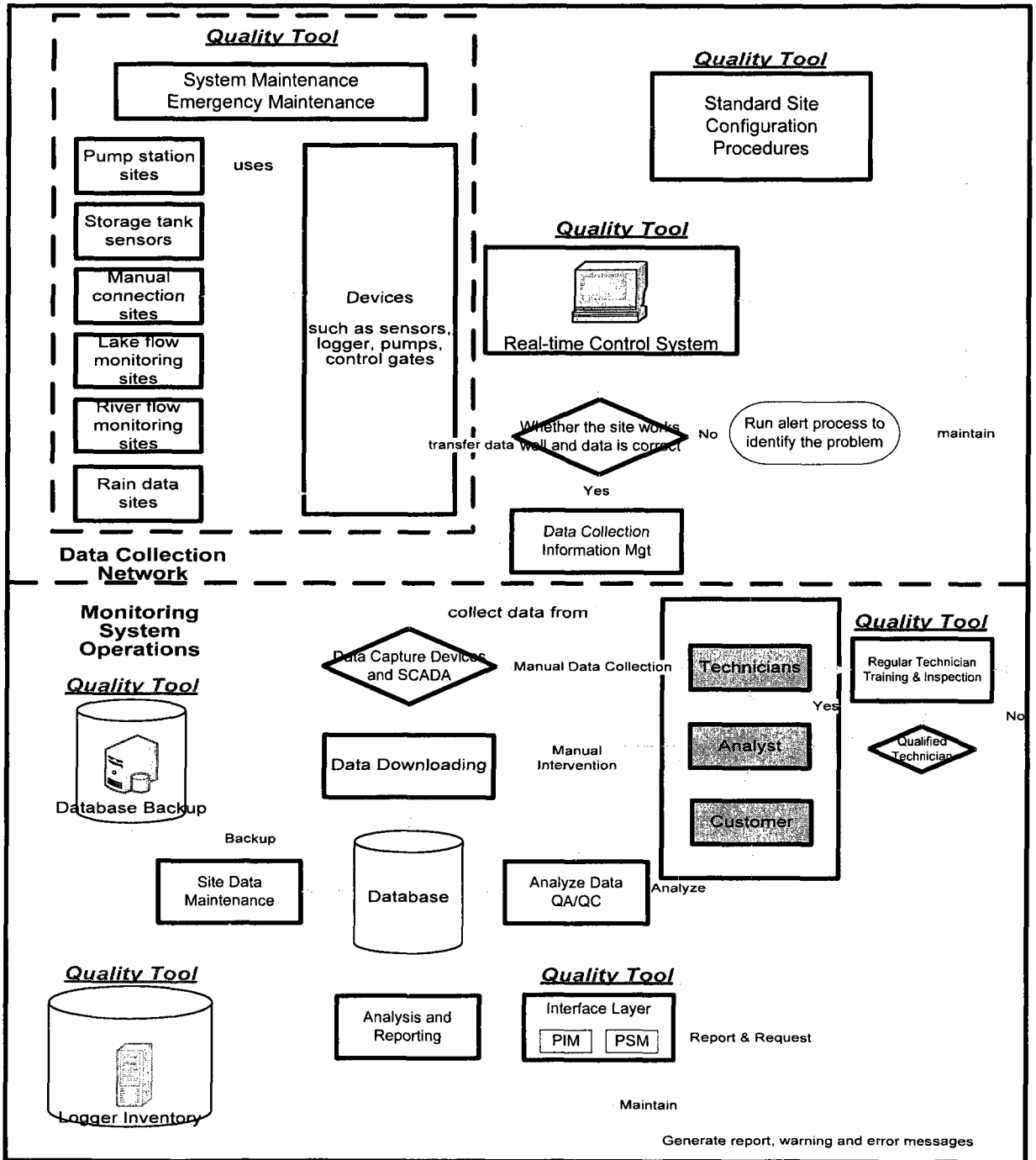


Figure 14 Future State of the Product (To-be) (Chan, Jim et al., 2008).

5.1.2 General Cause-effect Analysis

The purpose of a cause-and-effect diagram, also known as a fishbone diagram or Ishikawa diagram, is to graphically document the analysis of factors (that is, cause) that relate to a single problem or opportunity (that is, effect). Cause-and-effect diagrams are used in problem-solving situations and in general analysis to identify factors (that is, causes) related to a problem or opportunity (that is, effect) to help the problem-solving or analysis team understand how those factors may cause the given effect, and to help the problem solving or analysis team focus on next steps in process improvement. Major causes are normally associated with one or more of the following: People, Hardware/equipment, Environment, Methods, and Materials.

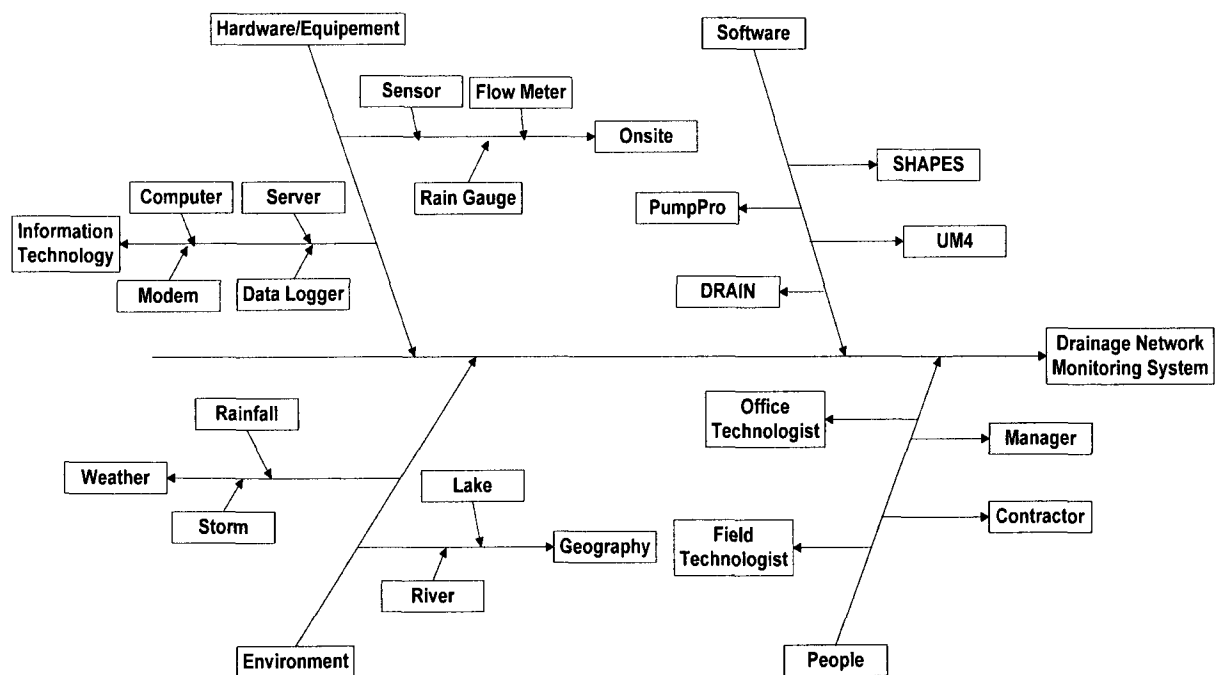


Figure 15 General Factors Cause-and-effect Diagram

Figure 15 is the fishbone diagram which was drawn to illustrate the main factors for drainage network monitoring system using general categories. The four generic headings including hardware/equipment, software, environment and people have been used to prompt ideas. Layers of branches show thorough thinking about the causes of the problem. For example, under the heading of people, there are four different kinds of factors related to people: office technologist, field technologist, manager, and contractor. To analyse the cause and effect of the target monitoring practice in System Engineering way, the Figure 10 can be redrawn from the environment and component point of view. The fishbone diagram in Figure 16 was drawn based on System Engineering Model. All systems can be considered as two parts, the system itself and the environment, according to the theory of System Engineering Model. The main factors for environment of the drainage network monitoring system have been classified by the priority levels of product requirements through partitioning product environment into natural, built, and human environments base on the Environment-Based Product Design. It is relatively hard to change the system itself; however we can find the key challenges and potential improvement by analyzing and modifying the environment, which is much easier. For example, it would be expensive and time-consuming to change the computer or flow meters (hardware), or upgrade the SHAPES system (software), but it might be easier to train the field technologists to be familiar with the equipment in order to improve the accuracy during data acquisition phase.

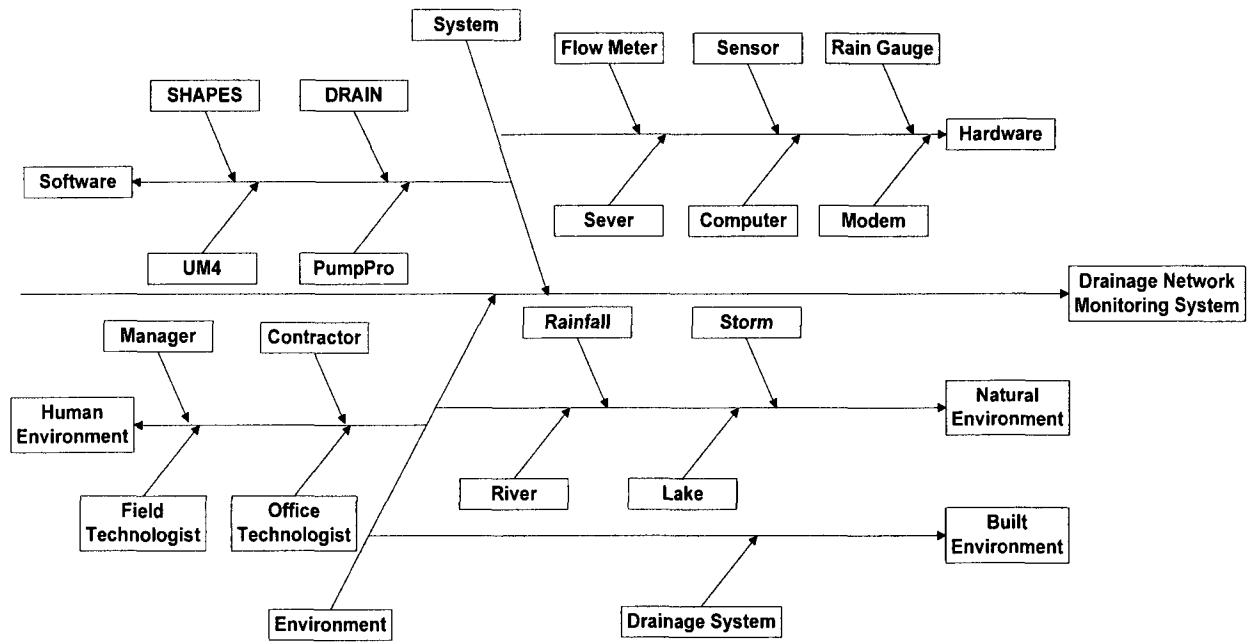


Figure 16 Cause-effect Diagram based on System Engineering Model

5.2 Quality Gap Issues

Based on the previous discussion, the following quality issues are formalized from the system.

5.2.1 Multiple components

From the existing model, we can find that the system is comprised of different software components related to each other, which makes it complicate to add a new functionality without breaking the current structure. It is also showing that in the past software components upgrade, some of the software features had been misused and brought in many restrictions to the business users. On the other hand, some component's features

have never been used and maintained. Some resources are only dedicated to one component and cannot be shared with others. Therefore, a redesign of current monitoring system is critical to the further development of this project.

5.2.2 Real-time monitoring

There is no such a monitoring application to monitor the behavior/performance of the hardware, software, and human components that are in operation. A failure from any part of the system should be reported automatically for proper handling. The diversified operation schedule, operation requirement, operation procedures and operation logs should be generated and implemented.

5.2.3 Logger Inventory

Different software applications will generate their own logs during the execution. However, the product does not provide a way to manage all levels of log effectively. In fact, it cannot even update the logger inventory. Logs for software component are important, which normally indicate a warning or potential error in the system. So, enable the logging ability of the product is also an improvement that we should include.

5.2.4 Automated Data Access

Under the current set up, only the data from those permanent sites are automatically collected and stored into the database. Due to the database access security, only limited operators can access the database. This ensures the system security but reduces the

flexibility when it is needed. Also, it is very difficult to access the database due to the existence of various types of database which require different permission.

5.2.5 Calibration Data

Calibration data are collected but never stored in the database. To include this information will be beneficial to the accuracy of the data and any further analysis on the data. Therefore, this should be included in the improved system.

5.2.6 Data Analysis

Limited data analysis functions are implemented in the current data acquisition program (called SHAPES). Using historical data to predict the future change is a commonly used methodology in real-time systems. This will also contribute to the system statistical control, which makes it easier to detect an outlier data during the process. The data standard, template, requirement, and verification procedure need to be set up.

5.2.7 Report Generating

In the current implementation, the reports results are mostly generated based on one specific requirement and normally in a fixed template. In other words, customized report cannot be produced in terms of different requirements. This may have a negative impact on the usability of the product. A powerful and flexible reporting feature should be provided in this product. Also, the report standard, requirement, and verification procedure need to be set up.

5.2.8 Universal interface

During the study, we also realize the importance for this product to provide a universal interface to other applications. Due to the nature of the product, it is very common for this product to communicate with other application, such as weather forecast applications, safety control applications. Therefore, a universal interface to a 3rd party application should be also highlighted during the redesign phase.

5.2.9 Configuration standards

There is no documentation that indicates any standards for site configuration and management for the SHAPES system. Documents contain these illustrations, such as when and where the site should be installed or removed, should be reviewed and baseline so that all sites can run the monitor service system uniformly.

5.2.10 System maintenance

System hardware and software could be aged and will reduce the performance of the system. A regular calibration and maintenance plan should be provided as well in order to access the quality of the system.

5.2.11 Emergency plan

Lack of emergency plan for monitoring site is another issue we found during the study. Currently, the system provides effective monitoring data only under normal environment. In case of emergency, for instance, site caught on fire or abnormally breakdown, we

could not use the system to collect data until such problems are manually fixed. In order to build a robustness system, we have to take all these accidents into consideration.

5.2.12 System backup

The monitoring service system is made up of a series hardware and software. A complete backup of the application database or even hardware devices will be necessary when system encounter any partial break downs. A minimum backup of all critical components will provide a stable product solution.

5.2.13 Technician training

Finally, technicians are responsible for many tasks including site location, instrument calibration and installation, data collection and analysis, as well as reporting, etc. The qualification of skills and experiences of the technicians is highly related to the quality of the monitoring services. Therefore, continuing professional development through regular quality trainings, examination, and certifying are necessary for flow monitoring staff. Meanwhile, some regulations, like staff requirements, training materials and procedures, as well as certification procedures should be developed.

Chapter 6

Concept Generation

The previous gap analysis indicated that there are rooms for the drainage system monitoring group to improve the performance. Based on the previous discussions, a total quality management system (TQMS) will fill the gap between the ideal requirements and the current practice. This subsection describes the procedures and rules for the automatic formalization of FBS models from the ROM diagram representing a text.

6.1 Quality Management Baseline

The following categories represent the environment requirements that have been identified in eight levels which can be partitioned into natural, built and human environments. Based on the previous discussion, the ideal quality management system of drainage monitoring process should meet the requirements shown in Table 4.

Table 4 Quality Management Requirements

Environment	Levels	Requirements
Human	Human-machine interface	Installing, removing and maintaining sites or devices require technicians. Some data is collected or checked using non-automated process Reports are provided to customers Responding to requests for specified Data
	Exception control	Providing Real Time Control (RTC) information of system performance

	Extended functions	<p>Maintaining information and physical data of sites using database systems</p> <p>Maintaining sites, logger and sensor configuration, device interface management, and telemetry setup</p> <p>Reviewing and planning the most appropriate monitoring locations</p> <p>Integrating manufacturer software with the system</p> <p>Transferring raw data by data downloading device (e.g. laptop, modem, desktop) as raw files</p> <p>Converting raw files collected from measurement devices into a standard files structure</p> <p>Producing tabular reports for any data required to interface with other applications</p>
	Basic functions	<p>Installing and configuring permanent or temporary flow sites</p> <p>Installing, removing and maintaining flow monitors in sites</p> <p>Installing, removing and maintaining tipping bucket rain gauges</p> <p>Verifying and adjusting devices (e.g. flow monitors, rain gauges)</p> <p>Collecting data from devices located at the sites</p> <p>Checking the data for quality and site problems</p> <p>Storing the data in the database</p> <p>Analyzing data to understand the drainage system performance</p> <p>Developing and calibrating simulation models that are used to plan, design and upgrade the drainage system</p>

Built	Cost, time, human Resource	<p>Purchasing devices (e.g. flow monitors, rain gauges)</p> <p>Purchasing weather radar data and rainfall analysis projects based on that data</p> <p>Flow sites to be monitored include permanent or temporary flow sites, rain data sites, pump station sites, storage tank sensors and manual connection sites.</p> <p>Scale of existing drainage system to be monitored: 4,700 kilometer long wastewater transportation network and a state-of-the-art tertiary wastewater treatment plant, and 49,500 catch basins</p>
	Technical limitation	Providing Real Time Control (RTC) information of system performance
	Social laws, technical regulation, or other mandatory criteria	<p>Respect the SWAP agreement, which was extended until 2015.</p> <p>Water quality and availability are quickly becoming high priority issues for both levels of government and the public.</p> <p>The monitoring system should conform to industry standard for EMS system ISO14001.</p>
Nature	Natural laws and rules	<p>The rain volume, river flow, storm level, storm frequency are monitored in the system.</p> <p>Post event storm analysis is done for intensity, return period and aerial extent.</p> <p>The city's population is forecast to increase by approximately 45,000 people between 2003 and 2008.</p>

6.2 Target Quality Management System

6.2.1 TQMS Implementation

According to the previous discussion, the Total Quality Management methodology will be implemented in the quality management in the Environmental Monitoring Group. The

objective of the total quality management system (TQMS) is to enable the monitoring group to provide higher quality products and more efficient services with the current resources. The foundation of the TQMS involves quality standardization, quality-related training, and quality information. Meanwhile, the quality management opportunities exist in the connections between the interfaces of the main monitoring process components, including devices, programs and staff.

6.2.2 Quality Control and Quality Assurance

The TQMS includes both Quality Control (QC) and Quality Assurance (QA) programs. To generate the complete requirements of the quality management system, we need to clarify the difference between QC and QA at first.

6.2.2.1 Quality Control (QC)

QC is a system of routine technical activities to provide routine and consistent checks to ensure product integrity, correctness, and completeness, to identify and address errors and omissions, and to document and archive inventory material and record all QC activities.

QC activities include general methods such as accuracy checks on data acquisition and calculations and the use of approved standardized procedures for data calculations, measurements, estimating uncertainties, archiving information and reporting.

6.2.2.2 Quality Assurance (QA)

QA is a systematic process integrated into laboratory and field procedures as well as data storage protocols to ensure a specified degree of confidence in the data collected for an

environmental monitoring service. Planning for quality assurance should occur for all steps of a project through implementation and operation. It is essential that all the phases of a project be documented thoroughly and supplemented by detailed field notes. In general, QA is a management process to ensure that the necessary QC activities are being adequately performed, while QC activities are those that detail the day-to-day operation of the system.

Figure 17 shows a schematic of QA/QC. Table 4 describes the contents of a QC/QA system.

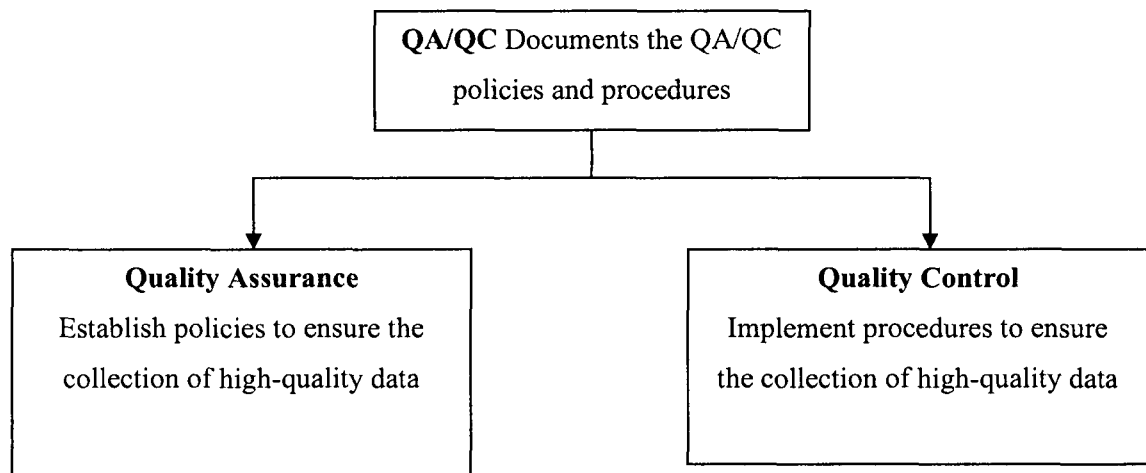


Figure 17 Quality Assurance/Quality Control Schematic(Council, 2008)

The QA/QC manual describes a complete program of activities to be implemented to ensure that the data generated will be complete, accurate, and precise. As a minimum, the manual must include the QA/QC procedures specified in this report. The recommended Table of Contents for the QA/QC manual is shown in Table 5.

Table 5 Quality Assurance/Quality Control Manual(Canada, 2008)

Subsection	Contents
Quality assurance policies and system descriptions	
1 Quality Assurance Goals and Objectives	Specific system goals relating to precision, accuracy, and completeness. Specific objectives as laid out in the regulations and guidelines. Data standards and reporting requirements.
2 Organization and Responsibilities	Description of the organization of personnel involved with the quality system. Defines the roles and responsibilities of the personnel involved as related to system operation and maintenance, control of documents/records, and control of data.
3 Calibration and Quality Control Checks	Description of the calibrations and QC checks that are performed on a routine basis, generally daily, to determine whether the system is functioning properly. Includes daily zero and calibration checks and visual checks of system operating indicators.
4 Data Acquisition and Analysis	Description of the data acquisition system and analysis program. Includes references to data completeness, validation, reporting, storage, and revision management. Roles and responsibilities of the personnel involved in the data handling should be included.
5 Preventative Maintenance Policy	Description of the preventative maintenance program, including how preventative maintenance scheduling is determined and

	maintained along with roles and responsibilities of the personnel involved.
6 Emergency Maintenance Policy	Description of the emergency maintenance program, including how emergency maintenance scheduling is determined and maintained along with roles and responsibilities of the personnel involved.
7 Corrective Action Program	Description of the policies for correcting any non-conformance. Parameters such as data download time/reliability should be addressed. Roles and responsibilities of the personnel involved in the corrective action program should be included.
8 Performance Evaluations/Audits	Description of the policies and specifications for performance evaluations/audits (i.e., staff annual audits). Describe the action necessary to ensure that the appropriate evaluations are carried out on the appropriate schedule.
9 Document Control System	Description of the policies and systems used to control all the documents that form part of the quality system. Lists how and where the related documents are located, how they are reviewed and revised, and how they are approved for use by authorized personnel prior to issue.
10 Reports and Records	Description of all reports and records collected. Description

	should contain method of collection, person responsible, data storage location, data security, data distribution, and length of data storage.
11 Modifications and Upgrades	Description of the policies regarding modifications and upgrades to the monitoring system. This section should include any regulatory requirements pertaining to modification or upgrade of the system.
12 Training and Qualification Policy	Training and qualification policy for monitoring staff and related maintainers, coordinators, IT technicians, pertaining department. Includes educational and experience requirements, on-the-job training, and classroom training requirements.
Quality control (standard operating) procedures	
1 Startup and Operation	Lists in detail complete, step-by-step procedures for the startup and operation of each monitoring activity.
2 Daily System Operation and Inspection	Detailed description of daily routine operation and inspection. Includes descriptions of equipment and data validation procedures. Examples include daily equipment checks, work log, etc.
3 Daily and Manual Calibration Procedures	Lists in detail complete, step-by-step procedures for daily and manual calibrations, includes schedule for manual calibration.

4 Preventative Maintenance Procedures	Detailed description of the preventative maintenance procedures along with the preventative maintenance schedule. This could include a preventative maintenance work order program for the sites that need to be routine visited.
5 Emergency Maintenance Procedures	Detailed description of the emergency maintenance procedures along with the emergency maintenance schedule.
6 Spare instruments List and Inventory Procedures	Detailed descriptions of the spare instruments and inventory available for the monitoring system, along with a description of the procedures for obtaining spare instruments from inventory and ensuring that the inventory is maintained.
7 Corrective Maintenance Procedures	Detailed descriptions of the non-routine maintenance that is performed when the system or instrument of the system fails.
8 Data Backfilling Procedures	Procedures for data backfilling when acceptable data is not available. Include Data backfilling algorithms.
9 Data Backup Procedures	Procedures for regular backup of data in hard or soft copy.
10 System Security	Includes security actions for monitoring equipment, software and data.
11 Data Approval and Reporting Procedures	Procedure for approval and reporting of data. Includes any systems for review, modifications, approval, summary, and release of data.

12 Quarterly Audit Procedures	Includes roles and responsibilities, requirements, scheduling, and test methods. Detailed procedures on conducting quarterly audit procedures.
13 Bias Procedures	Describes process of assessing and correcting for bias. Includes roles and responsibilities for assessing and approving bias factors.
15 Semiannual/Annual System Audit Procedures	Describes procedure for annual system audit. Includes selection of auditor, scheduling, audit plan, reporting format, test methods, and calibration requirements.
16 Adjustment Management	Procedure for managing adjustment when upgrades are required due to failure of equipment, changes in regulation, changes in system management. Includes approval process for accepting changes with roles and responsibilities.

6.2.2.3 QA and QC of Drainage System Monitoring Process

Based on the previous process analysis, the following are the quality assurance and quality control requirements of drainage system monitoring process, as presented in Figure 18. It shows the main steps that need to combine QA and QC activities with in the monitoring process.

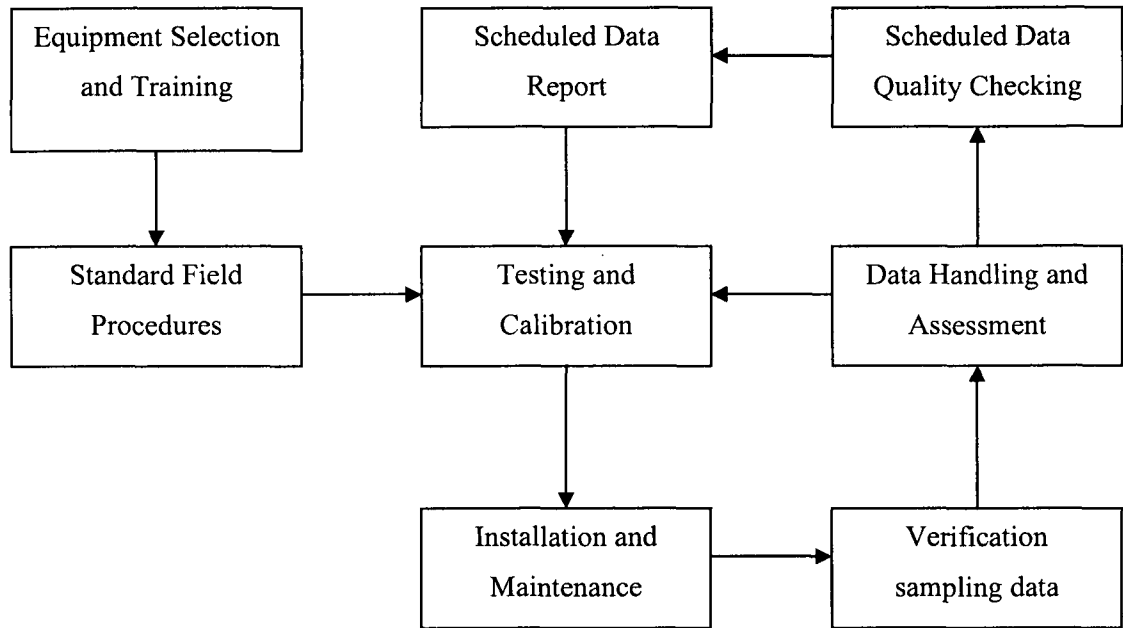


Figure 18 Incorporating QA/QC into the monitoring process

6.2.3 Functional Model of the target QMS

According to the updated design problem description and final requirement, combining with the QA and QC requirements, a graphical functional model has been built for the Total Quality Management System of the target project. The functional model is shown in the Appendix A.

In the diagram shown in Appendix A, the element “Human Resources” refers to all the personnel that relate to the monitoring business function, including internal and external customers, which should follow the rational organizational structure, job allocation, personnel placement, and be regulated by periodical work report and assessment policy.

The “Equipment” refers to all the hardware or material components that relate to the monitoring process, including devices, instruments, infrastructure, consumable material, etc. which need quality management as inventory control, maintenance record, performance report, etc.

The ‘Monitoring Objects’ refers to the current and potential drainage monitoring objects: wastewater, storm water, water quality. They need to build the quality mechanisms such as preventive system, emergency system, and sustainable development practice, e.g.: water quality monitoring, environmental monitoring, pollution control.

The “Work Flow” management refers to the non-substance components in the monitoring process, including work flow, software, operating regulation, operational procedure, etc. which need to set up unified standards and the up-to-date mechanism to ensure the functionality, advancement, and originality of the monitoring system.

The “Environment Control” refers to all the business regulations and performance specifications that the drainage monitoring group should respect, like ISO140001, national law, or industrial conditions.

6.2.4 Detailed Provisions of the QMS

Here are the main provisions of the target total quality management system, based on the flow chart in Appendix A:

A. Job design and Position locate

- Minimize monotonous or unpleasant tasks in the job design.

- Create provisions to adjust individual responsibilities or add resources when the volume of work changes significantly.
- Ensure enough personnel cross trained to provide an adequate supply of experienced personnel to fill in when needed.
- Ensure the personnel that have been selected to ensure the best match of their skills and job requirements.
- Generate, publish, and update the detail job descriptions, concrete task, work procedure, and evaluation metrics for each position.
- Clearly define the personnel responsibilities in terms of decisions and actions.
- Set up guides and aids (e.g., computer prompts) lead personnel to the next step in a job.

B. Procedures and standards

- Set up formal work procedures and job performance standards for quality and quantity requirements in written forms and publish the standards.
- Review and keep the job standard updated.

C. Training

- Provide training of personnel on the knowledge of job techniques, terminology, and background.
- Give staff an overview of the entire organization.

- Set up regularly scheduled training to provide staff with current information on customer needs and new technology.
- Let the staff provide input to their training needs.
- Let training include the why, not just the what.
- Consider the background of those to be trained when design the training program.
- Ensure the people doing the training provide enough detail.
- Consider provide mentor to new staff if it's appropriate.

D. Equipment Selection

- Monitoring equipment should be properly selected based on the flow conditions at sites.

E. Standard Field Procedures

- Field procedures must be standardized and documented.
- Detailed notes from each field visit must be recorded and maintained on standardized forms.

F. Testing and Calibration

- All equipment must be calibrated and bench tested prior to field deployment.
- Each instrument will have a duty cycle that defines the period between calibrations for which there should be confidence in the data.

- The duty cycle which is dependent on instrument type and deployment environment, must be determined for each monitoring program.
- For each instrument, a log of the calibration date and the date of next calibration should be maintained and could be entered into SHAPES.

G. Installation and Maintenance

- Each installation should have a specific plan and the visiting schedule between required maintenance.
- All information regarding installation maintenance should be recorded on standard field forms (Appendix B) and entered into the SHAPES.

H. Verification sampling data

- To verify the data, it is essential that instruments be tested against a standard to check performance and independent samples, or measurements.
- Instrument verification provides confidence in the performance of the instrument.
- Results from verification sampling should be transferred to the appropriate databases.
- Field verification programs include the calibration of the instrument.
- Calibration provides confidence in the output of the instrument. If the meter reads outside the instrument specific tolerances, the instrument must be considered inaccurate, and removed from service and sent to a qualified technician for repair, recalibration, and certification.

I. Work record and review

- Provide instructions and schedule to staff for performing self-review of their work.
- Create special checks to detect errors.
- Anticipate and minimize errors due to normal interruptions in the work cycle.
- Incorporate steps in data entry processes to reject incorrect entries.
- Include action provisions for submitted wrong data or missing data.
- Examine paperwork periodically, and destroy obsolete records to simplify working conditions.
- Set up method to detect errors easily and early.
- Let peer personnel or others perform independent checks on quality.
- Set up the review of work performed at various check points in process, not just when work is complete.
- Have an independent audit of the entire process to ensure that individual work assignments are integrated to achieve process objectives.
- Keep detailed log of daily work.

J. Handling problems

- Provide personnel with the training to identify problems, analyze problems, and develop solutions.
- Set up the provisions of deviations. Clarify the definition of deviations.
- Permit personnel to exceed process limits with the appropriate level of management approval.

- Ensure personnel aware how to seek assistance when they encounter an obstacle on a job, and ensure the assistance conveniently available.

K. Feedback

- Set up standards and methods for making corrections to output.
- Provide feedback to staff and discuss with staff.
- Request feedback from customers (external and internal)
- Request both positive and negative (corrective) feedbacks, if it's necessary, let negative feedback given in private.
- Distribute staff a detailed report of errors by specific type of error if it's appropriate.
- If certain types of errors tracked with feedback from external customers, put effort on tracking these errors within internal customer early.

L. Supervision Actions

- Ensure staff feel accountable for their output and declare if shortcomings are under their control.
- Ensure the processes (including procedures, equipment, software, etc.) given to staff meet standards for quality and quantity of output.
- Encourage personnel to suggest changes in job when they show that the change will provide benefits. And reward the practical proposal.

- Ensure the levels of management approval are required for instituting proposed changes.
- Confirm that they are open to recommendations from all personnel.
- Avoid external factors (e.g., contractor on strike, lack of certain kind of meter) hinder the ability to perform a task.
- Consider the possibility to schedule a “productive hour/hours” each day in which casual chatting, not work-related phone calls, and other interruptions are not allowed, thus providing time to be away from the work location to attend to other tasks.
- Ensure procedure given to personnel fully apply to the job they do in practice.

M. Operation-time limitation

- In service processes, a quality problem may be an error or a mistake, the correction of which requires effort and expense. By improving the service process, this wasted effort and expense can be avoided.
- The maximum amount of time to process an operation or to provide a particular service is one of the quality performance indicators. Service providers should target on avoiding and decreasing the waste, especially in terms of time, to improve the process.

6.2.5 Data Quality Assurance

All the above components belong to either input or process, which point at the same ultimate goal of the monitoring system: data or report. The quality of data collected is

dependent on the methods used to handle, assemble, operate, and maintain the equipment. Taken together, precision, accuracy, representativeness, completeness, and comparability comprise the major data quality indicators. At the same time, the system generates a variety of forms, logs, and other documentations as by-products. To improve the current product adapted to the new requirements, the data quality management and documentation management system are essential to the monitoring quality management business.

Figure 19 shows the flow of data, and meta-data (field notes, calibration logs, and maintenance logs), through the data assessment and approval process.

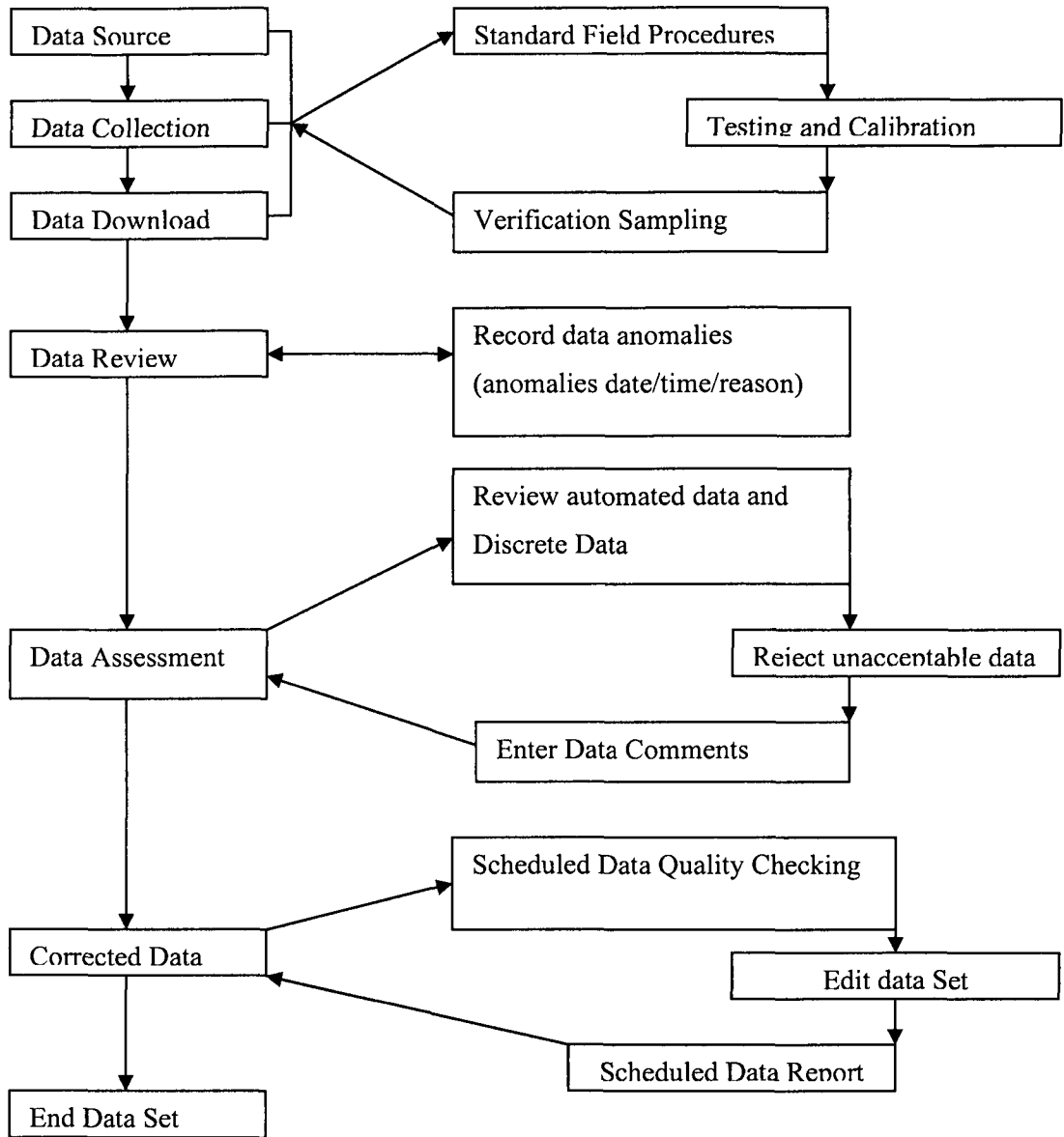


Figure 19 Flow of Monitoring Data from Raw to End Data Set

Data Handling and Assessment are to ensure the production of reliable and accurate data that can aid in the assessment and selection of Best Management Practices for the customers.

Scheduled Data Quality Checking and Scheduled Data Report are the essential process of the quality management system. The main provisions of the data quality assurance are as follows:

Data must be downloaded from the data source, entered into a database, then viewed and edited regularly. To maintain continuity in the data handling process, data approval should be conducted by field personnel. All steps in data handling, from downloading, screening, editing, and verification must be documented. It is important that when data are edited the original data set not be altered or destroyed, and that detailed notes be maintained and entered into the database. It is also imperative that all steps in data handling be documented.

To the data assessment and report, it is suggested to view data *graphically* since it aids in detection of obvious errors in the data and allow corrective measures to be taken.

6.2.6 TQMS Performance Evaluation

6.2.6.1 Establish measurement

To evaluate the performance of the quality management system, the control subjects need to be listed first. Generally, control subjects can be a mixture of features of the product,

features of the process, and side effects of the process. Quantification of control subjects involves two kinds of indicators.

A. Performance indicators, which measure the main components of the process and its conformance to customer needs, as defined by the unit of measure for the control subject.

B. Process indicators, which measure the activities or variation within the process that affect the performance indicators.

Table 6 shows the quality indicators along with the importance weights assigned to each indicator. These measures should be tacked every day, both individually and in total.

Table 6 Top Quality Indicators

Component	Indicator
Device	Accuracy of data
	Device performance
	Device reliability
	Thorough testing
Program	System downtime
	System response time
	Network reliability
	System performance
Staff	Individual performance
	Thorough Training
	Level of expertise

Table 7 shows the related internal metrics to business processes and customer needs.

Table 7 Relevant Internal Metrics to Business Processes and Quality Indicators

Overall quality		Business process	Quality indicator	Internal metric
	Site	Configure Sites	Configure on time	% configure on due date
		Verify Site Function	Features/Function	Performance test
		Install Site	Install on time	% install on due date
		Remove Site	Remove on time	% remove on due date
		Perform Site Maintenance	Break time	Repair reports #
			Maintenance frequency	Maintenance report
	Device	Verify and Adjust Device	Reliability	# repair call
			Features/Function	Performance test
			Easy to use	# calls for help
		Install Device	Install on time	% install on due date
		Repair Device	No repeat demand	# repeat call reports
			Fixed fast	Average time of repair
	Administer Maintenance	Maintenance frequency	Maintenance report	
	Program	Collect Non Automated Data	Thorough collecting	#Data non- collected log
		Collect Automated Data	Thorough collecting	#Data non-collected log
		Perform Data Transformation	Data delivery interval	Average order interval
		Perform Quality Checking	Data missing, data error	Data range, Statistical control
		Perform Data Analysis	Daily/seasonal/annual	Data analysis report

		Produce Error Reports	Instant error report	# Error reports
		Manage Monitoring Locations	Relevant data updated	Staff collaboration
	Staff	Develop Quality Checking Criteria	knowledge	Supervisor observation
		Respond to Requests	Response	% response made on time
			Follow-up	% follow-ups made
			Customer Kept informed	% customer informed
			Produce Specified Reports	Resolve on first call
		Easy to understand	# inquiries	

6.2.6.2 Quality System Evaluation Subject

By consulting Juran's quality handbook, a list of the performance elements that could be the base of the evaluation subjects to the drainage monitoring system on specific time interval has been generated (Appendix C). The components of this list refer to the quality aspects of various segments of the overall systematic approach to quality and related processes.

Chapter 7

Conclusion and Future Work

7.1 Conclusion

This research is about to ensure the performance of a public service sector by implementing a Total Quality Management (TQM) module. TQM is a strategic, long-term set of practices for management to introduce continuous improvement initiatives across all functions. Companies who fully integrate a QMS can reap significant benefits internally and externally in terms of quality assurance (Sroufe and Curkovic, 2008). However, while TQM has been heavily used in manufacturing in the United States, its applications in service organizations in general and information systems in particular, have been limited

The objective of this thesis is to develop a framework for the environmental monitoring group of the City of Edmonton to establish a Total Quality Management System, to improve the quality of drainage system monitoring services in the City by developing a quality management strategy and procedures based on quality management theory and techniques.

The development of the framework for TQM of the drainage monitoring system is accomplished by applying the methodology of environment-based design (EBD). EBD is the theoretical background for the whole project. It helps to present Recursive Object Model (ROM) diagram and elicit the complete requirements of ideal monitoring system, and then design the quality management system based on the product requirements.

Currently, there is neither considerable design methodology for public service sector's quality system nor a systematic method for designing service processes along with the quality management requirements haven't yet to be formalized in the design literature. The environment based design (EBD) methodology is a functional manner to fill in this gap.

Through this research, the completed requirements of the quality management system for City of Edmonton's Drainage Service Monitoring Group has been elicited by applying ROM analysis and generated the evaluation elements, observation components, and improvement recommendations.

The effectiveness of the EBD has been verified to be a functional methodology for a public service organization to verify and ensure a well developed drainage system monitoring program which provides good quality data for developing and calibrating simulation models that are used to plan, design, and upgrade the urban drainage and waste water collection and treatment systems.

The System also provides information for assessment and control of existing drainage system performance, and provides the flow data to meet the requirements of the provincial Environment and agreements with organizations outside of the City.

It can be observed that environment based design (EBD) is an effective methodology for the quality management system design of the public service process. On the other hand, the future works need to be done to set up the standard design framework and detailed

quality management manuals.

7.2 Future Work

The Quality Management System (QMS) is recommended to implement all the functions and activities related to quality management that were discussed previously. Based on the present case study and previous discussions, the functional module of Quality Management System has been developed.

The quality management information system (QMIS) is strongly recommended to be developed and implemented by the drainage monitoring service group. QMIS is a significant tool to support quality activities, which can perform “in-process” monitoring, store in data bases information useful in executing tasks or processes important to a customer, shorten lines of communication and get cycle time reduction.

The future works, such as system preliminary design, coding and testing, maintaining and updating, need to be pursued to develop and implement the QMIS.

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