QUALITY PERFORMANCE IN A DESIGN-BUILD MEGA-PROJECT

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SUMMARY

This paper outlines several significant lessons drawn from quality management of a major highway project from the initial proposal through three seasons of construction. The authors describe solutions and innovations in integrated quality management and assessment, including a web-based quality management tool developed for the project. Measurement and reporting of quality performance are used to drive an effective, participative quality improvement process with tangible benefits for both the Developer and the Owner.

INTRODUCTION

The authors were engaged in the Quality Engineering and Management aspects of the Fredericton-Moncton Highway Project (FMHP) in New Brunswick, Canada. As the successful proponent in a competitive process, the Developer, Maritime Road Development Corporation (MRDC), undertook to design, build and operate a mega project with unprecedented standards for quality, safety and environmental management. This project provided an excellent opportunity to apply both conventional and innovative quality management methods within the framework of ISO 9001:1994.

Inherent in a competitively bid, guaranteed maximum price contract is a strong incentive for the Developer to search out every opportunity to fulfill contractual obligations in the most cost-effective manner possible. MRDC found that several organizational and technical solutions helped to achieve this goal.

While the ISO 9000-related family of standards are not the sole defining documents for the FMHP, it is significant that several of the unique challenges and solutions of the project are clearly aligned with elements of these standards.

THE PROJECT

The Fredericton-Moncton Highway Project (FMHP) is a 195 km (120 mile) segment of the Trans Canada Highway under construction in the Province of New Brunswick. The facility is a four-lane, controlled-access highway with 20 interchanges and 73 structures, including two high-level bridges over the Saint John and Jemseg Rivers, three other major river crossings and 68 standard structures.

The Province required an ISO 9001-compliant Quality Management System (QMS) for all aspects of the development, design, construction and operation of the Project. The quality of the project is entirely the responsibility of the Developer and is overseen on behalf of the Owner by an Independent Agent empowered to assess conformance to all aspects of the contract by quality auditing.

The FMHP represents a milestone in Private-Public Partnering for such a large project as it cast the Developer with its subcontractors and the New Brunswick Department of Transport in new roles and relationships with respect to the management and assessment of work.

QUALITY IN THE PROPOSAL AND AGREEMENTS

The Request for Proposals, issued to three proponents in March 1997, set the stage for low cost provision of services. As is common practice, separate technical and financial responses were required; technically compliant proposals being accepted for comparison on financial and other relevant bases to determine the final Developer.

Included in the proposal schedule was a requirement to submit a draft Quality Management Plan complying with ISO 9001 showing how the quality of the project would be assured to the Owner. To accomplish this at the proposal stage, six months before the assembly of the full team of subconsultants and subcontractors, one of the authors (Collier) was engaged by the MRDC Engineers Joint Venture to work with them in preparing a model Quality System Manual for submission with the proposal and to serve as the basis for the later development and deployment of the Quality Management Systems (QMS). When MRDC became the successful proponent, this document served as the model for the project QMS governing Design, Construction and Operation of the facility.

The Quality commitment for the project began with the published mission statement which was reflected in policy, training and practice throughout the project; "... to develop, design, construct and operate the Fredericton-Moncton Highway Project with the highest regard for the New Brunswick Department of Transport's stated objectives and the safety, convenience, and economic well-being of its primary users, the people of New Brunswick." This was echoed in the Quality System documentation which committed to full contractual and regulatory compliance both directly and by assigning the responsibility for quality in all contracts to the subconsultant or subcontractor involved. Thus the original manual became the template for all quality systems throughout the project.

Agreements spanning 90 binders, (over 3800 pages) govern the conduct of the project with the aim of achieving new standards in Environmental, Quality and Safety management. Two principal agreements, the Development and Design-Build Agreement (DDB), including 33 Schedules, and Operation, Management, Maintenance and Rehabilitation Agreement (OMM), with 25 Schedules, incorporate by reference the Quality, Environmental and Safety Plans for the Project. In this way both the Owner and the Developer have embedded the Quality Management System into every aspect of the Project.

The principal business organizations involved in deploying these agreements consist of:

- Fredericton Moncton Highway Project Company (the Owner) and Delcan, its Independent Agent (IA)
- MRDC Construction Joint Venture (CJV) - "the Developer"
- MRDC Engineers Joint Venture (EJV) - "the Designer"
- MRDC Operations Corporation (OC) - "the Operator"
- Subcontractors, subconsultants and suppliers.

Lesson 1: To compete as the low cost provider in today's environment, a company must be willing to agree to world-class requirements for quality. By aligning the quality requirements with ISO 9001 and incorporating them directly into the agreements, the advantage went to the proponent who would accept extra responsibility and seek to delegate it effectively. This arrangement also allies the Owner and Developer closely in pursuit of their common interest - the Public-Private Partnership. (Reference ISO 9001:1994, Contract Review)

COORDINATION OF QUALITY, ENVIRONMENT, SAFETY (QES)

In addition to invoking ISO 9001 for Quality, the RFP called for development of a state of the art Environmental Management System aligned with ISO 14000 and a comprehensive Safety Management Plan to minimize risks to everyone involved in the project. While these systems are outside the scope of the present paper, it is worth mentioning that close liaison was maintained among the Quality, Environment and Safety Managers from proposal through implementation with the result that cooperation in auditing, training and corrective action could often lead to efficiencies for the project.

For example, the personnel of all New Brunswick Engineering and Contracting firms engaged on the project, several thousand people in all, received combined quality, environment, safety orientation training on the MRDC Quality, Environment and Safety requirements for the project. In turn, these subconsultants and subcontractors were held contractually accountable for these three aspects of their work subject to audit and approval by MRDC quality and engineering staff.

The worth of these measures was shown when on September 27, 1999, MRDC received the Transportation Association of Canada's Environmental Achievement Award for 1998. The award was for the Environmental Management Plan that MRDC prepared and that formed part of the contract for the construction of the Project. Additionally, the Project Risk Management-based Safety program was documented at the end of three seasons to be performing at about one third the lost time and injury rates of comparable projects.

The authors believe that fostering a common attitude of care and excellence in these related fields yields economies in training and enforcement through synergy.

Lesson 2: Competitive low cost providers can realize benefits both for themselves and their clients by recognizing and exploiting the common ground among Quality, Environment and Safety. Training and coaching these allied subjects together increases the return on the training time and expense by reducing the total time off the job and reinforcing related concepts and behaviors. (Reference ISO 9001:1994, Training)

OWNER'S ASSESSMENT OF QUALITY

A novel feature of the DDB Agreement is the identification of Quality Management as a "line item" in the Guaranteed Maximum Price (GMP) of the project. This item, approximately 4% of the GMP, is scheduled as a series of maximum monthly amounts (varying with the season and certain project milestones) to be paid out based on an independent assessment of the effectiveness of operation of the QMS.

This goes beyond the traditional role of the IA, which is to independently certify the completion of work for payment by the Owner. Normally such certification is based on verification of quantities and conformance to specifications of the work invoiced as complete. Now, in addition, the IA must introduce a means of assessing the effectiveness of the QMS for the same work period in order to approve that part of the payment. The means devised was to calculate a Quality Performance Score based primarily on the results of random auditing.

In order to qualify for the full monthly payment, the Developer is required to achieve a quality management performance score of at least 99%. Payment is reduced on an aggressive sliding scale so that, at a score of less than 85%, the entire payment is forfeit, as illustrated in Figure 1. In addition, other factors such as a major deficiency of the quality system or high cost of rectification for nonconformances would further reduce the payment earned in a month.

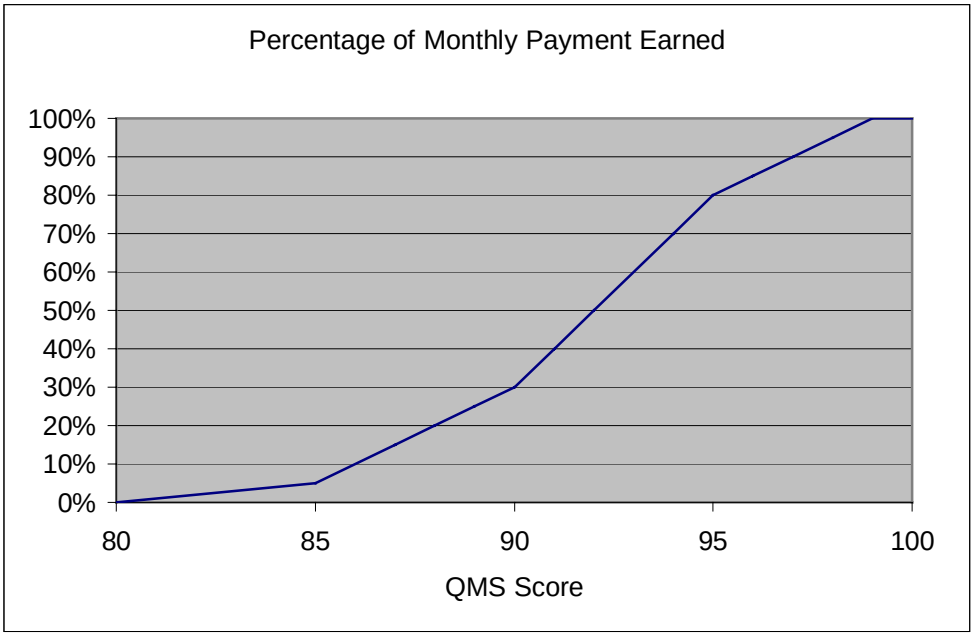

Figure 1: % of payment earned as a function of QMS Performance score

The method of assessment introduced by the IA at the commencement of the agreement used random auditing of an exhaustive list of the requirements in the DDB agreement. Random samples proportional to the budgeted or estimated cost of fulfilling each requirement were audited each month. The degree of conformance was reported as the total conformances divided by the total month's sample size (% conforming observations).

The system put in place at the outset of the Project was based on a matrix that included not only the material portions of the work (steel, concrete, asphalt, soils, etc.) but also non-material or managerial requirements. Thus, the sampling population for this assessment was the entire body of quality documents,

records, activities and products relating to any requirement in the agreement. All aspects of the Project were audited:

- Quality Management
- Environmental Management
- Design
- Construction - all completed or partially completed work
- Communications
- Purchasing - all materials, fabricated compoinents and services
- Economic and Industrial Benefits
- Safety

The Quality Performance Score was reported as the "Degree of Conformance" (defined above), further modified by deductions for certain classes of nonconformance (by cost of rectification) or failure to meet certain quality system requirements.

The auditing system reported all deficiencies and nonconformances with equal weight and treated the sampling population as a binomial population. This gave rise to some difficulties in application and interpretation. Different nonconformances may have widely differing impacts on the final utility and safety of the facility. Additionally, the distribution of some types of nonconformity may not be well represented by the binomial distribution; defects per unit area or distance, for example. These issues were addressed by changes to the assessment system in the second construction season as described later in this paper.

Another unanticipated source of concern was the perception of “double jeopardy” that would arise if payment was withheld for nonconforming or incomplete work and the same item of work was cited as evidence of under-performance of the QMS. Nevertheless, the novel idea of allocating a cost to the operation of the QMS as distinct from the completion of conforming work can be identified with the well established concepts of Cost of Quality. Viewed in this light, it serves as a reminder that when the aggregate costs of detection, prevention and failure are not minimized, they constitute unnecessary losses to the Developer, whether or not they are identified as pay items.

Lesson 3: The low cost supplier, even more than others, has an incentive to minimize the Cost of Quality by operating an efficient, effective QMS. (Reference ISO 9004-1:1994, 6.2.2 a, Quality-cost approach)

REVISIONS TO THE ASSESSMENT SCHEME

Because of the previously mentioned difficulties with the quality assessment methodology, three Quality Levels (QL) were introduced to ensure that both auditing intensity and corrective action would be commensurate with the impact of each audit element on safety and function.

Audit elements were classified as Quality Level 1, 2 or 3:

- QL 1 designates a requirement that judgement and experience indicate is likely to result in an immediate hazardous or unsafe condition for individuals constructing, using, maintaining or depending on the system, structure, item or design.
- QL 2 designates a non-safety related requirement that judgement and experience indicate is likely to result in failure or to reduce materially the usability of a component of the facility for its intended use.
- QL 3 reflects a non-safety related requirement that judgement and experience indicates is not likely to result in failure or reduce materially the usability of a component of the facility for its intended use.

Audit reporting terminology was also revised to convey a more constructive message. Deficiencies noted in the IA’s audits became “Observation Reports”. If Observation Reports indicated systemic or major issues, a “Nonconformance Notice” was issued, usually with the Observation Reports as the basis. If a non-fulfillment of quality system requirement was identified that matched the following criteria, a “Quality Finding” was issued, indicating:

- Non-existence of a part or an entire procedure required by ISO 9001:1994.
- Lack of evidence of the effective implementation and application of one or more procedures.
- A number of nonconforming observations that, taken together, reflect a weakness within a procedure.

The result was better acceptance of the auditors' role and improved cooperation in identifying and resolving problems because the auditee was able to differentiate between the "significant few" and "trivial many" observations that competed for attention.

Lesson 4: To be productive, quality auditing must be seen by all parties as a cooperative endeavour to drive improvement. It is best not to associate financial incentives or penalties directly with audit results in order to avoid defensiveness and confrontation. (Reference ISO 9001:1994, Corrective and preventive action)

THE MRAC APPROACH

Notwithstanding the improvement from introducing QLs, a concern remained that the Quality Management System performance is a multidimensional measure that should not be reduced to a single arithmetic score. In the second construction season, a new system of auditing, scoring and evaluation was instituted to encourage optimization of the Developer's QMS. An independent Management Review and Assessment Committee (MRAC) was formed to receive input from both the IA and the Developer and provide an evaluation of the Developer's QMS performance based on multiple factors. This committee is composed of an internationally known expert on ISO 9000 and construction, a local Professor of Civil Engineering and Project Management, a representative of the New Brunswick Department of Transportation (who is not directly involved in the daily activities of the Owner), a Professional Engineer and Construction Company Owner, and a retired Civil Engineering Consultant.

The MRAC meets monthly and uses a consensus decision making process to agree on the assessment of the Developer's QMS performance for the month. Key features of this analysis are:

- The committee receives as input for their deliberations representations from the Developer, the IA, the Owner and other stakeholders in the project quality.
- The procedure requires a written report with statistical evidence from the IA, that is forwarded to the committee, the Owner and the Developer simultaneously at the end of a monthly period. The Developer is provided with a short period to provide input to the report, recognizing that the report is factual, and that the Developer has been previously notified of all issues.
- Quality Performance Decision Indicators are sub-divided into "MUST" and "WANT" categories mutually agreed to by the entire MRAC.
- The committee reviews the written input and interviews all parties. An exit meeting is held with all parties in order to clarify and/or verify issues raised from the written input and interviews.
- The decision process is followed and an assessment made. Each committee member completes a composite performance scoring worksheet individually with the lead assessor making any final determination.

Central to their analysis is a decision process, based on Kepner-Tregoe methodology, to assign verbal descriptors: "Exceeds client expectations", "Meets requirements", "Improvement required", "Fails to meet requirements" to essential (musts) indicators of Quality, Safety and Environment and desirable (wants) indicators indicating degree of fulfillment or improvement.

Following this analysis, the MRAC provides the Owner, the IA and the Developer with a narrative commentary on the effectiveness of the Developer's QMS with areas of concern for future months, allowing improvement prior to the succeeding QMS review. The report also gives feedback to the IA on methodologies and points to areas of the Project and management that the committee feels worthy of further auditing.

The assessment provides the Developer with a score for the previous month and opportunities to improve (concerns that may affect Quality in the forthcoming period).

Lesson 5: Quality assessment is more palatable if it is not judgmental and if it includes an appraisal and recommendations for improvement of the measurement and assessment process as well as reporting the performance of the auditee. The goal of assessment should be to motivate change and place the Developer in the mode of prevention, correction and continuous improvement, rather than defense of the status quo.

ORGANIZATIONAL APPROACHES FOR QUALITY

The sheer volume and complexity of the agreements dictated that a decentralized approach be developed for quality management and quality control. Attempts to assess or dictate conformance centrally both by the Quality

Assurance organization and by the IA's staff often placed the assessor in an adversarial position with respect to the field engineer and subcontractor who felt they had a more detailed knowledge of the immediate work.

Each entity had its own manual, procedures and Quality Administrator with a common Quality Manager. In the beginning, the dedicated Quality Management staff consisted of the Manager and Deputy Manager. Other staff were trained as Quality Auditors and dedicated a portion of their time to internal auditing. Quality Control and Process control were completed by the subcontractors, suppliers and Resident Engineer's staff. All subcontractors had the overall requirements for Quality as part of their contractual obligations.

As each contract for design, construction or supply was negotiated, each subcontractor was required to provide evidence of a quality system that followed ISO 9000. Given the state of the industry at the time (few construction companies, design firms or material suppliers registered with ISO) the Developer assisted all subcontractors with Quality Plans to meet the requirements. In the absence of a Quality Plan or the desire to develop a Quality Plan, the Developer would increase QC activities to compensate, and apply its own Construction Quality Plan.

Subcontractors were required to designate Quality Managers and attend regular Quality meetings. Although the Developer was contractually obligated to allow complete access, the Independent Agent arranged for access to subcontractors and ensured that Developer staff was present during audits if considered necessary.

Improvements on Both Sides

Throughout the fall and winter of the first year of the Project, discussions ensued concerning the system of evaluating the Developer's QMS. It was generally agreed that continuous improvements in both the Developer's system and the system of the IA were necessary for improvement in the quality of the QMS and the facility.

In the second construction season, therefore, with more seasoned subcontractors and engineers in the field, the duties of the field engineers were formally redefined to include, with equal emphasis, quality, environment, safety, schedule and cost.

While this approach imposed a greater burden of knowledge and responsibility on the individual, it also promoted greater awareness of the quality, safety and environmental impact of decisions that might otherwise be made on the basis of immediate cost and schedule.

The Developer reallocated Quality staff and assigned the responsibilities for quality to a greater number of people. The Resident Engineer function was replaced by Quality Engineers reporting directly to the Quality Manager and Deputy Quality Manager. The Field staff were given the responsibilities for Quality Control, Environmental matters, Safety, Cost and Schedule.

Lesson 6: The strategies of delegation and empowerment are not new but, in an industry with a long legacy of control and adversarial management, we have learned that they can work if all parties are prepared to make them work.

TECHNOLOGICAL ASSISTANCE

A unique method of providing preventive action was developed in the first year of the Project in the way of memos to all staff titled "Quality Concerns". Analyzing the results of internal and external audits identified several issues that had the potential of affecting quality. Technical information was gathered (from technical sources and from knowledgeable Developer, IA and Owner staff) and provided to the field in order that potential problems would be minimized.

In the hiatus between the first and second years of the Project, this idea was refined to provide Corrective Action as well. In response to audits, the Developer provided training or reminders to staff by way of the Quality Concern memos. Following a spring training session, the idea was further refined as a result of requests for technical or procedural information from the field.

The memos became "Self Training Memos" (STMs), recognizing that the field staff were particularly self-motivating and considering the difficulty of providing training on issues to seven far-flung offices and to people who were needed in the field, not in the office. The STMs were originally developed to provide training based on information requests, but included training on issues arising from audit results and observations by Quality auditors in the field.

In order to track the effectiveness of the STMs, staff members were required to sign the front sheet of the memo and return to a data clerk who would enter the returned sheet in a Training Log. The front sheet also included a box with space for criticism, kudos and suggestions for further training memos. Close to 30 memos

have been produced, on topics ranging from the different types of bridge bearings to how to respond to IA Observation Reports.

Lesson 7: Building on the previous concept of delegation and responsibility, the low cost provider can implement an extremely economical training program; provided that there is a supportive environment and adequate auditing of critical areas.

INFORMATION MANAGEMENT

The initiative that had a major impact on the performance of the QMS was a change in the reporting methods used by the Quality Manager to his colleagues on the Management Team. The overwhelming amount of information coming from various sources resulted in much of the information being missed or ignored due to overload. As an illustration, consider the following documentation, approximate monthly numbers and sources:

DOCUMENTATION	SOURCE	MAGNITUDE	FORMAT
Environmental Checklists	Environmental Inspectors	100's	Paper
Quality Audits	Quality Engineers	100's	Paper
Test Results	Quality Laboratories	1000's	Database
MRDC Nonconformances	Field Staff	10's	Paper
Deficiency Lists	Field Staff	100's	Paper
IA Observation Reports	Independent Agent	1000's	Paper
IA Nonconformances	Independent Agent	10's	Paper
IA Quality Findings	Independent Agent	10's	Paper
Risk and Remark Notices	Independent Agent	10's	Paper
Design Variances	MRDC Design and Field	100's	Paper

One improvement in the second year was the provision of audit results by the Independent Agent in electronic format. At the same time, all MRDC paper documents were recorded in Excel spreadsheets for tracking and to provide Project Managers with updates on responses. Within the spreadsheets, charts were developed for ease of understanding the extent of the information and the response time to issues. These weekly charts replaced weekly memos on the same subjects, proving once again that a picture is worth a 1000 words.

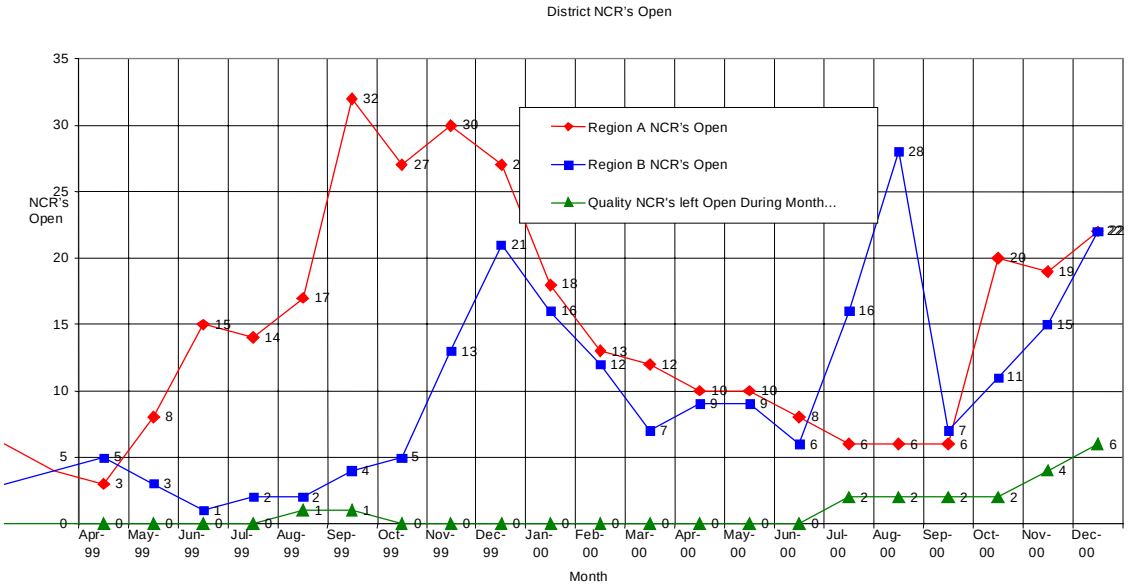

Figure 2: History of open nonconformances

The chart shown in Figure 2 is one example. It provides information as to segments of the Project where action is required to respond to and close internal Nonconformance Reports (NCR's). The increase in open NCR's towards the end of 1999 was the result of not tracking the NCR response adequately up to that point. The decline in early 2000 was the direct result of the provision of the charts to Project Management. Similar charts indicated that the mere charting of the documentation resulted in dramatic decrease in the number of open items and in response time.

Lesson 8: Information is most useful when presented in a graphic, readily understood form. The FMHP project never lacked information, but the participants had to learn how to process, share and analyze it.

ON-LINE QUALITY MANAGEMENT TOOL

Also, early in the third year, plans were underway to introduce a comprehensive database, the Quality Management Tool (QMT) to further allow Project Management to easily record, access, research, track and close all quality documentation. The QMT was originally seen as a tool for the Quality Manager to analyze all the information and ensure that corrective and preventive action was planned and carried out, but it soon became evident that it could make everyone's job easier.

The Developer authorized a project by one of the authors (Lundrigan) to create and implement the QMT to organize and access an extensive set of quality records via a server and web browser. Depending on the level of authority granted by the administrator, the user may update various data areas, records status changes, annotate a record or prepare a variety of reports.

The purpose of this project was to analyze MRDC's quality management system and to investigate ways to support the quality system with information technology tools. The result supports the quality management system and has lead to a general solution for supporting quality management initiatives in the construction industry.

The resulting software application addressed the following central themes during design and development: it will support various levels of detail in storage, viewing, and reporting information, it will be flexible in its set-up and use, it will employ an integrated approach to construction management information with an open data structure, and it will support analysis with the ability to analyze and report on captured information.

Specific deliverables for this project included: a software application to support the current information management needs of MRDC's quality management system, a documented analysis of the implementation to improve future initiatives, and a flexible system in support of quality initiatives within the construction industry.

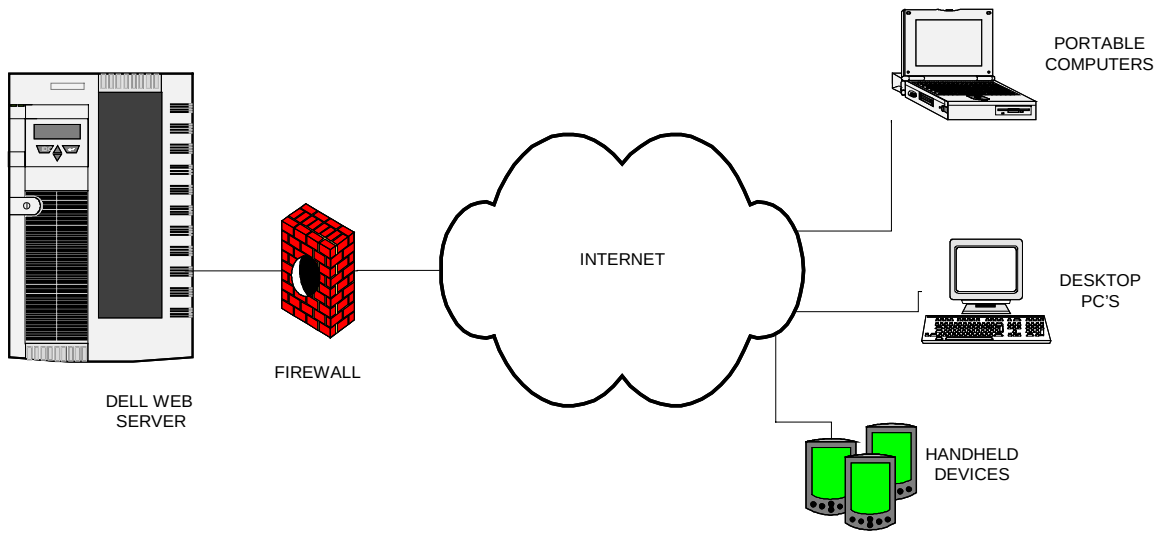

Figure 3: QMT System Architecture

The QMT (Figure 3) was built with the following software: Fusion Programming Language, Structured Query Language (SQL), Hypertext Mark-up Language (HTML) and JavaScript. Data is stored in a MS Access

database sitting on a MS Internet Information Server 4.0 running on NT Server 4.0 Operating System. The hard drive containing the operating system and web server is backed up continually through a mirrored hard drive and data is copied daily to a 4 mm tape cartridge. The QMT application is piped to the Internet on a T1 line.

A browser was chosen as the interface for users to accommodate the Project situation of field staff spread over 195 km with 7 site offices. MRDC management were not comfortable with hosting an application on their corporate LAN utilizing Virtual Private Network (VPN) technology. The quickest and most effective solution for the QMT was to build it on an externally hosted web server and control access through the interface. A Palm™ application was also developed and tested to allow field audits to be recorded "in the field" and later uploaded to the QMT.

The system fulfills several requirements of ISO 9001 for record maintenance, management reporting, and analysis and use of data for feedback and improvement.

All of the information listed above was downloaded regularly into the QMT for ease of access, analysis and closure. Because of the nature of the Project (195 km of highway) there were seven offices in use along the highway. The tool was designed to allow remote access by all users by placing the QMT on the Internet. All users within MRDC were provided with training and given a user name and password. Data entry became immediate. At this point users could see in one place all the information that previously required the researching of several spreadsheets, databases and paper files, all without leaving the field office, or by access from home.

In consideration of the workload of the field supervisors and the amount of construction accomplished this past year, data entry clerks were provided to ensure that the required data was entered within a reasonable period of time. The data clerks were also invaluable in entering all the “open” information predating the QMT.

The data entry clerks printed out a report each week for each field supervisor (and others identified as responsible parties) that listed all unresolved items. The requirement to respond to all the items was mandatory.

Lesson 9: Especially on a physically extended project, there is great value in computerizing the input, access and analysis of data. Using Application Service Provider (ASP) methods, permits the Developer to develop and maintain a single database and application on a server. This ensures that the data and software is secure and always up-to-date. The only software required for the user is a Web Browser (Internet Explorer or Netscape) which is standard on all computers. The handheld applications allow economical, highly mobile data gathering for the system.

CONCLUSION

A competitive bidding process and agreements, that combine responsibility for design, construction and operation of the project, provide the Developer with strong incentives to be the lowest-cost provider of all products and services for the FMHP. In order to succeed in such an endeavour, the organization must learn to regard itself as its own customer and to focus on lifetime costs. The authors believe that in this environment, both the Developer and the Owner benefit from the cost-effective utilization and automation of Quality tools.

The actions described here, coupled with improved reporting and information management by the Developer have resulted in improved Quality Performance Scores and Owner satisfaction. From January 2000 through November 2000, the Developer earned 100% payment for Quality Management System Performance, a marked improvement over previous periods.

Downloading of responsibilities for Quality, etc., resulted in increased documentation and quicker reconciliation of any deficiencies by the Developer. Personnel in the field interacted directly with the IA’s field auditors and worked together to improve quality on the work site.

Response to issues raised by the IA has also improved and the number of issues raised has dropped as can be seen in Figure 4. The chart indicates that close to 700 issues remained from the 1999 construction season and the response rate was a low 67%, compared with 150 issues after an equally busy 2000 season with a response rate of closer to 80%.

Intangible results accrued as well. Satisfaction and production improved project wide. Teamwork was obvious among all parties.

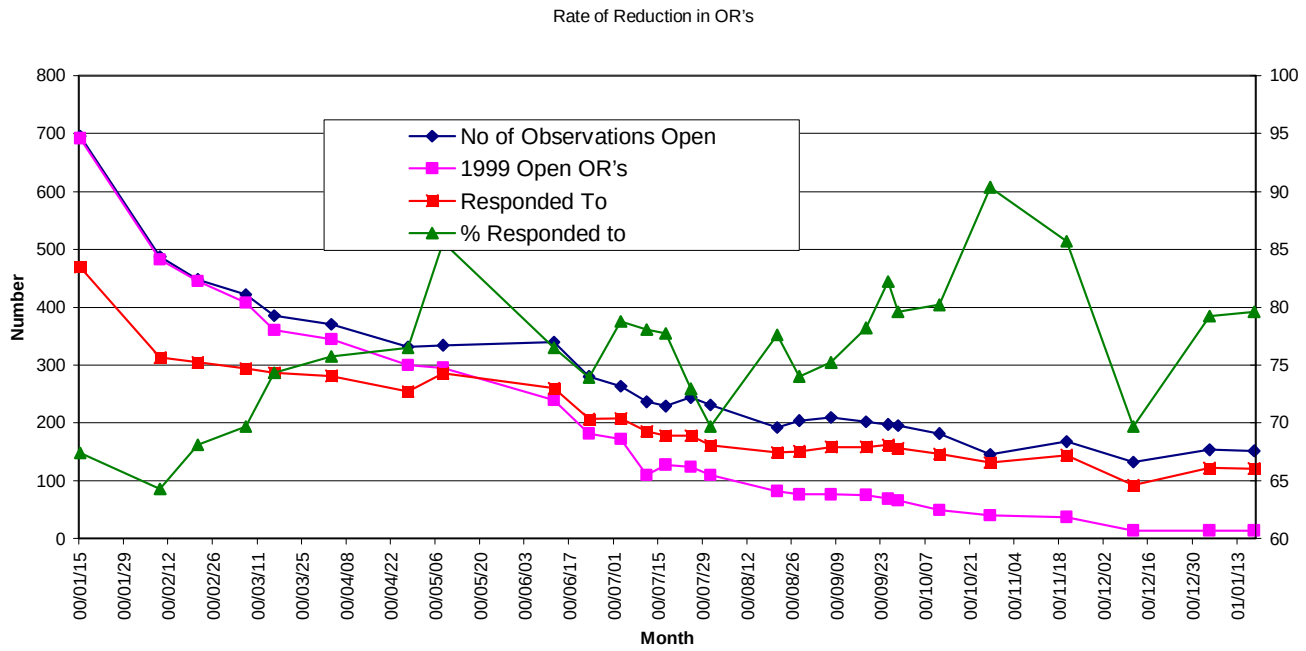

Figure 4: History of Observation Reports issued by the IA

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