Quality Performance on Successful Project

By W. B. Ledbetter,[1] Fellow, ASCE

Abstract: This is a summary of the quality performance efforts on project 12, a heavy industrial project with a total installed cost in excess of $100,000,000. Quality performance efforts are tracked using the quality performance management system (QPMS). QPMS tracks labor costs in three main categories: normal work, quality management work (prevention and appraisal), and rework (deviation correction). The cost of quality is the sum of quality management and rework. The system is implemented by all parties (the owner, the two designers, and the constructor) at the beginning of the design phase and continued through construction phase to mechanical completion. The overall cost of quality, less owner changes of 0.2%, for project 12 is 11.2% of the total labor expenditures, design plus construction. Quality management totals 8.1% and rework is 3.1%. QPMS is found to promote awareness and improve the understanding of the quality process, facilitate communication, focus management on where quality improvements could be made, and reduce the overall cost of quality. Data are generated to benchmark quality performance on future projects.

INTRODUCTION

Project 12 is a heavy industrial project, with a total installed cost in excess of $100,000,000. (The numerical designation was selected to maintain confidentiality.) The project involves a new unit within an operating facility, contracted on a cost-plus-incentives basis with two design firms performing the detailed engineering and procurement and a construction company performing the construction. The project includes significant piping (in excess of one-third of all labor costs during design and construction). The Construction Industry Institute's quality performance management system (QPMS), first introduced in 1990 (Ledbetter and Wolter 1990) and modified through use to its present form (Ledbetter and Wolter 1993) was implemented at the beginning of the design phase (mid-1990) and continued through the construction phase to mechanical completion (mid-1992). For the purposes of collecting QPMS information, the project was broken down into the 10 major disciplines (see Table 1 for definitions).

QPMS OVERVIEW

Three key issues are addressed by QPMS: quality, cost of quality, and quality performance. Quality has many meanings; however, for projects, conformance to established requirements (Ledbetter and Wolter 1990) has relevance and clarity. While simple, this definition cannot stand alone. Another definition is needed for the term requirements.

Requirements are contractually established characteristics of a product, process, or service. A characteristic is a physical or chemical property, a dimension, a temperature, a pressure, or any other specification used to define the nature of a product, process, or service (Ledbetter and Wolter 1990).

---

[1]Quality Measurements Consultant, 1006 Challedon Way, Pendleton, SC 29670.

Note. Discussion open until August 1, 1994. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on January 14, 1993. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 120, No. 1, March, 1994. ©ASCE, ISSN 0733-9364/94/0001-0034/$2.00 + $.25 per page. Paper No. 5445.

TABLE 1. Discipline Breakdown for Project 12

Discipline (1)	Description (2)
Project services	Project management and control, materials management, general staff, site construction services, procurement
Project engineering	Project and process activities such as engineering flow diagrams, process flow diagrams, line tables, hydraulics, process data
Tanks/vessels, and heat transfer	Vessels, tanks, columns, drums, heat exchangers, reactors, heaters, air fin exchanges, ducts
Instrumentation	Control components and devices, control systems, instrument cabling, instrument wiring and tray, uninterrupted power supplies, instrument piping
Piping	Pipe and valves, pipe supports, underground piping, catch basins, design models
Structural	Steel, concrete, platforming, handrail, ladders, roof decking, floor decking, stairways
Electrical	Power transmission and distribution, switchgear, power and control wiring, grounding, lighting, electrical wiring, electrical tray and conduit, cathodic protection, communications equipment
Civil/architectural	Stabilization, piling, foundations, paving, anchor bolts, grading, backfill, civil demolition, buildings
Mechanical	Pumps, compressors, blowers, drivers, cranes, elevators, packaged equipment, filters
Fireproofing/insulation/painting	All insulation, painting, and fireproofing

The requirements are initially set by the client/customer (ordinarily the user/operator of the facility) and are then translated during the preplanning phase into a conceptual design and estimate, developed into a project scope, and more fully defined. During the design phase, the requirements are translated into specific design documents (drawings, plans, specifications, purchase orders, and the like). Procurement of fabricated items often proceeds concurrently with design. The products of design and procurement reach the construction site for erection and installation during the construction phase. Following construction, the facility is started up during the startup phase, which can be as simple as turning the keys over to the user or as complex as executing a two-year team effort optimizing a metallurgical processing line.

The cost of quality is the penalty paid for an imperfect world. It is the cost associated with everything we do that we would not have to do if we lived in a perfect world with perfect systems and perfect people. QPMS defines the cost of quality as "the cost associated with quality management activities (prevention and appraisal) plus the cost associated with deviations." Deviations resulting in doing things over, termed rework, reduce a project's profitability, and is generally recognized as such. On the other hand, unnecessary quality management costs also reduce a project's profitability, a fact often overlooked. Deviation correction costs plus unnecessary prevention and appraisal costs are often termed "quality losses" and their reduction (and ultimate elimination) will result in increased quality performance.

J. Constr. Eng. Manage., 1994, 120(1): 34-46

QPMS is a simple tool involving labor costs only. It is a self-measurement system based on project personnel keeping track of their time spent in three main endeavors: (1) Normal work; (2) quality management work (prevention and appraisal); and (3) rework (deviation correction).

Normal work is the minimum amount of work required to do the job in a perfect world. Designing a foundation, erecting a structure, planning a schedule, and checking your own work are examples of normal work. Quality management work is the work we do to prevent deviations from occurring or to appraise a product to insure that it meets the requirements. Examples of quality management work include checking someone else's work, shop inspections, design reviews, expediting, and preparing quality manuals. Deviation correction, or rework, involves doing something over, for whatever reason. Often deviation corrections are necessary and even desirable, such as when an owner or designer changes the design to make the plant operate more efficiently or safely. But QPMS captures the cost associated with all types of deviation correction.

There are eight types of quality management work defined for QPMS (Table 2). While many other activities could be added to the list, the Construction Industry Institute (CII) considers these eight to be the most important for reducing quality losses. Note that some of these activities are "traditionally" considered to be normal work because we are in the habit of doing them. In a perfect world, they would not be necessary.

QPMS calls for the user to categorize rework into seven root causes (Table 3). Note that parties cause rework, "unknowns" or "others" do not! Also note that errors include omissions. As with quality management, many other rework categories could be added to the list. Again, CII considers these seven to be the most important, keeping the system as simple as possible while maintaining sufficient detail to provide management with useful information.

Capturing QPMS data is simple and straightforward for normal work and prevention and appraisal work. The discipline is simply your own discipline and the only paradigms that must be changed are the ones concerning the definitions of normal work and phases. QPMS defines the phases as follows:

1. Design phase. Any work performed on a design product (drawing, diagram, purchase order, spec. sheet, data sheet, etc.) prior to "issue for construction" or "issue for fabrication" or "approved for construction."
2. Construction phase. Any work performed on a design product after "issue for construction" or "issue for fabrication." The exception is work on designated "holds." A design engineer who is answering questions from the field related to work already issued for construction is performing construction phase work—not design.
3. Start-up phase. Any work performed on a product or system after it is "mechanically complete" and before the system is turned over for operation.

Note that phases change on each product as the product progresses through design, construction and start-up. Thus project phases are different than contracts.

To reduce rework to its absolute minimum (zero in an ideal state), the root cause(s) of rework must be determined. When tracking rework, three pieces of information are needed:

J. Constr. Eng. Manage., 1994, 120(1): 34-46

TABLE 2. Quality Management Activities

Activity (1)	Description (2)
Quality systems	Activities of developing quality systems, programs, standards, and goals: • indoctrinating and training personnel in quality systems • QPMS data collection, analysis, reporting
Supplier Qualification	Activities to investigate and evaluate ability of suppliers, vendors, contractors, subcontractors to perform capably if awarded contract: • vendor prequalification • supplier reviews/ratings
Personnel qualification, testing, and quality training	Testing personnel to perform quality work according to specified standards; training to perform quality activities; this is not regular training: • craft certification • personnel training for QA/QC activities
Expediting	Activities with suppliers and vendors before delivery to ensure delivery on schedule and as specified: • expediting third-party engineering information • expediting all purchased materials/equipment/services
Operability/safety/value review	Activities performed to evaluate operability, safety, or value of design in compliance with client, industry, and government requirements: • process hazards analysis • operability reviews • maintainability reviews • safety analyses • value engineering studies
Constructability review	Activities to ensure that design and planned construction methods are most efficient: • dewatering studies • prefabrication/preassembly studies • rigging studies • standardization studies • construction site layout studies
Internal examinations	Reviewing, checking inspecting, testing, and observing products/services already produced internally by others in your organization: • interdiscipline check/review • design/drafting/document check/review • quality control testing of internal work (concrete testing, soil testing, weld x-ray, hydrotesting pipe, site Loop testing, equipment alignment checks, and so forth)
External examinations	Reviewing, checking, inspecting, testing, and observing products/services produced externally (outside your organization) by others: • shop inspections • design/construction reviews of third parties • vendor document reviews • receiving inspection of materials and equipment

TABLE 3. Rework Causes

Category (1)	Description (2)
Owner change	Change authorized by owner-client after some work has been performed (may occur during design, construction, or startup)
Designer change	Change made by designer in design of product or process; change may occur during design, construction, or startup; often, change results in improved value and operability of the product or process, or is result of "out-of-sequence" work
Vendor change	Change made by vendor to purchased product or to its interface with project; change may occur during design, construction, or startup; often, change results in improved value and operability of product or process
Constructor change	Change made by constructor on product or process; change may occur during design, construction, or startup; often change results in improved constructability, value, or operability of product or process, or is result of "out-of-sequence" work
Designer error	Error or omission made by designer of product or process; rework may occur during design, construction, or startup
Vendor error	Error or omission made by vendor furnishing product for project; this rework may occur during design, construction, or startup
Constructor error	Error or omission made by constructor on product or process involved on project; rework may occur during construction or startup

1. The root cause of the rework (see Table 3).

2. The instigating discipline. Sometimes rework in one discipline creates rework in another discipline. To properly identify the full impact of all rework, costs should be assigned to the instigating discipline, regardless of who else has to perform the rework. This is straightforward during construction, but confusion arises during design. The confusion concerns when design development ends and rework begins. To remove this confusion, QPMS follows the practice that usually deviations do not occur during the design phase. However, there are exceptions. Deviations during design can occur from the following situations:

- Owner changes after some work has been performed.
- Alterations to such products as process flow diagrams, piping and instrumentation diagrams, and plot plans after "issue for downstream to the next steps in the design." Once a document (drawing, data sheet, and so forth) is given to an internal customer—even if the information is marked preliminary—and that internal customer uses that information, rework can occur if that information is changed. For example, if the piping discipline provides a preliminary plot plan to the structural discipline and then changes the plot plan based on updated information, forcing the structural discipline to alter their design, the structural discipline should charge their rework

time to design change and assign their rework hours to the piping discipline. (If the owner was the root cause of this change, the rework time should be charged to owner change and still assigned to the piping discipline.)

- Other out-of-sequence situations, if easily captured. For example, the project management discipline may establish a very tight schedule, forcing the civil discipline to assume some vessel loads for foundation design. When actual vessel loads become known, the civil discipline would have to alter their foundation design and could charge their deviation correction time as design change, instigated by the project management discipline.

3. The phase in which the rework was detected.

IMPLEMENTING QPMS ON PROJECT 12

QPMS was implemented by all parties (the owner, the two designers, and the constructor) at the beginning of the design phase and continued through the construction phase until the facility was mechanically complete. A QPMS Committee was established with representatives from each major firm involved in the project. The writer served as facilitator and QPMS data processor. This arrangement kept individual firm proprietary cost data confidential.

Implementation required changes to paradigms about quality, a commitment to the quality process, a willingness to admit mistakes, and an atmosphere of openness, trust, and teamwork across all organizations. Through the leadership of the owner, together with monthly QPMS meetings, the process was successful.

QPMS RESULTS—OVERALL PROJECT

The overall cost of quality, less owner changes, for project 12 was 11.2% of the total labor expenditures, design plus construction (Fig. 1). This represents a savings of over 6% in quality costs when compared with project

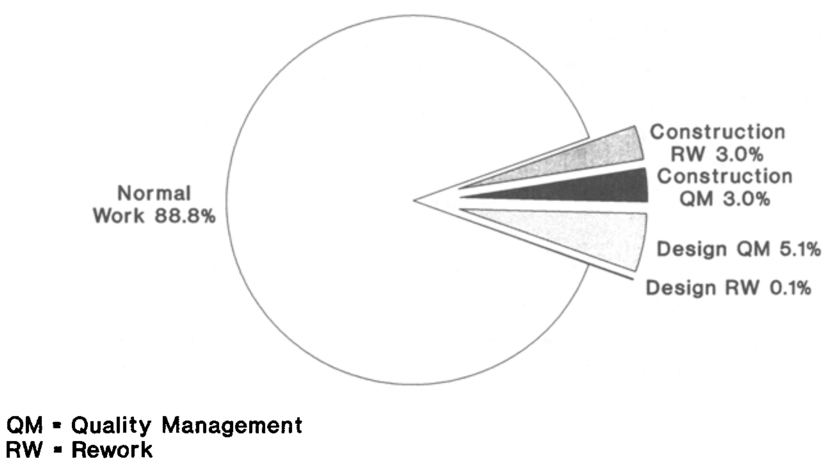

FIG. 1. Overall Cost of Quality for Design plus Construction

J. Constr. Eng. Manage., 1994, 120(1): 34-46

8 (another hydrocarbon facility utilizing QPMS, which was completed in 1990). The breakdown of the cost of quality are shown in the figure. Owner changes, which represented 0.2% of the total labor expenditures, have been omitted from all data. Each project is unique, but the owner changes are "really unique." By omitting owner changes, the remaining six rework causes can be more readily compared with other projects and utilized for benchmarking.

The overall quality trends are shown in Fig. 2. The trends are given in terms of total labor expenditure on the project (design plus construction). Several important factors can be seen in this figure. First, this was a "typical" fast-track project with construction starting fairly early in the life of the project (at around 20% complete by labor expenditure). Second, the construction rework trended upward during the last 20% of the project. Again, this seems rather "typical" and was the result of reporting rework costs at the conclusion of major subcontracts. Third, design quality management was significant (over 5% of the total labor, design plus construction). Finally, this figure represents the "blueprint of quality efforts" on this project, which can be used as a comparison with other projects.

Fig. 3 depicts the quality management and rework labor expenditures on the project. "Examinations internal" represent the largest quality management effort and "designer change" represents the largest rework expenditure. Remember, changes are often made to add value to the project (safety, operability, constructability improvements are some of the reasons for changes) and thus they may be "good." On the other hand, errors should always be avoided and eliminated, if possible. The three error categories (designer, vendor, and constructor) amount to 55% of all the rework. These are the areas to concentrate on for improvement.

Fig. 4 depicts the discipline quality costs as a percentage of the total project cost of quality (in bar graph form). The disciplines are arranged in order of decreasing percentage of total labor budget, which are shown on

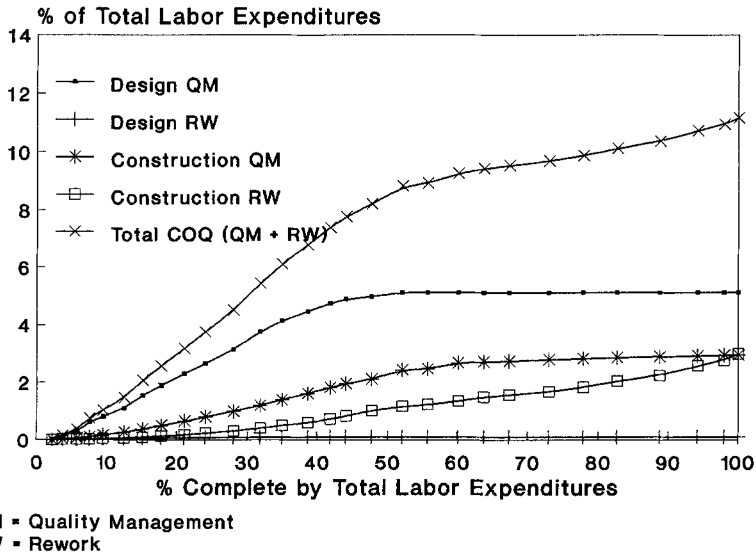

FIG. 2. Overall Quality Trend for Design plus Construction

J. Constr. Eng. Manage., 1994, 120(1): 34-46

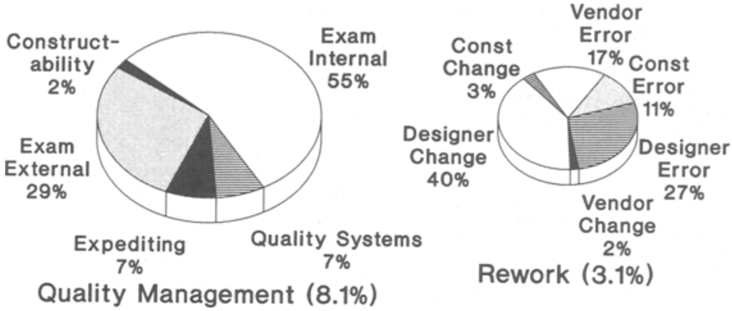

FIG. 3. Overall Quality Management and Rework for Design plus Construction

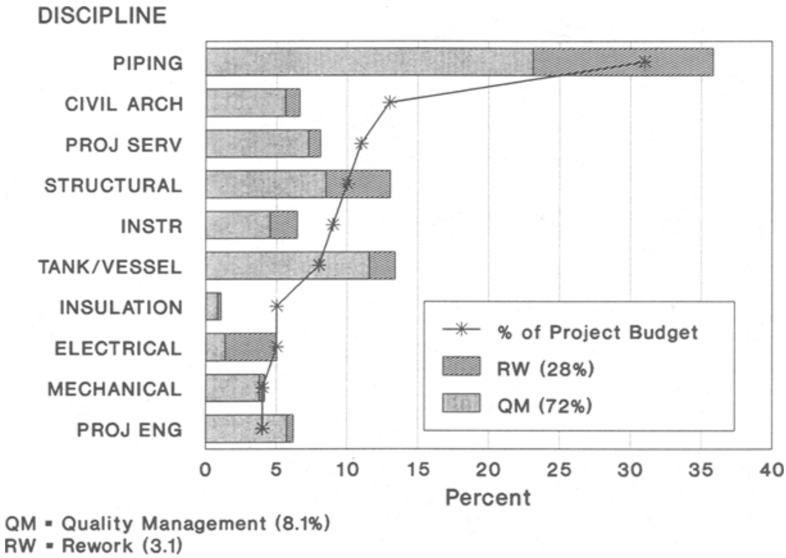

FIG. 4. Discipline Quality Costs as Percent of Overall Project Cost of Quality

the figure. This graph highlights any apparent discrepancy in cost of quality for the various disciplines. Piping, as expected for this type project, has the greatest influence on quality with relatively large expenditures in both quality management and rework. Structural, instrumentation, and electrical seem to have relatively large amounts of rework.

QPMS RESULTS—BY PHASE

QPMS provides information at various levels of detail. For the design phase, the overall quality trends for all disciplines are shown in Fig. 5, expressed as a percent of design phase expenditures. The top curve shows the total quality management expenditures, while the second curve indicates those that are traditionally considered to be prevention and appraisal activities (excluding quality systems, expediting, and personnel qualification). Note that the bottom curve, rework, is almost zero, reflecting the definition of rework followed by the parties.

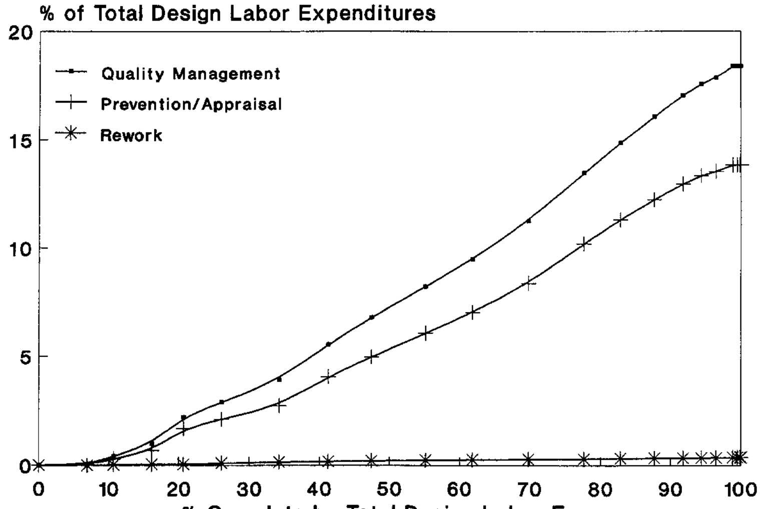

FIG. 5. Quality Trend for Design Phase

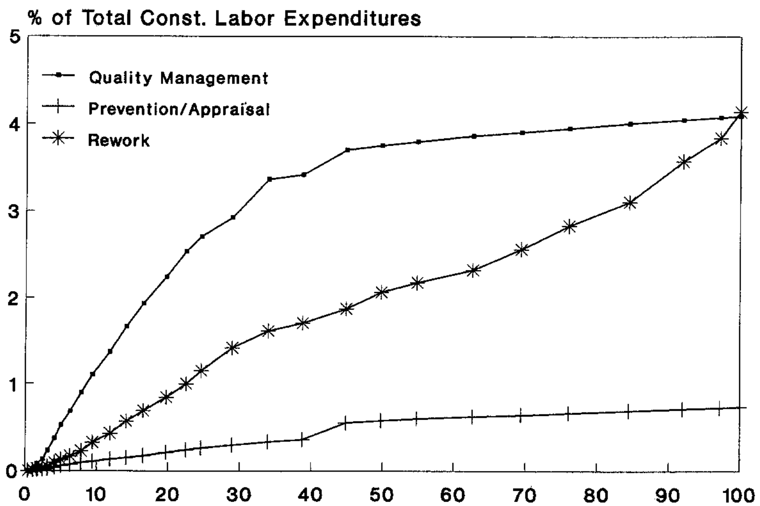

FIG. 6. Quality Trend for Construction Phase

Turning to the construction phase (Fig. 6) portrays the quality trends for all disciplines. Here the full effect of rework as the project neared mechanical completion is depicted.

COMPARISONS WITH OTHER PROJECTS

QPMS is still quite new. Therefore, there is very little information relative to other projects for comparison. On hydrocarbon projects, QPMS information has been gathered from seven design firms on five different projects. These projects involve both fixed-price contracts and cost-plus contracts.

While the designs are completed, only four of the projects are mechanically complete at this time.

Fig. 7 depicts the design quality management trends for the seven firms, expressed as a percent of the total design labor expenditures for all disciplines. The arithmetic average is also shown. It is interesting that design quality management ranged from a low of around 9% to a high of around 17% of the total design labor expenditures. While many factors influence the amount of quality management expended by designers, the spread is significant. What these design trends mean by themselves is not at all clear. Obviously they only portray one side of the equation—activities expended to reduce rework. The other side of the coin involves the rework experienced during construction!

Fig. 8 portrays the cost of quality relationships on five hydrocarbon facilities (projects 8, 12, 14, 15, and 16) through mechanical completion. The abscissa is quality management expenditures expressed as a percent of total labor expenditures (design plus construction). The ordinate is simply percent of total labor expenditures. The three sets of data are quality management (which is a straight line since the ordinate and abscissa are the same value), rework, and total cost of quality (quality management plus rework).

Project 8 spent the least amount of effort on quality management and ended up with the largest expenditure for rework. Project 15, on the other hand, spent the most on quality management and ended up with low rework. The sum of the two types of quality expenditures, cost of quality, reflects the fact that neither project 8 or project 15 spent the least amount of money on quality-related activities. Remember, changes and errors are all corrected and the facility is "defect-free" at mechanical completion (insofar as is possible). Therefore the question is not whether deviations are found, but what is the most cost-effective method of correcting deviations? Should they be inspected and checked out so that none occur, or is it more cost-effective

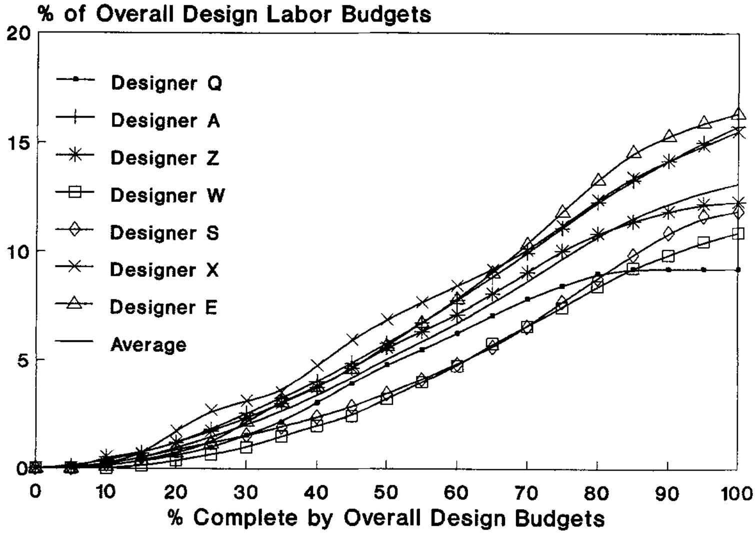

FIG. 7. Design Quality Management Trends for Seven Design Firms on Hydrocarbon Projects

J. Constr. Eng. Manage., 1994, 120(1): 34-46

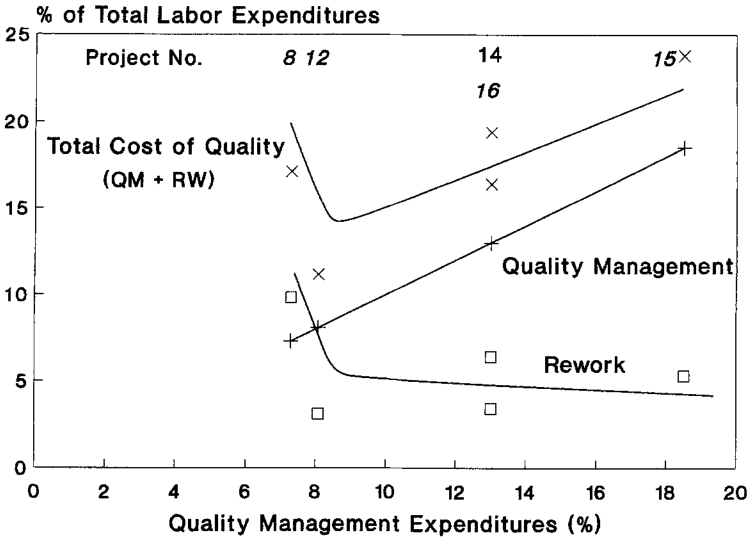

FIG. 8. Quality Management, Rework and Overall COQ versus Quality Management on Hydrocarbon Projects

to correct some deviations during construction? This type of graph will be very valuable as more projects are added to the database.

Fig. 8 seems to indicate there is an optimum amount of quality management to be performed and that firms can spend too little or too much. Project 12 seems to have spent the optimum amount on quality management. While project 12 is an outstanding success, this conclusion is premature! Remember, all the projects are different, with different owners, designers, constructors, and contract types. The effects of schedule are not portrayed. So what does the figure tell us? The concept of a minimum cost of quality with an optimum cost of quality management is valid. Firms should examine their quality management efforts and use this type of figure for benchmark comparisons, evaluating each of their projects in the light of its unique requirements.

LESSONS LEARNED FROM QPMS

- Quality performance management is a process, not a product or goal.
- Successful quality performance management involves leadership, willingness to admit mistakes, teamwork, and a commitment to continual improvement. It involves a race you never win, or even finish.
- The QPMS is simply a tool, providing management with information on where improvements can be made. It provides no answers, is no substitute for sound management practices, and will not work unless a corporate culture of trust and honesty exists.
- What gets measured gets done. The fact that the cost of quality is being measured will result in people striving to reduce both rework and unnecessary quality management activities

J. Constr. Eng. Manage., 1994, 120(1): 34-46

- Combined with a corporate culture embodying integrated TQM principles, QPMS can be "self-correcting." Root causes of rework are identified by persons doing the work. Management examines these causes in order to find solutions to their elimination. Incorrectly defined causes are quickly isolated, and appropriate corrections made.
- QPMS must be combined with other measurement tools and analyzed to improve project performance.
- QPMS requires a disciplined approach to capturing time, analyzing data, summarizing the data into useful information, and utilizing the information for continuous improvement.

IMMEDIATE BENEFITS FROM QPMS

Following are statements made by firms using QPMS on their projects. They represent the judgments of managers utilizing QPMS in their quality improvement programs. QPMS:

1. Promotes awareness and improves understanding of the quality process.
2. Facilitates interdisciplinary communications, which enhances product value.
3. Reduces through monitoring the total cost of quality (prevention/appraisal costs plus rework costs), while maintaining the requisite client quality expectations.
4. Improves the customer/supplier relationship, both internal and external.
5. Facilitates better understanding of going to the right parties for needed information.
6. Reveals the "real" value of quality control efforts.
7. Teaches that many traditional functions are really prevention/appraisal and not "normal" in the quality sense.
8. Highlights where the greatest amounts of prevention/appraisal and rework are occurring, indicating where priorities should be focused for improvement.
9. Promotes a change to the paradigm about not trending deviations relating to a firm's own rework to trending all rework regardless of the root cause.
10. Serves as a validation technique for trend analysis.
11. Transforms the paradigm that "piping and instrumentation diagrams are always being changed; one really cannot freeze the design completely prior to erection," to the conviction that designs must be frozen if we are to avoid costly quality losses.
12. Focuses the owner on the full effect of owner changes, especially if they are made after "issue for fabrication or construction."
13. Reinforces the growing realization that all rework, or deviation correction, is not bad. To the contrary, rework is expected. To drive rework to absolute zero requires an almost infinite amount of time and prevention/appraisal efforts.
14. Generates a better understanding that changes to the design before issue of the design for fabrication or construction is generally good.

15. Facilitates communication among all parties regarding quality efforts, especially rework, in an open and nonadversarial manner.

LONG-RANGE BENEFITS OF QPMS

Again, users of QPMS state that QPMS:

1. Fosters improvements in prevention/appraisal activities by:

    - Spotlighting special efforts such as constructability and operability/safety/value reviews.
    - Focusing on within-discipline checking in complex disciplines such as piping.

2. Fosters better understanding of optimizing quality efforts on the project as a whole rather than on optimizing each phase, or contract, involved in designing and constructing a facility.
3. Provides a database for future actions on other projects.
4. Contributes information leading to improved cost estimates using the quality cost data to include more realistic estimates for prevention/appraisal and "expected" rework.
5. Indicates where the "most bang for the buck" can be obtained in the prevention/appraisal efforts on projects.
6. Highlights the quality impacts of accelerated schedules.
7. Helps identify and eliminate root causes of rework.
8. Provides a useful parameter of contractor selection basis, i.e., optimally lowest total cost of quality (prevention/appraisal cost plus rework cost).
9. Helps quantify the degree of success or failure on a project.
10. Provides information for evaluating yourself against others in the industry, as opposed to evaluating yourself against yourself on projects in terms of your standards and norms.
11. Facilitates kick-off meetings on new projects by providing benchmark information for goal setting and helping the team better understand the quality process.
12. Empowers workers to correct deviations at the root cause.

ACKNOWLEDGMENT

Although only my name appears on this report, the information, results, and data are the products of a collaborative effort of the QPMS Committee on this project. To maintain confidentiality, the names of organizations and individuals involved have been omitted. The committee's efforts were vital to the success of QPMS on this project and I wish to thank them for their active participation, careful review, and strong support of the program.

APPENDIX. REFERENCES

Ledbetter, W. B., and Wolter, W. F. (1992). "Quality Performance Management System." *CII Product No. EM-4*, 1st Ed., Construction Industry Inst., Univ. of Texas at Austin, Austin, Tex.

"The quality performance management system: a blueprint for implementation." (1990). *CII Publication 10-3*, Construction Industry Institute, Univ. of Texas at Austin, Austin, Tex., Feb.