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A CASE STUDY OF CONSTRUCTION MANAGEMENT ON THE BOSTON HARBOR PROJECT REFLECTIONS AT PROJECT COMPLETION

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PROJECT BACKGROUND

The Boston Harbor Project is the largest court-ordered compliance action in the history of the Clean Water Act. The project emerged from a unique set of economic and political circumstances and the approach adopted to manage the Boston Harbor Project was greatly influenced by the historical context in which the project was created.

Decades of Neglect

Boston Harbor has achieved notoriety as a dumping ground, from the famous Tea Party in 1773 through the heated debates of the1988 presidential election campaign. Wastewater generated by the Boston region was discharged into the harbor from two undersized and outmoded primary treatment plants. Lacking processing facilities for upland disposal, these plants also discharged 70 tons of sludge into the harbor each day during outgoing tides. The combined discharge of marginally treated primary effluent and sludge into the shallow waters of Boston Harbor imposed a significant burden on the marine ecology and resulted in serious deterioration of the aesthetic, commercial and recreational qualities of this vital resource.

Passage of the Federal Clean Water Act in 1972 required that all municipal sewage treatment systems incorporate secondary treatment by 1977. Secondary treatment provides removal of significantly higher levels of both solids and biochemical oxygen demand from wastewater. These new standards placed the Metropolitan District Commission, the agency responsible for wastewater treatment for much of the Boston metropolitan region, in violation of the law. The law, however, allowed jurisdictions that discharged into coastal waters to apply for waivers from the secondary treatment requirement. The Metropolitan District Commission applied to the U.S. Environmental Protection Agency (EPA) for such a waiver in late 1979.

The EPA was slow to act on the waiver request and the continuing deterioration of Boston Harbor prompted affected communities and environmental groups to take action. In 1982, the City of Quincy, location of the then 30-year-old Nut Island Treatment Plant, filed a suit in Massachusetts Superior Court charging violations of laws prohibiting discharges into coastal and tidal waters. The court imposed a moratorium on new sewer hookups in the

Boston region, raising the issue to new heights of public awareness. Although the moratorium was quickly overturned on procedural grounds, the threat of halting new construction during an economic boom in the region provided increased impetus for resolving the problem.

The legislative response was to create an independent state authority. In late 1984, the Massachusetts Water Resources Authority (MWRA) assumed responsibility from the Metropolitan District Commission (MDC) for providing wholesale water and sewer services to 60 eastern Massachusetts communities. In addition to its operating responsibilities, the new authority was made responsible for rehabilitating the water and sewer systems and bringing them into compliance with applicable environmental laws. In effect, the fledgling authority was charged with the long-awaited cleanup of Boston Harbor.

Within a month of its creation, the authority became a defendant in a suit brought by the Conservation Law Foundation and the U.S. Environmental Protection Agency over the MDC's failure to comply with the Clean Water Act. On September 5, 1985, U.S. District Court Judge A. David Mazzone ruled that discharges into Boston Harbor were in violation of the Clean Water Act. Following intense negotiations, a court-ordered schedule for constructing modern secondary treatment facilities to serve the Boston region was issued on May 8, 1986. The court order required the authority to commence construction of new primary treatment facilities in 1990 and complete all facilities by 1999.

Economic Climate

The long debate and associated delay surrounding the cleanup of Boston Harbor resulted in losing the opportunity to seek federal funding for the bulk of the harbor cleanup's projected cost. During the 1970's the federal government provided up to 75 percent of the funds necessary to construct wastewater treatment facilities. Throughout the 1980's, however, the total amount of federal grants declined steadily. By the end of the decade, federal grants for constructing sewage treatment facilities ceased. The federal role was ultimately re-defined to help states capitalize low interest loan programs from which local communities could borrow. Boston, like San Diego, Los Angeles and other coastal cities which had sought secondary treatment waivers, was now facing an extraordinary financial burden to achieve compliance with the Clean Water Act.

Financing the Boston Harbor Project was further complicated by a sharp downturn in the local economy. During the 1980's, Boston had one of the strongest economies in the U.S., driven by the concentration of high technology industries within the region. Unfortunately, the "Massachusetts miracle" ended just as the Boston Harbor Project began. Unemployment rates in late 1989 rose in the Commonwealth while they declined for the nation as a whole. The economic downturn was disastrous for state revenue receipts. Massachusetts ended fiscal year 1990 with a $1 billion deficit.

Lacking federal funding, the cost of the Boston Harbor Project would be largely borne by the MWRA's ratepayers, the households and businesses who are the ultimate consumers of the services it provides, and as the project shifted into construction the charges for sewer service in the Boston region grew dramatically. In 1984, prior to the creation of the MWRA, the typical household paid less than $100 per year for sewer services. From 1985 to 1990, the MWRA increased total sewage charges by nearly 400 percent and planners forecast that average household charges would exceed $1,200 by 2000 when the project was to be completed. In response, the public outcry against the costs of the Boston Harbor Project mounted, culminating in the Spring of 1993, when 300 ratepayers re-enacted a modern version of the Boston Tea Party by donning colonial clothes and tossing their water and sewer bills into the harbor.

Shortly thereafter, the state legislature created a debt service assistance program to help mitigate the annual increases in sewer bills and the Massachusetts legislative delegation was successful in securing Federal aid, which ultimately funded approximately 20% of the cost of the Boston Harbor Project. These resulted in significantly lower annual rate increases, however, the intense public scrutiny and unrelenting pressure to control and hopefully reduce the projected cost of the Boston Harbor Project remained and became deeply ingrained in the project's management approach.

Project Description

The Boston Harbor Project (BHP) is one of the largest wastewater projects ever undertaken in the United States. The project involves the planning, design, construction and start-up of a vast new wastewater treatment system costing $3.6 billion. Except for final paving and landscaping, the project is complete as of December 2000 and provides secondary treatment of wastewater generated by more than 2 million residents and over 5,500 businesses in the greater Boston metropolitan area.

The project consists of five major components:

- Primary treatment facilities, consisting of four batteries of primary clarifiers, an on-island headworks, pump stations and disinfection facilities. In dry weather, the primary plant handles roughly 350 million gallons per day, but can handle peak wet weather flows of 1.27 billion gallons per day.
- Secondary treatment facilities, consisting of three batteries of secondary reactors and clarifiers, supported by a cryogenic oxygen plant, capable of treating up to 780 million gallons per day.
- A remote headworks facility providing pretreatment to 400 million gallons per day of wastewater from the southern part of the Boston region connected to a 4.8 mile long rock Inter-Island Tunnel that transports these flows beneath Boston Harbor to the Deer Island Treatment Plant.

- A 9.5 mile long rock Effluent Outfall Tunnel which discharges treated effluent into the deep waters of Massachusetts Bay through a series of 55 diffusers spaced along the last 1.5 miles of the tunnel.
- On-island residuals processing facilities (including the project's landmark egg-shaped digesters) and an off-island sludge pelletizing plant that convert sludge generated by the new plant into 33,000 dry tons of fertilizer annually.

In addition, the development of an extensive network of utilities and support activities was required to support construction and ongoing operation of the new treatment plant, including:

- On-island and off-island utilities to support both construction and ongoing operations, featuring a thermal/power plant capable of generating over 70-megawatts of electricity.
- Extensive demolition/site preparation and the implementation of a public access plan (the perimeter of Deer Island and Nut Island, the two principal construction sites, are part of the recently created Boston Harbor Islands National Seashore).
- On-island and off-site transportation facilities and the associated bus and water transportation services to move workers, equipment and material to/from Deer Island.

The design and construction for the project involved the execution of 32 design contracts and 133 construction and support services contracts. Ultimately, the activities of multiple contractors, subcontractors, and material and equipment vendors needed to be scheduled, coordinated and tracked to ensure that delays were avoided, the aggressive court schedule was met, and costs were rigorously controlled.

In any situation, managing a large, multi-year capital program poses a formidable management challenge. The complexity of the management task faced by the MWRA was further compounded by several factors associated with the Boston Harbor Project, particularly with the determination that Deer Island (a small peninsula at the entrance of Boston Harbor) was the only feasible location for the treatment facility. The major factors adding to the project's complexity were:

- Schedule constraints - The aggressive Court-ordered schedule required plant construction to commence by December 1990. The new primary plant was to be completed by 1995 and all process facilities were to be completed by December 1999.
- Site constraints – The small Deer Island site strongly influenced the design of the new treatment facilities (requiring use of space saving designs more commonly found outside the U.S.), affected the phasing of construction, and required use of off-site locations for construction staging. In addition, roadway access was limited to narrow two-lane streets winding through dense residential neighborhoods that could not support the massive volume of construction traffic.

- Mitigation commitments - All construction was to occur close to established residential neighborhoods and access to the construction sites was through these communities. To mitigate construction impacts, the MWRA moved essentially all equipment, and materials to/from Deer Island by barge and almost all workers were transported to the site by bus or passenger ferry service. Stringent limitations on air emissions, noise and visual impacts were also established for both construction and operation of the new plant.
- Maintain existing operations - The design of the new facilities and phasing of construction had to permit the ongoing operation of two existing wastewater treatment facilities.
- Competition with other projects - The Boston Harbor Project had to be coordinated with other major construction projects in the Boston area, particularly the $14 billion Central Artery/Third Harbor Tunnel project, which would exert concurrent demands for available resources, including management, labor, equipment, materials, water transportation, and disposal sites for excess materials.
- The successful management of the project depended on the ability to overcome the obstacles described above, control project costs, complete the construction within the court mandated timetable, deliver quality operable facilities, and maintain a positive relationship with affected communities.

SELECTING AND IMPLEMENTING A PROJECT MANAGEMENT STRUCTURE

The aggressive court-ordered schedule, intense public pressure for cost control and daunting logistical challenges associated with the Boston Harbor Project dictated that the MWRA quickly implement an effective management structure to take the project from the facilities planning stage into design, construction and start-up. As a new agency, the MWRA had relied heavily on consultants to prepare the secondary treatment facilities plan. Within the authority, responsibility for managing the project initially resided with the MWRA's engineering division, which was responsible for all MWRA engineering and construction projects encompassing both rehabilitation projects and the new capital projects generated by the court order. The MWRA was able to assign only two full time staff to manage the facilities plan for what was projected to be a $4.0 billion program. Although this structure was successful for the initial facilities planning phase of the program, the MWRA faced numerous questions as the project was ready to progress into the more intensive phases of design and construction:

- How could MWRA maintain adequate control over the design and construction of the new court-ordered facilities? What was the preferred organizational structure for generating effective agency oversight?

- How could the MWRA effectively manage the $4.0 billion Boston Harbor Project while concurrently implementing a $100 million per year system-wide capital rehabilitation program?
- What would be the role of private firms and how should the private sector resources be organized? How should the relationship between in-house (public) and private sector resources be structured?

In developing answers to these questions, the authority reviewed the management approaches used by two relevant large-scale public works projects: the North River Water Pollution Control Plant in New York City and the Central Artery/Third Harbor Tunnel in Boston.

New York City's North River Water Pollution Control Plant was selected because it was one of the most expensive wastewater treatment plant under construction at the time and presented complex construction management issues. The facility, which cost $1.1 billion, was constructed on a small site with its limited access impeded by a major highway rehabilitation project. Like the planned MWRA facilities, the project had to conform to milestone dates stipulated in a federal court order. The management approach for the North River Plant was distinguished by the following characteristics:

- Use of consultants for design and construction management of the plant - This decision reflected recognition of the project's complexities and the internal resource constraints of an agency (the New York City Department of Environmental Protection or NYC/DEP) already encumbered by substantial ongoing capital and operating responsibilities. The reliance on consultants was particularly significant in this case because the agency had previously designed a 300 million gallon per day wastewater treatment plant entirely with in-house staff.
- Retention of agency control in key programmatic areas – Although the consultant team had primary responsibility for design engineering and construction management, the NYC/DEP elected to maintain management control, allow its own staff to have input into the design process, and retained the authority to advertise bids, select contractors, issue change orders and make progress payments. The consultant had input on these decisions, but only NYC/DEP could provide final written approval.
- Integration of construction–related knowledge into the design and implementation process – NYC/DEP recognized that the project's planning and design would have a direct impact on the ability to manage construction effectively. Therefore, construction-oriented personnel were involved in design reviews, value engineering, scheduling and cost estimating early in the project.

The Central Artery/Third Harbor Tunnel Project was selected because of its similar scale, geographic proximity, similar requirements in labor and materials, and similar logistical issues, such as material disposal. With the goal of doubling the capacity of the Central

Artery and moving traffic from west and south of Boston to Logan Airport without passing through downtown Boston and East Boston, the project was estimated at that time to cost approximately $4.4 billion.

The approach adopted by the original sponsoring agency (Massachusetts Department of Public Works or MDPW) shared many similarities and has some differences in approach to the North River Plant. The similarities are:

- The use of outside consultants rather than in-house staff for design and construction services;
- The retention of agency control of areas such as contractor selection, change orders and progress payments; and
- The integration of construction-related knowledge into the design and implementation process.

The main ways in which the two approaches differed are:

- The creation of a special program management office within the sponsoring agency – The MDPW created an in-house program management group to provide oversight and monitoring of the consultant team. The group, which initially consisted of 40 people, had management, technical and support personnel. The responsibilities and organization of the in-house team mirrored those of the consultant team for effective interaction.

- Early decision to use a single firm to manage both design and construction services – Both MDPW and the NYC/DEP used a single team to manage the design and construction of their respective projects. MDPW made this judgment at the start of design and sought an integrated team with multiple capabilities. NYC/DEP, perhaps because of the more specialized design requirements associated with secondary treatment facilities, initially sought the best design engineering team and later decided to use the same team for construction management services.

- Use of multiple design firms – In the Central Artery/Third Harbor Tunnel Project, the prime consultant team has overall responsibility for design but does not perform all design functions. The approach is for the prime consultant to prepare the conceptual design and the MDPW contracts directly with "section designers" who complete the detailed design of various project components.

Implementation of a Management Approach for the Boston Harbor Project

In September 1987, the MWRA Board of Directors approved a recommendation to recruit a management team consisting of three components to manage the Boston Harbor Project:

- a newly created in-house team dedicated solely to the project, known as the Program Management Division;

- a consultant team to serve as Program/Construction Manager; and

- a second consultant team to serve as Lead Design Engineer.

This management model adapted many ideas from both the North River Treatment Plant and the Central Artery/Third Harbor Tunnel, but differed with them in several respects, most notably, in the decision to clearly separate responsibility for design and construction management.

The Program Management Division

The mission of the MWRA's Program Management Division (PMD) is to provide the authority with control and oversight of the Boston Harbor Project. PMD has been responsible for the executive direction, management and coordination of the program, including oversight of consultants. Through PMD, the MWRA retained the sole authority to bid and award contracts, select consultants, authorize change orders and progress payments, and resolve claims. The MWRA also retained the ability to perform independent review of all consultant work products.

As with the Central Artery/Third Harbor Tunnel Project, the MWRA saw the following advantages in creating a dedicated in-house team:

- prevent the project from consuming the resources of existing engineering and construction staff, which had on-going responsibility for a sizeable ($100 million per year) capital program;

- focus the full attention of a specific group of individuals on the harbor project rather than involving staff with multiple responsibilities; and

- provide the opportunity for the MWRA to recruit personnel with the needed program management skills from within and outside MWRA.

The team was initially composed of individuals with backgrounds in design engineering, construction management, finance and budgeting, contract administration, program management, information systems, environmental planning and community relations. Approximately 85 percent of the staff was recruited from outside the MWRA and 60 percent of the initial PMD staff had some private sector work experience. PMD's staffing peaked at 51 during the design and early construction phase and has subsequently decreased to 22 as the project reached substantial completion. Over time, the mix of skills has also changed in response to shifting project needs, with a greater emphasis on construction management, contract administration and claims/litigation management. Two-thirds of the current staff were drawn from outside the MWRA and 60 percent of the remaining staff has private sector work experience, primarily with consultant engineering firms.

Program/Construction Manager

A Program/Construction Manager (P/CM) was incorporated into the management structure to bring an organized, systematic approach to managing the program from pre-construction planning and design through start-up and acceptance of the new facilities. Day-to-day program management responsibilities reside with the P/CM rather than the MWRA's in-house staff.

As previously discussed, the aggressive court mandated timetable, the requirement for careful coordination of numerous contractors, subconsultants and equipment vendors on constrained construction sites, and the project's logistical challenges necessitated the use of an experienced, private-sector construction management firm. The use of such a firm was also viewed as providing a program-wide perspective that would increase the likelihood of meeting the project's schedule and cost objectives, and integrate construction-related knowledge into the design and implementation process.

As the principal management consultant, the P/CM has responsibility for resident engineering and inspection, project scheduling, cost estimating, contract administration, document control and information systems, community relations, environmental permitting, water transportation, bulk materials handling, value engineering, pre-purchase of equipment, facility testing, start-up and staff training. The P/CM team for the Boston Harbor Project is led by Earth Tech, Inc. (formerly Kaiser Engineers), with Stone & Webster serving as its principal subconsultant. This team began work in April 1988.

Lead Design Engineer

The third member of the management team, the Lead Design Engineer (LDE) was responsible for directing the design of the major project components. The LDE developed design standards (including a project-wide design manual), implemented a standardized CADD system, prepared conceptual designs (10 to 15 percent design level) for all facilities, prepared a final design of those facilities requiring early completion and coordinated the work of other design firms preparing detailed designs of various project components. As design and construction progressed, a key role of the LDE was to review design and contractor submittals to insure the integrity of the plant-wide design. During the course of the project, the LDE's role also expanded into construction testing and start-up.

The LDE for the Boston Harbor Project was Metcalf and Eddy, Inc., which began work in August 1988 and completed its LDE services in July 1998.

Key Features of the Boston Harbor Construction Management (CM) Approach

The MWRA's construction management model is distinguished by the following features:

- <u>The CM was selected prior to the selection of the Lead Design Engineer</u>. Immediately after assembling a core in-house team (PMD), the MWRA began the selection process for a CM. The CM was selected prior to the hiring of the design team because it was to have day-to-day management responsibility for the project. The CM would be responsible for construction planning and sequencing which would guide the design schedule and early input from the CM was essential to ensure that Constructibility and operability concerns were included in the design.
- <u>The MWRA Procured the LDE separately from the CM</u>. The CM and LDE were procured separately by the MWRA to ensure that the most qualified design and CM firms were selected in independent procurements. A joint selection would have left the MWRA subject to the uncertainty of the marketplace as to teaming of design and construction management firms. The MWRA was concerned that a joint selection could likely result in a situation where a single proposal did not contain both the most qualified CM and LDE.
- <u>The LDE has ultimate responsibility for coordinating the work of all designers</u>. In its design role, the LDE reported directly to the MWRA's Program Management Division.
- <u>Used multiple design firms</u>. The MWRA separately contracted with individual design firms to developed detailed design of various project components and provide engineering services during construction.
- <u>The CM performed value engineering and reviewed designs for Constructibility and operability</u>. This involvement brought an added dimension of quality control to the design and utilized the construction and plant operations knowledge of the CM at key points in the design process.
- <u>The CM is responsible for managing the overall program for schedule and budget control</u>. All design consultants and construction contractors submit their schedule and cost information to the CM for analysis and monitoring.
- <u>The CM was created to be the "Owner's Representative"</u>. Except for a clearly defined role in value engineering and constructibility review, the CM had no responsibility for design. The CM, therefore, provided resident engineering and inspection and oversaw start-up of the new facilities without having a vested interest in the performance of the design, equipment or construction.

MANAGEMENT TECHNIQUES AND THEIR EFFECTIVENESS

In a paper presented at the 1992 National CM Conference sponsored by the Construction Management Association of America, a number of techniques to enhance management effectiveness on the Boston Harbor Project were reviewed. This section provides an update on the effectiveness of these techniques including, where feasible, a quantification of project outcomes.

Design Management

Controlling construction costs was achieved, in part, through the design standardization and oversight provided by the Lead Design Engineer (LDE), the application of computer-assisted design and drafting (CADD) technology and the use of independent value engineering, Constructibility and operability reviews led by the CM.

The creation of a standard design manual and the development of a project-wide conceptual design eliminated many initial questions from the detailed designers (project design engineers or PDEs), and thereby reduced design cost and time. PDEs were given a limited amount of time to generate suggestions on ways to improve the conceptual design. Soon thereafter, the basis for the detailed design was locked-in, to the extent feasible, so that design could be expedited.

Standardization was further enhanced by the use of a single CADD system used by all designers. The MWRA took an aggressive step in determining that a single CADD system should be used by all designers, and furnished the requisite hardware and software to the firms. This unusual step was motivated by the desire to achieve the following:

- timely completion of a massive design effort by enabling the use of multiple design firms working simultaneously on separate detailed designs;
- ensuring consistency of design and quality control while using multiple designers; and
- creating the basis of an information system for the ongoing management of the completed facilities.

Of equal importance in controlling costs was the use of independent teams led by the CM to review designs for value engineering, Constructibility and operability concerns. The value engineering reviews were conducted on the conceptual design prepared by the LDE and on the 60% submittals prepared by the detailed designers. Constructability and operability reviews were done on the 30, 60 and 90% submittals. Operability reviews also were conducted on groups of construction contracts that comprised linked facility components. These reviews were aptly name “will-it-work” reviews.

Early in the project, a goal was established to limit design costs to between 5% and 7% of total construction costs. With design complete and construction physical progress at 99.4% complete, design costs on the BHP are 5.2% of construction. In addition to costs related to preparation of detailed designs, engineering costs were also incurred during construction. Although the CM provides resident engineering and inspection, in the BHP management structure, the detailed designers provided support services during construction to insure the integrity of the original design intent, including review of contractors' submittals and shop drawings and support during checkout and testing. To date, the cost of engineering services during construction are 4.0 % of construction costs compared to a project target of 4 to 6%. Overall, engineering services on the BHP represented 9.2% of construction costs versus a program target of 9% to 13%.

The estimated cost of value engineering reviews, approximately $2 million, was more than offset by estimated savings of approximately $200 million documented by an independent review of the value engineering program conducted in 1994 by KPMG Peat Marwick and Lewis and Zimmerman. An example of the value-engineering program was the redesign of the North System Tunnels on Deer Island. Two 11.5 foot diameter tunnels were required to transport flow approximately 2,250 feet from a rehabilitated pump station to a new headworks facility to commence the treatment process. Originally, these tunnels were to be built using open cut construction techniques. This approach would have significantly affected on-going construction on a highly constrained site. The value engineering review of this construction contract recommended building the soft ground tunnels using a tunnel boring machine (TBM). Further analysis demonstrated the feasibility of this technique and the tunnels were built using a TBM, resulting in estimated savings of $10 million and avoiding substantial disruption of other ongoing construction projects.

The effective management of design also benefitted the MWRA in successfully bidding the construction work and controlling cost escalation once construction was underway which is discussed below.

Enhancing Competition Through Contract Packaging

The MWRA delineated the mammoth construction effort into discrete, logically sequenced construction packages in order to increase price competition. The project was subdivided into 133 construction packages ranging in value from less than $10 million to over $200 million. This breakdown was intended to maximize competition among local construction firms by orienting packages within the limits of the bonding capacity of local firms. By expediting the design and bid of these construction packages, the MWRA was also able to largely avoid competition with the Central Artery/Third Harbor Tunnel Project and take advantage of a downturn in the regional economy that occurred in the early 1990's when the MWRA bid the bulk of BHP construction. The combination of effective packaging and timely bidding from late 1990 to early 1992 resulted in construction bids that were, on average, 10.4 percent below the engineers' estimates and yielded savings of $225 million.

Reducing Bid Contingencies and Encouraging Cost Savings Through Progressive Contracting Practices

Often public owners of complex construction projects require that construction contractors bear all risk associated with the variability of subsurface conditions. Under this type of approach, substantial contingency monies are included by contractors in their bid prices for differing site conditions.

Recognizing that construction of the 9.5 mile undersea Effluent Outfall Tunnel and the 4.8 mile Inter-Island Tunnel is by nature unpredictable, the MWRA sought to minimize contingency bids by engaging in extensive geotechnical investigations and adopting the risk-sharing contracting practices recommended by the Underground Technology Research Council (UTRC).

During the two summers preceding the bidding of the Effluent Outfall and Outfall Diffuser contracts, the MWRA conducted geotechnical investigations along the prospective tunnel routes at a cost of $20 million. The core borings and associated data were made available to all prospective bidders as they assembled their bids.

Both construction packages attracted competitive bids close to the engineer’s estimate, suggesting that the geotechnical documents and risk sharing contracting practices included in the bid documents limited the amount of contingency embedded in the bids. Differing site conditions and other unforeseen contingencies were, however, encountered in both tunnel projects resulting in substantial increases in the cost of the BHP tunnels. The combined cost of the projects rose from $274 million as bid to $451 million.

In addition to sharing the risk associated with the two tunnels and reducing the contingencies in the bids received, the MWRA also sought to encourage cost savings through use of a value engineering clause on all construction contracts. Value engineering is included as an incentive clause to promote innovative construction methods and techniques. Should the contractor conceive of a more cost-effective approach for construction of the facilities and that approach is approved by the MWRA and its design engineer, the MWRA and the contractor will negotiate a sharing of the associated cost savings. The most notable example of contractor-generated value engineering was the redesign of the foundation for the egg-shaped digesters. This value engineering effort received an award from the local chapter of the Associated General Contractors.

Ensuring Labor Harmony Through a Project-Wide Labor Agreement

In formulating the labor relations policy for the Boston Harbor Project, the MWRA’s most significant concern was the avoidance of delay. Any delay in the construction schedule could substantially increase the total cost of the project. Initial estimates were that a one-week delay in construction could result in a $2 million increase in costs.

Labor disputes presented a particularly concern for delay on the Boston Harbor Project because of the geographic limitations involved. As a result of the close proximity of the workers employed by multiple contractors on the job site and the common use of buses and passenger ferries to transport workers to/from the site, any disputes could spread quickly throughout the project. Similarly, picketing at the limited number of access points, such as the personnel ferry and barge transportation terminals, also had the potential to disrupt the project.

To respond to this potential problem, the MWRA's CM, Kaiser Engineers (now Earth Tech, Inc.), entered into a Project Labor Agreement (PLA) that ensured labor harmony with more than 15 international and 25 local unions represented by the Building and Construction Trades Council of the Boston Metropolitan District.

The PLA was designed to avoid delay by assuring, to the extent legally and practically possible, that labor disputes will not occur. Moreover, if they do occur, the agreement contains procedures to resolve disputes quickly and efficiently. The agreement establishes written rules for the employment of all construction workers and standardizes certain working conditions for all workers (such as work hours and travel allowances). The agreement contains a no-strike guarantee from the unions which prohibits all of the employees covered under the agr eement from striking, picketing or otherwise disrupting the project through its duration.

The PLA also contains provisions to resolve individual employee grievances, as well as jurisdictional disputes among unions, through three-step grievance procedures which culminate in final and binding neutral arbitration by professional labor arbitration.

To date, the BHP has employed over 23 million hours of construction labor without a single day lost to disruption. Approximately 300 disagreements have been successfully resolved through the agreement's dispute resolution clause since the agreement was signed in May 1989.

The effectiveness of the Boston Harbor PLA in resolving disputes and ensuring labor harmony has been well documented. Similarly, a legal challenge against this agreement has been well chronicled in legal journals. The challenge culminated in a landmark United States Supreme Court decision issued March 8, 1993 when the agreement's legality was upheld unanimously.

In brief, the court ruled that the MWRA, acting in the role of a construction owner, had the same right as a private owner to utilize project labor agreements authorized by the National Labor Relations Act. As the court stated, "Absent any express or implied indication by Congress that a state may not manage its own property when pursuing a purely proprietary interest such as MWRA's interest here, and where analogous private conduct would be permitted, this court will not infer such a restriction." (Massachusetts Water Resources Authority, et al vs. Associated Builders and Contractors of Massachusetts/Rhode Island, Inc., et al).

Taking an Aggressive Role in Safety

Although individual construction contractors have the primary responsibility to establish, implement and actively maintain effective safety programs, the CM has developed a project-wide safety program with which all individual safety programs must comply.

The project-wide safety program run by the CM begins with safety orientation for new workers and includes follow-up instruction during the first six months on the job in order to promote safety consciousness. The CM also has developed and implemented administrative procedures for emergency medical response, hazardous waste discovery response and accident response, and provided an on-site medical station. The CM also conducts safety inspections of all contractors on a regular basis. The MWRA's construction contracts require each general contractor to develop and implement a safety plan. The CM reviews this plan to ensure its consistency with the contract requirements and monitors each contractor's compliance with its own plan.

To date, with over 36 million exposure hours recorded, the lost time incidence rate on the Boston Harbor Project is 40% lower than the national average for heavy construction.

One other component of the safety program, the substance abuse program, deserves special recognition. The BHP CM negotiated a comprehensive substance abuse agreement with the Building and Construction Trade Council of the Metropolitan District, effective August 1, 1991. The program requires new hires on the Boston Harbor Project to pass a pre-employment drug test. A substance abuse test will also be administered when there is reasonable suspicion that a worker may be under the influence on the job or after accidents on the project. No random testing was included in the program.

Through the eight-year history of the program, approximately 4.6 percent of those tested have failed. The annual percentage has varied within a very narrow band from 4.5 to 4.7 percent. Both labor and management legitimately tout the program's success.

Developing and Administering Effective Change Order Procedures

A key management goal of the Boston Harbor Project is to keep the cost of change orders and claims on plant construction (excluding the two major tunnel projects) within 10% of the awarded value of construction contracts. This is an important target because it reflects the performance of both the project's design and construction management approach. Considerable effort has been made by the CM and the MWRA to develop effective change order and claims procedures that include checks and balances to safeguard the expenditure of public funds. The change order procedures require an initial analysis to determine the legitimacy and magnitude of the proposed change order and a detailed analysis that includes the preparation of independent fair cost estimates and schedule analyses. All change orders are processed initially by a dedicated CM contract administration staff located on site that interact closely with resident engineers and cost and schedule analysts. Ultimate signatory authority, however, resides with MWRA staff. The final settlement of change orders is, on average, 37% less than the contractor's proposal.

The award value of plant construction value (excluding the two major tunnels) is $2.04 billion. The change order percentage on these contracts, with the contracts 99.3% complete, is 12.3 % of the original bid price, exceeding the program target. As with many large-scale projects, a disproportionate share of the change order increase is attributable to a handful of specific contracts. In the case of the Boston Harbor Project, two construction packages, the rehabilitation of an existing pump station and construction of an on-site thermal/power plant generated a large volume of change order activity. The pump station was the only process facility rehabilitated as part of the Boston Harbor Project and during construction numerous unforeseen problems, many attributable to years of neglect, resulted in the contract increasing from $59 to $96 million. Similarly, the on-site/thermal power plant presented unique challenges as one of the few large power plants ever built under the constraints of Massachusetts public bidding laws and the cost of this project escalated from $54 to $98 million. Excluding these two projects, the change order percentage for non-tunnel projects decreases to 8.9% of the award value. (It should be noted that the change order percentages discussed in this section include all off-contract claim settlements.) Change orders and settlements associated with the $451 million in tunnel contracts represent 64.3% of the original bid value.

Planning for Construction Support Services

Among the major contributions made by the CM was the planning for site-wide construction support services contracts. These contracts provide centralized services such as water transportation for equipment and material, ferry transportation of workers, hazardous waste remediation, security, concrete supply, road maintenance, trash disposal, fuel supply, rodent control, snow removal and "on-demand" construction services for diverse small-scale needs such as trailer hook-ups and haybales along the shoreline. The total dollar value of these contracts is approximately $188 million.

The early involvement of the CM in the planning and procurement of these services was critical in the overall success of the project. The site's remote location and the restrictions placed upon the authority to mitigate the project's impact on neighborhood communities by extensive use of a water transportation system increased the complexity of an already complex construction project. With a substantial pre-construction planning effort, the difficulties posed by working on an island-site have been overcome. The transportation and other support systems functioned routinely and without problems.

Quality Assurance/Quality Control (QA/QC)

The CM has undertaken an aggressive QA/QC program for the Boston Harbor Project. Although the contractor has the responsibility for quality control, the CM routinely monitors contractor compliance with its (contractor) Quality Control Program. The CM's activities include: (1) preparing a checklist that clearly defines the requirements of the contractor's QC program; (2) developing a list of critical equipment for which the contractor is expected to provide off-site inspection; (3) conducting audits of each contractor to verify that the QC program is being implemented; (4) tracking the audit findings to make sure that the contractor has responded satisfactorily to the findings; and (5) analyzing audit trends to determine if and where program-wide modifications are needed to improve quality.

Over the course of the project, the CM performed 185 quality audits involving approximately 36,000 individual observations. Approximately 3,230, or less than 9% of these audit observations identified unsatisfactory work or materials requiring contractor correction. The CM's QA/QC program has proven a highly cost effective management tool which saves money by minimizing the required amount of rework by contractors while insuring quality construction that meets design specifications.

Overall Performance of the BHP Management Structure

In evaluating the overall performance of the BHP management structure, two questions must be answered:

- Has the management model been <u>effective</u> in managing the BHP, i.e. controlling project costs and maintaining schedule?
- Has the management model been <u>efficient</u> in managing the program, i.e. are management costs a reasonable percentage of total project costs?

Management Effectiveness

In May 1988, the Boston Harbor Project was projected to cost $2.6 billion in constant dollars with no allowance for contingencies. Escalating this baseline cost at 7% per year, the program was forecast to be completed at a total cost of $4.0 billion. With over 99% of construction completed, the current projected cost to complete for the project is $3.55 billion or $450 billion below the original current dollar budget estimate. Viewed another way, over the past 12 years, the cost of the Boston Harbor Project has increased at an average annual rate of 2.62% per year from the original $2.6 billion constant dollar estimate prepared in 1988.

A key element in controlling the cost of the Boston Harbor Project has been effective management of the project's construction schedule. Effective schedule management is also important because it has enabled the MWRA to comply, to the greatest extent feasible, with the court-ordered schedule, a fundamental program objective. The BHP management team was successful in maintaining construction progress close to this aggressive schedule established almost fifteen years ago:

- Eleven of the 17 court-ordered milestones were achieved on or before the milestone date.
- The milestone for start-up of the first phase of the primary treatment plant, which involved bringing on-line all or part of 17 separate construction packages with a combined value of $880 million and involving the checkout of over 32,000 individual components was met within six months of the milestone date, despite the adverse impact of severe winter weather.
- The complex start-up of the first battery secondary treatment facilities was achieved within seven months of the milestone and the second battery was brought on-line ahead of schedule.
- With the completion of the third battery of secondary treatment facilities, the final project milestone $3.6 billion construction program with an original duration of almost 15 years was completed within one year of its original target date.

The project did, however, experience its share of setbacks. Completion of the Inter-Island Tunnel was delayed by three years resulting in missing the milestones related to transfer of south system flows to the new treatment plant by over three years. The Effluent Outfall Tunnel proved an even more challenging project. Originally scheduled to be completed in July 1995, the tunnel was not placed into service until September 2000, over five years behind schedule. These delays are attributable to several factors. Despite, the extensive geotechnical investigations under taken prior to bidding the tunnel contracts, differing site conditions relating to rock conditions and the extent of water inflows were encountered in both tunnels which adversely affected productivity in mining and lining the two tunnels. Additionally, these were the first deep rock tunnels to be constructed within the Boston area in over a generation and neither construction planners nor bidders fully understood the productivity that could be achieved with this comparatively inexperienced workforce. It also took considerable time and effort to establish effective-labor management relations.

Delays in completion of the final milestone, the third battery of secondary treatment facilities, are related to another concern identified early (and largely avoided) on the project – competition with the Central Artery/Third Harbor Tunnel for available resources. During the major concrete placement phase of the contract, the contractor limited the size of the workforce, apparently out of concern over the availability of experienced, highly productive workers and the ability of his own management staff, spread thin overseeing several billion dollars of ongoing work on the Central Artery, to effectively manage a larger workforce and/or work extended hours. As a result, completion of the concrete work was delayed by almost a year, which directly affected follow-up mechanical and electrical work and absorbed any float in the schedule that would have allowed for schedule slippage which often occurs during the final stages of construction, check-out and testing.

Management Efficiency

In early 1992, prior to the commencement of major construction, PMD adopted a goal of keeping program management costs to less than 10% of total project costs. On the Boston Harbor Project, program management costs consist of PMD's expense budget, the CM contract and the management and coordination components of the LDE contract. This goal was viewed as ambitious, given the extensive number of owner-supplied services requiring CM management and the extensive number of contractors and subcontractors working on the project.

Currently, with construction over 99% complete, these management costs are at the targeted 10.0% of total project costs. Management costs are now projected to be 10.3% of total project costs upon completion and closeout of the project.

LESSONS LEARNED

The success of the management approach is most visibly demonstrated in the ability of the project to remain within budget and remarkably close to an aggressive schedule established almost 15 years ago.

In achieving the success noted above, the following items were of particular importance:

- ❖ <u>The ability to recruit a talented in-house management team</u> – The creation of a "special" unit with a clear, finite and somewhat all-consuming mission led to an ability to attract a talented and experienced group of individuals who were dedicated to moving the project forward.
- ❖ <u>The ability of the MWRA to retain adequate control of the program</u> – The size of PMD was adequate to maintain control and provide sufficient direction to consultants on the key elements of the project. The size of the team also was adequate to assign clear responsibility among individuals and to monitor their progress in achieving their objectives.
- ❖ <u>Private sector resources have helped to provide necessary experience and resources</u> – private sector firms supplied 450 of the approximately 500 members of the PMD/CM/LDE management team at peak staffing. It would have been extremely difficult for the MWRA to have assembled a team of that size as quickly for a project with a finite life. In addition, the CM and LDE teams have provided senior personnel with extensive world-wide experience in large-scale program/construction management and all engineering design disciplines – neither of which could be replicated in a newly created public authority undertaking a single mega-project.
- ❖ <u>Constructability and operability concerns have been well-integrated into the design process</u> – The value engineering process led by the CM has brought

valuable insights to the design process and may avoided potential construction problems which may have been encountered without early construction input.

- Pre-construction planning for key logistical elements of the project was completed at an early stage – The early involvement of a program/construction management firm led to the completion of plans and specifications for the water and bus transportation systems, a remote construction laydown area, an on-site concrete batch plant and other support services. These elements proved crucial to the successful completion of the Boston Harbor Project because of the constrained construction sites and the restrictions placed upon the MWRA to mitigate the project's impact on neighboring communities by extensive use of a water transportation system.

The project sponsor, the MWRA, has used a variety of management and cost control techniques to produce significant financial savings. The MWRA, assisted by the private sector resources of a construction management firm and a lead design engineer, has managed to maintain the vigorous pace set by the court-ordered schedule. In a project where the cost of delay is estimated to be $2 million per week, the ability to keep on schedule is a critical cost control factor.

Creative and imaginative design, planning and management also have contributed to cost savings. Design costs are running approximately 4.3 percent of construction costs, well below the industry standard, partly due to the adoption of project-wide design standards and the successful application of CADD. Value engineering reviews have saved $195 million to date.

Substantial cost savings were also generated by extremely competitive construction bids. Bids were ultimately more than 10% below estimates by the completion of bidding. Contributing factors included the regional slowdown in the construction industry in the late 1980's and early 1990's, combined with the MWRA's attempts to maximize competition through an aggressive outreach program and by segregating the project into smaller, discrete construction contracts. In addition, the MWRA worked on reducing bid contingencies by collecting a substantial amount of geotechnical data and including risk-sharing provisions in its construction contracts.

Despite the many successes, the management approach also encountered some difficulties. For example, a period of adjustment was needed for the two private sector firms to develop a smooth and effective working relationship. As noted previously, the firms were selected separately by the MWRA as opposed to a joint venture created by the two firms. Joined together by the owner, the firms had to set out the appropriate reporting and working relationship. Of particular importance was the ability to develop a smooth relationship in design where the CM had a limited but critical role reviewing value engineering, Constructibility and operability. Teamwork reached its pinnacle when it came to starting facilities, and when the required expertise of all parties was needed to ensure smooth operations.

Some difficulties also were experienced in introducing a new and "elite" group such as the PMD into an existing public agency. The PMD was structured to be a small management team drawing resources from private sector firms and also from other divisions within the MWRA. For example, PMD had one community relations specialist who had to work closely with the authority's public affairs department and a single financial planner who worked closely with the finance division. The MWRA's other divisions not only provided support to the Boston Harbor Project but also served all the authority's other capital and operating groups. As with the reporting relationship among PMD/CM/LDE staff, the relationship between PMD and other divisions required clearer definitions of roles and responsibilities in order to produce a smooth and effective working relationship.

The integration of plant operators into the organizational structure also could have been improved. Operability input into design came almost exclusively from consultants. Operators of the previous facility could not participate due to the overwhelming burden of running the old plant. Although the senior management team for the new plant was recruited in 1992 and 1993, their attention was diverted to running the previous facility, with little time available for input into the remaining design and construction of the new facilities. The majority of input from plant staff came during the checkout and testing process, which led to changes being made very late in the construction process. An alternate approach might have been to have a private operator handle the facility during the first year of operations with agency staff in training mode until all "bugs" were worked out. This approach may have taken the initial burden away from the operating staff and allowed for even more training of the MWRA's plant staff.

Another lesson learned was the need to continue holding operability reviews throughout construction. Despite the numerous reviews held throughout the design cycle, the start-up effort of the first facility was hampered in part by routine design errors and omissions. Subsequently, a series of additional design reviews entitled "System Integrity Reviews" were initiated during construction prior to mechanical and electrical installation. The reviews were extremely effective in eliminating routine start-up issues. Although the reviews led to late change orders, these were generally less problematic and less costly than enduring the start-up difficulties and even later change orders.

Lastly, and also pertaining to startup, it became apparent after the check out of the initial facilities that a dedicated check-out/testing team was necessary to help resident engineers start up these complex facilities. The start-up team was led by an individual with extensive experience in starting large industrial plants. The dedicated check-out team not only brought specialized technical experience to each separate facility startup but carried the "lessons learned" forward to the next facility.

CONCLUSION

The management approach used for the Boston Harbor Project has particular relevance to new or understaffed public agencies charged with the responsibility of completing massive and complex public works projects. The major elements of the management approach that have led to success are:

- The creation of an in-house project management team dedicated to the mega-project, which focuses agency resources on the project and allows existing staff to continue to carry out the agency's ongoing mission.
- The recruitment of an in-house project management team with both public and private sector experience and a broad diversity of program management experience.
- The use of substantial private sector resources to fulfill the project's extraordinary staffing requirements and to bring specialized skills and experience to the management team.
- The early retention of a CM prior to selection of the design team.
- The designation of a single entity with sole responsibility for managing day-to-day activities to ensure schedule adherence and budget control.
- The creation of an independent owner's representative with the removal of one private sector firm from any responsibility for design, construction and material equipment supply; and
- The implementation of numerous cost control techniques designed to reduce costs and maintain quality.

These elements have been critical in keeping the $3.5 billion Boston Harbor Project in compliance with the rigorous court-enforceable schedule and can be applied to other public agencies and private sector owners faced with similar program management challenges.

KEY WORDS: *Construction Management, Boston Harbor Cleanup, Project Labor Agreement, Value Engineering, Constructibility, Design Management*

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