MANAGING THE EAST RIVER BRIDGES IN NEW YORK CITY

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ABSTRACT

The history of the Brooklyn, Williamsburg, Manhattan and Queensboro bridges across the East River in New York City is examined, seeking to determine trends and most recent developments in their management. Reconstruction and maintenance costs are summarized. Crucial federal and local decisions and policies are identified. An attempt is made to draw conclusions from the management of the East River bridges during the 20th century and make recommendations for their future.

INTRODUCTION

Approximately 120 years ago New York City claimed its place among the greatest centers of urban activity worldwide by the construction of the four bridges crossing the East River between the boroughs of Manhattan, Brooklyn, Queens and the moveable bridges across the Harlem River between Manhattan and the Bronx. In 1883 the Brooklyn Bridge (Fig. 1) put New York City on the map as the previously independent boroughs of Manhattan and Brooklyn were linked by this world's longest suspension structure, (main span: 487 m, side spans: 284 m each). The Williamsburg Bridge (Fig. 2) pushed the main span record to 488 m in 1903 (but did not venture into side span suspension). The Manhattan (Fig. 3) was opened in 1908. It was the first fully suspended bridge to be designed by large deflection theory, with a 449 m main span and 222 m side spans. The 5-span Queensboro of 1912 (Fig. 4) is a cantilever truss structure with a longest span of 361 m and total length of 1136 m.

At their peak (Figure 5) the four East River bridges carried nearly 2 million passengers daily. Thus, even before the great New York bridges became an internationally recognized trademark, they made the City possible. Today the East River bridges carry more than a million passengers and remain a vital link for the City and the Metropolitan area. Over or near one hundred years old, these bridges have undergone numerous repairs and are undergoing rehabilitation at a cost expected to exceed $2.5 billion. The rehabilitation of the bridges has evolved over two decades and will continue into the next millennium. Many innovative design and construction solutions have been considered; some have been implemented.

The first report detailing the condition of the New York City bridges covered the years 1898-1901. The second report included 1902 to 1904. The third covers the period 1905-1912 [1]. The four East River bridges were already in place with Brooklyn and Williamsburg carrying over half a million passengers daily while Manhattan and Queensboro had just opened to traffic. Also new were most of the movable bridges, some of them replacing much older ones. Tolls were abolished on July 18, 1911. The average age of 42 of the 45 City bridges was less than 15 years in 1912 and they were in good condition.

According to the 1998 Bridge Condition Report [2], published under the mandate of the City Charter, the Bridge Division of New York City Department of Transportation was responsible for 766 bridges and 5 tunnels. Their average age was approximately 75 years. Table 1 compares basic data from the annual bridge reports of 1912 [1] and 1999 [2].

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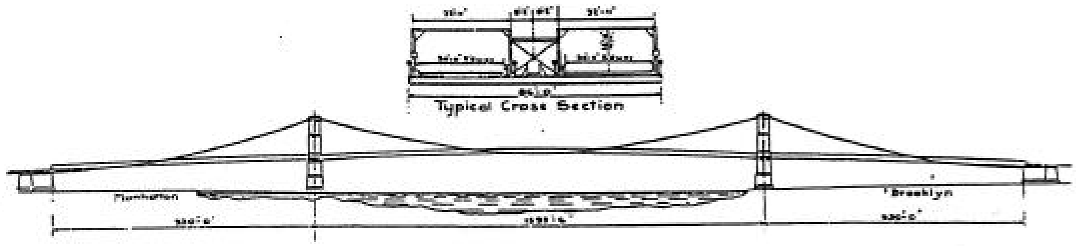
FIGURE 1

BROOKLYN BRIDGE

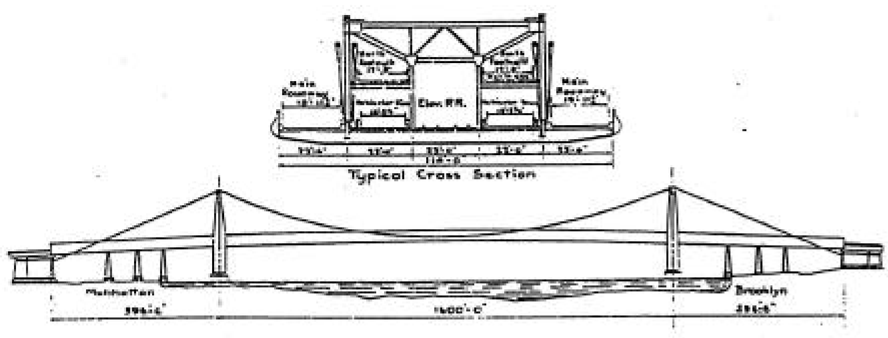


Construction of masonry commenced	Jan'y 3 1870
Construction of steel work commenced	May 29, 1877
Opened to traffic	May 24, 1883
Total length	6016 feet.
Length of main span	1595½ "
Length of each of the four cables	3578½ "
Diameter of each cable	15¾ inches
Total number of wires in each cable	5296
Total length of wire in the four cables	14,357 miles
The clear height over river channel is 135 ft. above mean high water	
Height of towers	272 ft. " " " "
Total weight of steel and iron in bridge & approaches	24,000 tons
Cost of construction of Bridge	$ 17,909,412.44
Cost of land	$ 7,185,165.00
Total Cost	$ 25,094,577.44

Commissioner

FIGURE 2

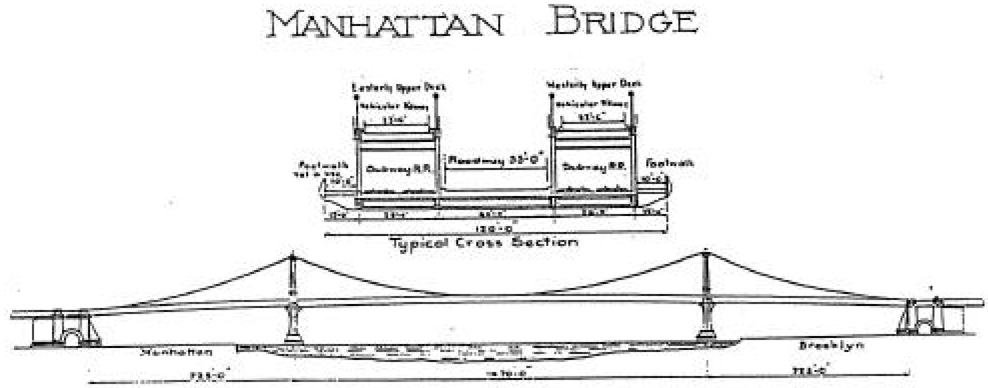
WILLIAMSBURGH BRIDGE



Construction commenced	November 7 1896
Construction of cables began	August 11 1901
Opened to Traffic	December 19 1903
Total length	7308 feet
Length of main span	1600 feet
Length of each of the four cables	2985 feet
Diameter of each cable	18¾ inches
Total number of wires in each cable	7696
Total length of wire in the four cables	17,404 miles
The clear height over river channel is 135 ft. above mean high water	
Height of steel towers	332 ft. 9 in. " " " "
Total weight of steel and iron in bridge & approaches	47,800 tons
Cost of Construction	$15,091,497.08
Cost of Land	$ 9,096,593.67
Total Cost	$ 24,188,090.75

Commissioner

FIGURE 3



Construction commenced	October 1st 1901	Diameter of each cable	$24\frac{1}{2}$ inches	Cost of construction	\$16,698,188.98
Const. of cable comm. Aug. 1, 1908, finished Dec. 10 1908		Total number of wires in each cable	9462	Cost of land	\$14,386,316.40
Opened to traffic	December 31 1909	Total length of wire in the four cables	23,132 miles	Total Cost	\$31,084,705.38
Total length	6855 feet	The clear height over river channel is 135 ft. above mean high water			
Length of main span	1470 feet	Height of steel towers above mean high water	336 feet		
Length of each of the four cables	3224 feet	Total weight of structural steel in bridge & approaches	60,000 tons		

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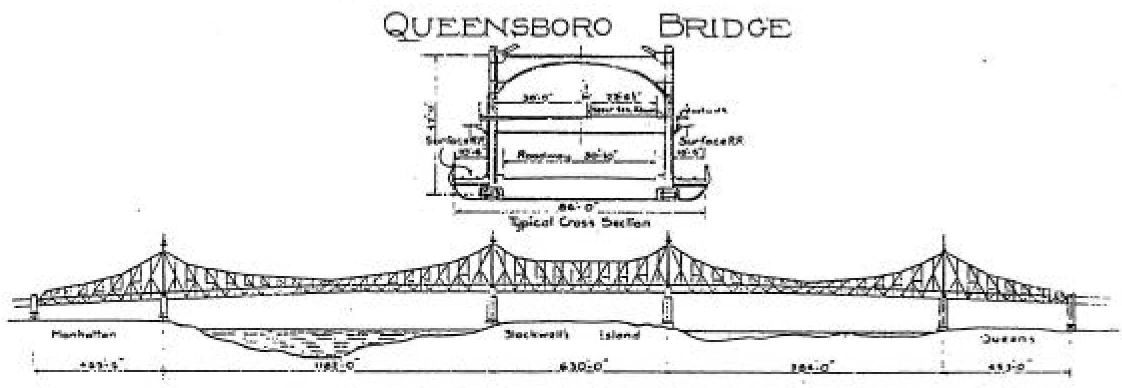
FIGURE 4



Construction commenced	July 19 1901	Height of Blackwells Is. towers to balconies 333 ft. above mean high water		Cost of construction	\$12,872,363.89
Opened to traffic	March 30 1909	" " " " " to top of flagpole 406 ft. " " " "		Cost of land	\$4,719,397.92
Length of Manhattan Approach	1052 feet	Height of highest masonry piers 124 feet " " " "		Total Cost	\$17,591,761.80
" Queens "	2672 feet	Weight of Steel and iron in main bridge	52,600 tons		
Total length of bridge & approaches	7443 feet	" " " " " " approaches	20,066 tons		
Clear height over river chan. 135 ft. above mean high water		Total weight of steel and iron in structure	72,666 tons		

Commissioner

FIGURE 5 - ERB'S TOTAL DAILY CROSSINGS

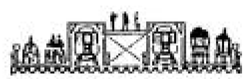
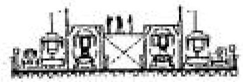
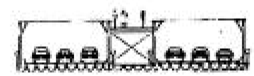
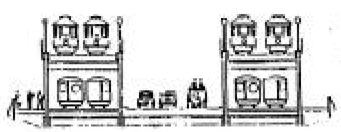
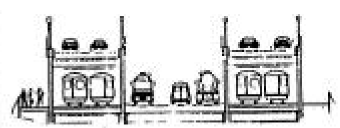
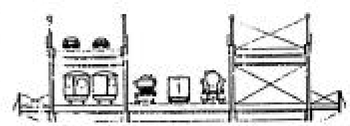
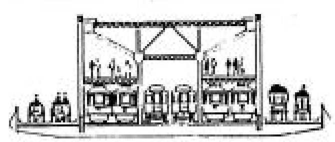
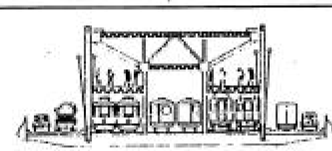
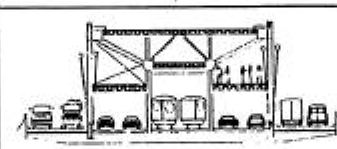
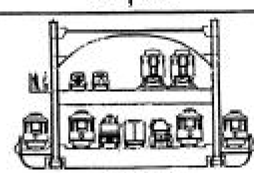
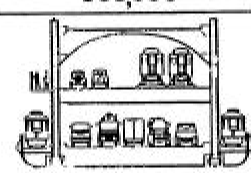
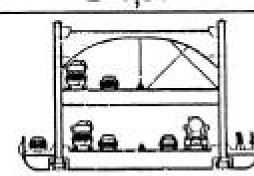
	FULL TRANSPORTATION OPENING	PEAK YEAR	1989
BROOKLYN BRIDGE 1883	 341,000 (1902)	 426,000 (1907)	 178,000
MANHATTAN BRIDGE 1909	 229,000 (1917)	 703,000 (1939)	 360,000
WILLIAMSBURG BRIDGE 1903	 227,000 (1910)	 505,000 (1924)	 240,000
QUEENSBORO BRIDGE 1909	 44,000 (1910)	 326,000 (1940)	 248,000
TOTAL	841,000	1,960,000	1,026,000

Table 1. Summary from New York City Annual Bridge Reports 1912 [1] and 1999 [2].

Year [1]	Bridges [2]	Deck Area [ml.m^2] [3]	Construction [ml. $/annum] [4]	Maintenance [ml. $/annum] [5]	[5/4] [%] [6]	Flagged Conditions [7]
1912	45	0.072 (est.)	71. (act.)	1.3	1.8	-
1999	769	1,500 (act.)	20,000 (est.)	42.0	0.2	2880

A number of trends are condensed in the numbers of Table 1, notably the following:

Bridges have remained of world-class size. World records for single span length were repeatedly set and broken. After the Brooklyn (487m, 1883) and Williamsburg (488m, 1903) suspension bridges, records were established by the George Washington (1067m, 1931), the Bayonne (511m arch, 1931), the Verrazano (1320m, 1964), and other bridges in the area. Structures counting hundreds of spans and running for miles over water and land became common. The cost of new construction per m^2 of bridge deck area can be assumed to have remained the same at a discount rate of approximately 3.3%.

Bridges have aged. On the average the age has grown by 60 years, but in the extreme and most significant cases of the 4 East River and 25 moveable bridges—by the entire century. No new bridges have been built since approximately 1964. The current bridge work in the City consists primarily of reconstructions. Thus bridge reconstruction, maintenance, and inspection have become newly active fields of bridge engineering.

Bridge maintenance and bridge conditions have declined. Bridge inspection, carried out under the auspices of the New York State Department of Transportation, found that 69.26% or 523 of the 769 bridges under the ownership and maintenance responsibility of New York City were classified as deficient in 1999. See the following section for a discussion of the rating system used by New York State.

As a by-product, potentially hazardous or flagged conditions, negligible over the first 7 decades, proliferated in the last three at an annual rate of 30% and at considerable cost (USD 15,000 per repair is an average estimate) [3]. At a 4% discount rate the total amount of bridge maintenance expenditures would be comparable. Thus, while the number of bridges has increased almost 20-fold, the maintenance expenditures have remained nearly constant.

The exceptions are noteworthy. The 1.8% ratio of annual maintenance to construction cost, obtained in 1905-1912 in New York City still applies at the George Washington bridge, also in the City, but under the responsibility of the Port Authority of New York and New Jersey, and annually grossing up to USD250ml. from tolls. A similar ratio has been reported by other toll-collecting agencies worldwide, for instance the Tokyo Metropolitan Transportation and the Honshu-Shikoku Bridge Authorities in Japan. However, the annual maintenance to construction cost ratio, for bridges owned and maintained by the City is 0.2%.

The expected bridge life has declined. While the East River bridges were built with the premise that, if properly maintained they would last forever, bridge reconstruction today may be designed for a 30-year life.

In identifying the above trends, bridge engineers have tried to impress federal and local governments with the need for a consistent effort for bridge management.

BRIDGE INSPECTION AND MANAGEMENT

The bridge management strategy tacitly applied over the period leading to the current bridge condition level is one of minimizing first and current costs. During the Pre- and Post-World War II decades the fundamental management policy nationwide was defined by a vast Federal investment in new construction. The pattern was retained and the idea behind many (usually implicit) bridge management decisions was to obtain maximum service from a structure at minimum cost (such as for maintenance) and then replace it. On the local level this strategy had an additional attraction since bridge reconstruction was Federally funded, while maintenance was funded by local taxes. Various events or actions on the part of the Federal Highway Administration and the New York State Department of Transportation have changed or are changing this philosophy. Two of these events included the adoption of both a bridge inspection program and the development of bridge management strategies.

Various catastrophic bridge failures, in the 60’s and 70’s prompted action by the Federal government establishing a national bridge inspection and inventory program. The National Bridge Inspection Standards (NBIS) was established in 1971 and set national policy regarding bridge inspection frequency, personnel qualifications and various other inspection and reporting procedures.

The New York State Department of Transportation, established a Uniform Code of Bridge Inspection, which prescribed standards for bridge inspection and evaluation for all publicly owned bridges in New York State. Chapter 781 of the Laws of 1988 of New York State also gave the State DOT the responsibility to inspect all publicly owned bridges in New York State. Thus, the inspection of the structural condition of the East River Bridges, fell under the auspices of the State DOT.

New York State’s bridge inspection program is unique from the FHWA inspection system. The State system identifies 30 – 40 items per span that are to be visually inspected and rated in accordance with the State rating system.

New York State uses a 1 to 7 rating scale as opposed to the 1 to 9 Federal rating system. New York=s scale is as follows:
1 Item totally deteriorated, or in failed condition
2 Used to shade between 1 and 3 ratings
3 Serious deterioration, or not functioning as originally designed
4 Used to shade between 3 and 5
5 Minor deterioration, but functioning as originally designed
6 Used to shade between 5 and 7
7 New condition. No deterioration.
Additional, numeric codes are:
8 Item is not applicable.
9 Condition of item and/or existence is unknown.

The above rating scale applies to all bridge items excepting Apaint@ and the Ageneral recommendation@.

The general recommendation is an overall rating that the inspection team leader applies to the bridge. It is the team leaders assessment of the overall bridge condition. The condition of items such as the primary members, abutment and piers, weighs more heavily than the condition of items such as wearing surface or curbs, in determining this rating. The rating scale for the general recommendation is similar to the above rating scale.

Based on New York State=s bridge inspection rating system, a bridge condition rating is developed. This condition rating is based on the weighed average of 13 items, from the bridge inspection report. Items such as the primary member or the deck again carry a much greater weight, in determining the condition rating than do curb or sidewalk. A bridge with a condition rating less than ›5' is classified as deficient.

With the inception of an intensive and regularly scheduled bridge inspection program, the critically deteriorated conditions of the East River Bridges, began to come to light and be quantified.

These inspections found that the four East River Bridges were deficient. The following table compares condition ratings for these bridges for the years 1989 and 1998:

Bridge	**1989 Condition Rating**	**1998 Condition Rating**
Brooklyn Bridge	2.79	2.88
Manhattan Bridge		
Lower Roadway	3.23	3.42
Upper Roadway	1.81	3.64
Williamsburg Bridge	1.88	2.37
Queensboro Bridge		
Lower Roadway	2.65	4.86
Upper Roadway	1.62	4.39

REHABILITATION OF THE EAST RIVER BRIDGES

The East River Bridges rehabilitation program began in 1980 with the letting of the first rehabilitation contract. This contract was for the installation of pier protection on the Brooklyn Bridge. Since that time numerous other rehabilitation contracts (as detailed below) have been let for the four East River Bridges. The rehabilitation of the Brooklyn and Queensboro Bridges is essentially complete with painting being the remaining major item of work. Work is currently progressing on the rehabilitation of the north roadway on the Williamsburg Bridge. This and tower and cable rehabilitation will carry this work into the year 2005. Rehabilitation of the north and the south outer roadways remains on the Manhattan Bridge. Coupled with tower and cable rehabilitation, contract work will continue until the year 2008.

Upon completion of these rehabilitations, over $2.5 billion will have been expended to rehabilitate these structures. Federal aid programs will have funded a large part of these costs.

Each of the four bridges presents different technical and logistical problems, while they all share the feature of providing services essential to the City and receiving no dedicated funding from tolls. It is instructive to Table 2 compares the estimated rehabilitation costs for the projects involved as they evolved over the last decade.

Table 2. East River Bridges Rehabilitation Cost Estimates [USD ml.]

	Year of Estimate		
	1990	1996	1999
Brooklyn	231.32.	321.29	351.26
Manhattan	316.20	611.30	702.20
Queensboro	337.60	447.70	516.40
Williamsburg	398.53	697.21	748.51

The comparison has been occasionally interpreted to report gross underestimates in 1990 [15]. Yet these costs would be equivalent to the ones of 1999 [2] if discounted at approximately 5.5%. In reality added reconstruction items and discounting share the burden, since the expenditures occur over 15 years. It is of interest to review each of the four cases in greater detail. Major rehabilitation items and their total estimated cost are listed below as they appear in [2]. (Totals are not summation of table columns, but total of all rehab. contracts)

Note: * Construction Complete; ** Design-Build Contract in Progress;
In Design; * In Construction

BROOKLYN BRIDGE

Rehabilitation Item	Est. Cost (Million USD)
Rehabilitate cables in anchorage and replace short rod suspenders; rehabilitate balance of promenade and construct bikeway and new pedestrian ramp. (1988)	22.68*
Rehabilitate and paint York, Main, William and Prospect Street structures and main bridge roadway deck overlay. (1988)	6.21*
Replace suspenders, cable posts, stay cables, hand-rope necklace lights, main cable wrapping; paint suspended spans. (1991)	53.57*
Rehabilitate ramp D and H in Manhattan, permanent improvement of promenade at Manhattan approach. (1993)	17.92*
Rehabilitate floor systems, stiffening trusses, roadways of suspended spans and Franklin Square trusses. (1994)	66.30*
Rehabilitate ramp D and widening along the FDR Drive. (1996)	11.39*
Arch supports for Franklin Square truss structure.	7.50*
Replacement of Suspended Span Deck (In Progress)	33.80**
Resurfacing of the main spans (1998)	6.67*
Rehabilitate and paint Brooklyn approach & ramps (B.S.F.) and Rehabilitate and paint Manhattan approaches and remaining ramps (A,B,C,F,G,H,I,J). (In Progress)	115.00***
Total:	$ 351.26

It is recalled that the Brooklyn Bridge is a unique hybrid of suspension and cable stay systems. Crucial to the current rehabilitation effort of the bridge was the break of a diagonal stay in 1981,fatally injuring a pedestrian. The ensuing inspection revealed that the entire stay and suspension system was corroded and required urgent replacement. The rehabilitation also focused on the condition of the main suspension cables, which were found in good condition.

As a result of the findings, all stays and suspenders were replaced in the 1980s. The main cables were re-wrapped. The anchorages were repaired [16]. A recent emergency contract replaced the concrete filled steel grating of the bridge deck. Another contract introduced steel arches to support the approach Franklin Avenue truss span on the Manhattan side of the bridge, after the pin and eye-bar bottom chords of the trusses were found to be deficient.

WILLIAMSBURG BRIDGE

Rehabilitation Items	Est. Cost (Million USD)
Replace main span outer roadway. (1983)	11.20*
Replace one third of suspenders. (1984)	3.20*
Component repairs of flag conditions on the north outer roadway and north inner roadway. (1994)	4.12*
Rehabilitate main cables and new redundant suspender system. (1996)	74.00*
Demolish DOS and DOH buildings, replace entire south outer roadway approach structures, rehabilitate south outer roadway deck and south inner roadway deck of the main bridge, and replace south inner roadway substructure of the approaches. (1998)	155.00*
Portion of Contract #6 BMT track structure work transferred to ongoing Contract #5 south approach roadway reconstruction work. (1998)	65.00*
Paint main and intermediate towers. (In Progress)	7.40
Reconstruct BMT Subway structure; install new signals, tracks and communication system. (In Progress)	130.00**
Miscellaneous rehabilitation work: tower rehabilitation, replace bearings travelers, architectural work, painting, suspender adjustment, tower jacking, construction of colonnades.	73.50***
Replace north approach structures (Manhattan/Brooklyn), rehabilitate north half of bridge and paint the main bridge. (In Progress)	202.80**
Total:	$ 748.51

The Williamsburg Bridge was temporarily closed to all vehicular traffic (including 8 automobile lanes and two subway tracks) during its biennial inspection of 1988 until an estimate could be made of the structural safety. Subsequent investigations differed on the bridge condition, particularly the remaining useful life of it's four suspension cables. Recommendations to replace the bridge were made, however, an expert task force appointed by the Mayor determined that a rehabilitation, rather than replacement would be the best course [17].

From a technical standpoint the decision to rehabilitate was predicated upon the determination that the four suspension cables, consisting of 7696 high-strength, non-galvanized wires could be saved with a complete re-wrapping, preceded by wedging, cleaning, oiling, re-splicing of broken wires, and re-anchoring of broken strands [16] (now complete). The approaches were found to require total replacement. The concrete-filled steel grid deck of the main bridge is being replaced with an orthotropic deck. Full re-painting with lead removal is in progress.

MANHATTAN BRIDGE

Rehabilitation Items	Est. Cost (Million USD)
Repair floor beams. (1982)	0.70*
Replace inspection platforms, subway stringers on approach spans. (1992)	6.30*
Install anti-torsional fix (side spans) and rehabilitate upper roadway decks on approach spans on east side. (1989)	40.30*
Eyebar rehabilitation – Manhattan anchorage chamber "C". (1992)	12.20*
Replacement of maintenance platform in the suspended span. (1996)	4.27*
Reconstruct maintenance inspection platforms, repairs to structural steel support system of lower roadway for future functioning of roadway as a detour during later construction contracts. (1997)	23.50*
Install anti-torsional fix on west side (main and side spans); west upper roadway decks; walkway rehabilitation; rehabilitate cables in both anchorage chambers; dehumidify Brooklyn and Manhattan anchorages. (1993)	96.90**

Removal of existing suspender ropes and sockets in the suspended spans; removal of existing main cable wrapping; cleaning of main cables; application of new protective paste on main cables; replacement of new main cable wrapping; reinforcement of truss verticals and gusset plates. (1987)	70.00***
Interim Steel Rehabilitation and Painting-cable and saddle repairs lower roadway; cable and suspender repairs, removal of parking deck, painting entire west side, all four cables. (1997)	124.10**
Stiffening of Main Span; Reconstruction of North Subway Framing; reconstruction of North upper roadway deck at suspended spans; rehabilitation of north approach span trusses; painting of north side of bridge; new inspection platforms and debris protection in approach spans; installation of Intelligent Vehicle Highway System for North and South Upper Roadways as well as for Lower Roadway. (Present)	201.00***
Rehabilitation of Lower Roadway (Present)	17.00***
Total:	$ 702.20

Manhattan was the third New York City suspension bridge, but the first one to be designed taking of account large deflections and to be a purely suspended structure. Ralph Modjeski was the engineer of record, however Leon Moisseieff is credited with applying large deflection theory to the design. Since the onset the bridge exhibited excessive transverse flexibility. As shown on Fig. 1 this is exacerbated by the live load configuration, concentrating subway and automobile traffic on two levels near the bridge fascia. Fatigue cracks induced by torsion quickly became manifest. A study by Steinman in the 1950's [18] concluded that the bridge would have problems of this nature as long as there are trains on it. After an extensive investigation of the bridge response to live loads [19,20], a stiffening scheme was recommended and is currently under construction.

Extensive and innovative work was also conducted in the bridge anchorages in order to rehabilitate the cable eye-bars. As reported in [21], new anchor girders were installed and suspension cable strands were re-anchored, relieving the load on eye-bars with cross-sections reduced by corrosion. De-humidification is planned for the anchor chambers to reduce the risk of recurring corrosion problems.

QUEENSBORO BRIDGE

Rehabilitation Items	Est. Cost (Million USD)
Repair lower outer roadways/reconstruct two ramps in lower Queens (1984)	18.80*
Reconstruct south upper roadway, replace inspection platforms, lighting (1986)	31.50*
Interim rehabilitation contracts A, B, & C (repairs to lower deck and main bridge approaches). (1985)	2.80*
Interim rehabilitation, contract D (repair to lower deck, main bridge, and new median barrier). (1988)	3.00*
Reconstruct north upper roadway and Queens approaches A & B, rehabilitate bearings at Queens approach. (1989)	50.00*
Reconstruct ramps C & D (Queensboro only, not Thompson Ave.) (1988)	10.40*
Rehabilitate bridge bearings, pier tops, and truss lower chords. (1989)	18.00*
Rehabilitate Queens approach trusses, lower inner roadways on the main span and approaches. (1996)	172.00*
Rehabilitate lower outer roadways main span and approaches, (bikeway) cleaning and painting. (In Progress)	161.40**
Cleaning and painting main bridge upper trusses. (In Progress)	48.50***
Total	$ 516.40

As illustrated in Fig. 5, Queensboro Bridge was designed for predominantly rail traffic. As streetcars and trains yielded to automobiles, live loads were reduced. This proved fortuitous during the post WWII years, when corrosion severely reduced the floorbeam sections. No longer functioning as designed, the bridge was still adequate for the current loads. Currently the roadways of both levels have been replaced with concrete filled steel gratings. Re-painting with full lead removal has been performed in certain areas, while others are pending.

Several features are common to the projects to rehabilitate the four East River bridges:

Bridge age and condition. All four bridges are approximately 100 years old. Their condition has deteriorated to the point of jointly generating up to 2880 structural and safety flags during New York State biennial and interim inspections. They are rated "not functioning as designed.

Nonetheless, the load bearing capacity of the bridges is better than their condition rating for three reasons:
a) the structures were designed for heavier rail traffic than they are receiving today;
b) the design was highly conservative;
c) construction quality was superior.
It is noteworthy that bridge managers cannot apply similar considerations to post-WWII bridges.

Structural complexity. Three of the four structures are among the record-holders for suspended span length circa 1900. The fourth is a cantilever truss with eye-bar chords. The bridges are rich in details, fracture-critical, inaccessible to routine inspections and hard to evaluate analytically.

Bridge function and importance. The bridges have carried up to 2 ml. passengers daily and still carry more than 1 ml. (Fig. 5). Their function in providing vehicular and subway passage between the boroughs of Manhattan, Brooklyn and Queens is essential to the City. Their location is fixed. Consequently the bridges can only be replaced "in kind" and their life is, from a manager's standpoint, infinite.

Bridge inter-dependence. Full closure to traffic was not an option available on any of the bridges. Williamsburg and Manhattan are the only truck arteries connecting the Holland tunnel truck traffic from and to New Jersey with Long Island. Thus the two bridges could not simultaneously close all traffic lanes in the same direction. It is estimated that these constraints have roughly doubled the duration of the reconstruction and added perhaps as much to the costs. Although there is no direct estimate, however, it is assumed that this hardship is more than offset by the amount saved in user and community costs. As an indirect measure of the community benefits from the bridge service, it is recalled [22] that the George Washington Bridge, operated by the Port Authority of New York and New Jersey annually collects approximately 250 ml. USD in tolls. The 4 East River bridges, operated by the City of New York collect no tolls, but the service each of them provides is entirely comparable, perhaps even higher, if the train traffic is considered.

Various measures were taken over the years in order to accelerate the execution of the contracts addressing the successive construction stages. Providing incentive / disincentive to the contractor in terms of a bonus or fine for days respectively gained or lost to traffic appears to be an effective tool.

Updating the bridge design concepts. The most important new aspect of the rehabilitation design that gained significance and understanding during the duration of the work was the provision for resistance to seismic events. Although not in a highly active seismic zone, the 4 East River bridges are considered "at risk". "Risk" in this case is defined as the product of the likely earthquake hazard (relatively low) and the magnitude of the expected losses (extremely high). A panel of experts provided a seismic hazard estimate [23] and corresponding strengthening measures are incorporated in the design according the Federal and State guidelines.

Updating the bridge management. The magnitude of the rehabilitation investment draws attention to the future management of the bridges. In the past they have been alternatively under New York City, State and, since 1989, once again City purview. Reconstruction has been funded from Federal, State and City sources. Contracts have been managed by both City and State with Federal participation. Maintenance has traditionally been funded from local taxes. The lack of dedicated funding is considered as the principal cause for the decline in the bridge condition.

Since all management can be reduced to money management, the bridge manager asks: if the existing funding allocation obtains optimal bridge service. That question has received much attention worldwide over the last two decades. During this period the United States introduced bridge management programs and lifecycle cost analysis. A number of Federal Highway Administration (FHWA) and Transportation Research Board (TRB) publications contain the guidelines on bridge management in the United States. Primary among them are the Guide for Bridge Inventory and Appraisal, FHWA [5], the Bridge Management Systems (BMS) Report, NCHRP 300 [6] and PONTIS, TRB Circular 423 [7], TRB Records 1183 [8] and 1184 [9], 1290 [10], 1490 [11]. The Bridge Management Report by OECD [12] summarized a great deal of Bridge management knowledge from all the member countries. The most significant result of the worldwide bridge management effort to date is the development of comprehensive databases of bridges, their components and, to the extent currently attainable, their conditions. It is increasingly realized that a BMS can eventually conduct evaluations, but should not be expected to make decisions. The question who should is, of course, subject to continuing discourse.

PROTECTING THE INVESTMENT

As various phased contracts, associated with the overall rehabilitation of these bridges were completed, subsequent inspections, by engineers from the Federal Highway Administration, indicated failure or deterioration of recently rehabilitated elements. These inspections indicated premature failure or deterioration of recently applied paint systems, debris clogging or interfering with the proper functioning of joints, bearings or drainage structures and excessive wear to electrical and mechanical components. In light of the extraordinary costs involved in the rehabilitation of the East River Bridges, engineers associated with this project explored means of protecting this investment by encouraging implementation of a preventative maintenance program on these bridges. The conclusion of these inspections and recommendations can be found in the FHWA Special Maintenance Review Report of October 1996.

This report recommended a number of points relative to the current maintenance and future development of a preventative maintenance plan for the four East River Bridges. These points included:

?? Rehabilitation designs consider maintainability – numerous elements installed during portions of the rehabilitation of these bridges provided difficult or impossible to maintain. Some elements were difficult to access. Other elements, installed during the rehabilitations, were duplication of original elements, which were not lent to easy maintenance.

?? City DOT structure and staffing – this review indicated that restructuring of the City Department of Transportation had reduced the influence of those engineers and personnel charged with maintenance and upkeep of the East River Bridges. Severe staffing cutbacks had also occurred.

?? New York State Inspections – it was revealed that little information from the NYSDOT inspections was being incorporated into a New York City DOT maintenance plan.

?? Debris and other corrosive material were found to be accumulating on newly rehabilitated elements causing premature failure or deterioration.

The report went on to further recommend the following points:

?? NYCDOT evaluate organizational changes that would facilitate preventative maintenance programs and provide special emphasis on preventative maintenance on the East River Bridges

?? Staffing levels be adequately increased at the engineering and maintenance level.

?? Anti-icing salt substitutes be tested and application programs instituted.

?? Regular bridge washings and painting in salt splash zones be implemented.

Initial consultation with upper level management of the New York City DOT indicated a willingness to explore implementation of such a program. However, City funding of a preventative maintenance program, to the degree necessary to preserve all aspects of the on-going rehabilitation work could not be certain. Federal Highway engineers thus began exploring Federal funding options with both the State DOT and the City.

As a first step, engineers from the New York Division of FHWA worked with the State DOT in preparing Engineering Bulletin 96-034. This bulletin released in July 1996, provided guidance and instruction relative to the use of Federal-aid for element specific work. Eligible work is summarized in the table below.

Federal-Aid Eligible Bridge Work	
Cyclical Work	**Element Specific Work**
Bridge Washing	Bearing Replacement/Repair
Bridge Painting	Bridge Railing Upgrades
Deck Sealing	Joint Replacement/Repairs
Bearing Lubrication	

FEDERAL FUNDING POLICIES

Of further significance in the promotion of preventative maintenance and bridge management strategies, on the East River Bridges, was the evolving flexibility of federal funds toward the application of these programs. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) amended the United States Code to " provide specific Federal-aid fund eligibility for preventative maintenance" activities.[1] Bridge work such as crack sealing, joint repair and painting were now considered as eligible for Federal-aid participation where this work would preserve or extend the life of the structure. Preceding policy memorandums from the Executive Director of FHWA allowed further flexibility of STP, NHS and HBRR funds relative to preventative maintenance applications.

As outlined above, Federal-aid funds, under programs such as STP, NHS and HBRR, were now available for preventative maintenance activities. The aforementioned EB provided State and local government agencies, the vehicle for the application of those funds.

On the basis of this EB and greater flexibility in Federal-aid funding a Preventative Maintenance task force was formed. This task force, consisting of representatives from the Federal Highway Administration, New York State Department of Transportation and the New York City Department of Transportation, was charged with developing a preventative maintenance plan for each of the East River Bridges. As a foundation for the development of this plan, the task force looked to the 1990 Final Report of the Consortium of Civil Engineering Departments of New York City Colleges and Universities.

1990 CONSORTIUM REPORT

In the late 80's The Consortium of the Civil Engineering Departments of the New York City Colleges and Universities was established, under the sponsorship of the City DOT, with the objective of developing a Preventative Management System for the bridges of the City of New York. The final report, issued in March of 1990, established essential components of a preventative maintenance plan including:

Debris removal and sweeping
Maintenance of drainage systems
Cleaning of deck and substructure units
Bridge washing
Spot painting of steel
Painting salt splash zone areas
Maintenance, cleaning and lubrication of mechanical components

The report also recommended required staffing levels and associated costs, to accomplish these maintenance activities as well as detailing the work involved in these activities and proposed frequencies. The Consortium Report detailed many of the same concerns echoed in the 1996 FHWA report.

Using the 1990 Consortium report, and proposed maintenance plans, developed in conjunction with associated rehabilitation contracts, the East River Bridges Preventative Maintenance Task Force started meeting on a quarterly basis in 1995. The Task Force began development of the specifics of a bridge maintenance plan, for each of the East River Bridges. At these task force meetings division of work items between contract and City maintenance forces were determined. Funding splits between Federal-aid and City sources was also determined.

In 1999, the first three-year stand-alone maintenance contract, for the Brooklyn and Queensboro Bridges was awarded to Tower Painting. This contract provides for paint removal and application in salt splash zone regions; bridge washings; joint and drainage structure cleanings and cleaning and lubrication of other structural and mechanical components. Frequencies are per the contract as established through the East River Bridges PM Task Force.

Other preventative maintenance activities have been incorporated into ongoing rehabilitation contracts, on the Manhattan and Williamsburg Bridges. Upon completion of these rehabilitation contracts, stand alone preventative maintenance contracts will be established for these bridges.

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1 FHWA Policy Memorandum by Anthony R. Kane July 27, 1992

ANTI-ICING INITIATIVE

On the basis of the recommendations contained in the aforementioned FHWA Special Maintenance Review, the City began to explore anti-icing alternatives to sodium chloride (salt). Initial efforts, in cooperation with the New York City Department of Sanitation were less than satisfactory. The Department of Sanitation, which is responsible for snow plowing and salt spreading, throughout the City of New York, was reluctant to change years of entrenched snow and ice fighting methods. The City Department of Transportation eventually took control of these activities, on the East River Bridges, in an effort to implement anti-icing methods as recommended in the FHWA review.

To date these activities have been significant. Foremost of these have been the in-house development and implementation of the Fixed Anti-icing Spray Technology (FAST) system on a portion of the Brooklyn Bridge. Designed and installed by the Bridge Maintenance Unit of the New York City DOT, an automated sprinkler system delivers potassium acetate over a portion of the eastbound roadway of the Brooklyn Bridge. Further expansion of this automated anti-icing application system is expected in upcoming contracts. ITS technology will be integrated into this system to further enhance its value. Additionally, the City is using specially equipped spreaders for the application of salt substitutes on the other East River Bridges.

STAFFING

Prior to 1938, the maintenance of the East River Bridges was under the auspices of the City Department of Bridges. During this time up to 200 workers were responsible for the maintenance of the Brooklyn Bridge, alone. By 1938, 435 workers maintained 50 waterway bridges, in New York City, including the East River Bridges. By 1987, organizational changes and restructuring, within the City of New York, had reduced the influence of those overseeing these bridges. Thus by this time, 160 workers oversaw maintenance of 1426 State and City bridges in New York City.

In various reports relative to the need for establishing a preventative maintenance plan for the East River Bridges, including those already mentioned, the need for restructuring and adding additional staff was consistently established and recommended. In the aforementioned 1996 FHWA Special Maintenance Review, not only was an increase in staffing levels for maintenance personnel recommended, but also increases in staffing of engineering and inspection personnel associated with the Preventative Maintenance Program for the East River Bridges was strongly encouraged. To that end, FHWA funding has been made available to fund increased staff levels for those maintenance personnel involved in the cleaning and lubrication of the suspension cables on the Brooklyn, Manhattan and Williamsburg Bridges.

To date the structure of the City Department of Transportation has been revised to provide an Executive Director of Preventative Maintenance. Assisting this individual is a Deputy Director for the East River Bridges PM program and one for a Winter Plan. Structures have also been established for an In-House Specialized Maintenance section and a PM Contract Supervision section. See the attached flow chart on the following page for more information.

DESIGN FOR MAINTENENCE

An innovative feature common to all 4 rehabilitations is the requirement that a bridge-specific maintenance manual be prepared by the consultant and implemented by the owner upon the completion of the work. Items, such as painting, oiling, cleaning, etc, are identified with their recommended frequency and respective cost. Plans prepared for the various phases of rehabilitation are also subject to peer review. Plans are reviewed by other design consultants to ensure that elements incorporated into the rehabilitation can be effectively maintained under preventative maintenance contracts

COSTS OF PM PROGRAM

As previously mentioned, a stand-alone preventative maintenance contract currently is in place for the Brooklyn and Queensboro Bridges. This three-year contract is for approximately $9 million. Preventative maintenance contract work on the Manhattan and Williamsburg Bridges have been incorporated into existing rehabilitation contracts and amount to approximately $3 million per year per bridge. With additional costs for anti-icing efforts, cable cleaning and lubrication and inspection staff a total of approximately $12 million is being outlaid each year for the preventative maintenance program for the four East River Bridges.

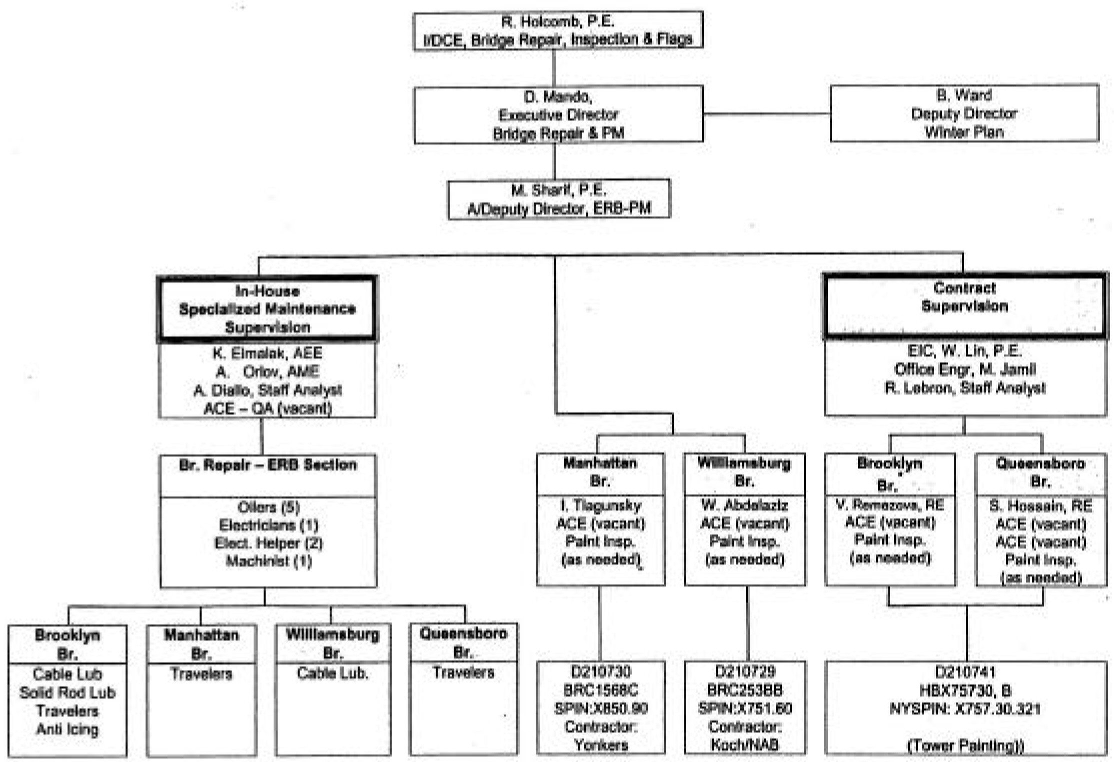

FIGURE 6 - PM PLAN FLOW CHART

DATA COLLECTION

Another important aspect, in the development and the furtherance of a preventative maintenance plan is the collection of data relative to the existing efforts and their successes or failures. This data will then be incorporated into a computerized database, which will then further fine-tune this on-going program. This data can also be used to estimate the annual funding necessary for the protection of the considerable rehabilitation investment already made. The cost/benefit analysis of maintenance versus reconstruction is neither simple nor fully resolved. As pointed out, the management of one or several bridges can never be perfectly optimized, because the process is not isolated from the rest of the community activities. Current discussion has focused on the use of discount rates in the analysis [24], as well as the validity of the assumptions regarding the ability of maintenance to extend bridge life [25]. The New York City DOT has under contract a design consultant to collect and track this data and develop a computerized Preventative Maintenance management system and thus assist in the determination of cost/benefit data for the PM plan as well as optimizing the use of funds.

CONCLUSION

The rehabilitation of the four East River bridges in New York City is an important example of the bridge management challenges that a major metropolitan center can expect to face. The task has received enormous attention from the Federal and State governments, as well as from the international engineering community.

In a letter to Dr. Yanev, dated October 6, 1993, the President of the United States wrote: " *America must address the problems of its vast network of bridges and highways if we are to remain a strong nation in the next century*." In a large country governed by democratic principles, however, such a commitment does not lead automatically to the adoption and implementation of a national management policy.

Some of the problems are summarized by the (then) Chief Administrator of FHWA and later Transportation Secretary Rodney E. Slater in a follow-up to President Clinton's letter, dated October 21, 1993. In it Secretary Slater states: "…*Needs typically exceed the means available to address them. At the national level, ISTEA has allowed us to set new funding records for highway and bridge projects, but still, needs far exceed the available funding. Resources, therefore, must be distributed as equitably as possible…. Clearly, if funds were unlimited, we would do more. However, we are proud of our role in helping New York City preserve its major bridges as important transportation links and as a valuable historic legacy for generations to come*." To date the effort of Federal, State and City transportation agencies, to rehabilitate and preserve the four East River Bridges has been outstanding.

It is realized that an identical approach does not apply to all the 766 New York City bridges. With reconstruction techniques advancing and traffic demands constantly changing, certain small bridges may prove easier to replace than to maintain intensively. Thus it becomes essential to establish a cost-effective policy particularly for bridges justly considered irreplaceable, such as the East River ones. Numerous innovations and creative solutions have been and are implemented on these structures by the owner with the help of a large number of consultants and contractors. From a bridge management standpoint, the future task of the owner is to make the benefits of the accomplished work as long lasting as possible in a cost-effective way. What makes the 4 East River bridges unique is the combination of their age (100 years) the traffic capability they must provide (over a million passengers/day), their size (world record holders at opening dates) and their expected future life. The most important new management aspect is the close cooperation between Federal, State and City government. The result should be to eliminate the past error of designating maintenance as an "expense" item and deferring it until the "capitally" funded reconstruction becomes inevitable.

ACKNOWLEDGMENT

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