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Using systems thinking to evaluate a major project

The case of the Gateshead Millennium Bridge

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Abstract

Purpose – The purpose of this paper is to set out the results of a study of a major landmark construction project and to use systems thinking to shed light on the organisation, management and performance of the project.

Design/methodology/approach – The three main methods of gathering the data were a series of formal and informal interviews with representatives of Gateshead Metropolitan Borough Council and their main project partner Harbour and General, regular visits to the main construction site and the secondary site where the bridge was pre-fabricated and an extensive study of newspaper and magazine articles, Council minutes and memoranda and other relevant literature. The paper also employs a systems-based approach whereby the project is represented as a system and compared with an ideal model of a system that is capable of purposeful action without failure.

Findings – This paper has shown that shown that, although many aspects of the management of this construction project such as its decision-making processes were very effective, the project was over budget and significantly late. Analysis using systems thinking has been able to reveal that the problems encountered during the construction were caused by unforeseen environmental influences and failure to appreciate the viewpoints of those directly and indirectly affected by the project. It is suggested that the lessons learned from investigating this project in real time can provide a valuable insight into understanding the challenges faced by similar projects.

Originality/value – Unlike many reports of similar-sized projects, this case study uses data gathered throughout the life of a lengthy construction project. It uses these data to conduct an assessment of project performance and evaluate the way the project was managed. The method used to do this is transferable to a wide variety of design and engineering projects and is of value to academics and practitioners alike.

Keywords Construction management, Project management, Systems design, Case studies, United Kingdom

Paper type Case study

1. Introduction

This paper looks at the building of an innovative new footbridge across the river Tyne between Gateshead and Newcastle and uses an approach based on systems thinking to examine the workings of the construction project. This was a landmark project undertaken by Gateshead Metropolitan Borough Council (GMBC) with financial support from the Millennium Commission, an independent body established in 1993 to distribute Lottery money across the UK to projects marking the start of the third millennium. Since the bridge has been completed it has won more than 20 prizes including the Royal Fine Art Commission Trust/British Sky Broadcasting Building of the Year Award 2002, the Structural Steel Design Award 2002, the RIBA Stirling Prize 2002 and the IStructE Supreme Award for Structural Engineering Excellence 2003.

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Unlike most accounts of projects, this study was carried out in real-time whilst the bridge was being built. The three main methods of gathering the data were a series of formal and informal interviews with representatives of GMBC and their main project partner Harbour and General (H&G), regular visits to the main construction site and the secondary site where the bridge was pre-fabricated and an extensive study of newspaper and magazine articles, Council minutes and memoranda and other relevant literature. The last of these has continued since the opening of the bridge.

2. Background to the project

After the Second World War, industry on both banks of the River Tyne between Newcastle and Gateshead declined and many riverside building began to decay. This deterioration continued until the 1980s when Newcastle City Council's (NCC) decision to build its new Crown Courts on the north bank of the river triggered a regeneration strategy for the whole of the Quayside area. This renovation was undertaken by the then Tyne and Wear Development Corporation (TWDC) and included leisure and tourist activities interspersed with high quality commercial buildings and houses. However, the south bank of the river, home mainly to disused warehousing and heavy industry, continued to degenerate.

In June 1995 GMBC joined with English Partnerships to commission a regeneration strategy for a 400-acre site along the south bank. Proposals were drawn up to convert the Baltic Flour Mill (a disused grain warehouse built in the early 1950s) into an international centre for contemporary and visual arts and to construct a brand new centre for musical education, performance and conferences (the Sage Gateshead). Not long afterwards GMBC decided to bid for Millennium Commission funding to provide half of the finance needed to build a new footbridge across the Tyne to link the area around the Baltic Flour Mill with Newcastle Quayside. GMBC realised that to qualify for funding the new bridge would have to be an exciting project that was visually stimulating as well as functional, so it instituted a competition to select the design to put forward in its bid.

The design competition was launched in July 1996. GMBC, in discussion with NCC, TWDC, the Port of Tyne Authority (PTA), the Environment Agency and the Ministry of Agriculture Fisheries and Food (MAFF), set the following design criteria:

- complement the six existing Tyne Gorge crossings;
- be a landmark worthy of its unique setting;
- not have any part of its supporting structure built on either quay;
- have an "air draught" of 25 metres;
- possess an opening mechanism to allow ships to pass;
- have a minimum width of passage through the bridge of 30 metres;
- cater for cyclists and pedestrians; and
- be capable of coping with up to 1.5 million crossings a year.

Expressions of interest from 150 parties resulted in 47 submissions. Six, short-listed by a panel representing GMBC, NCC, TWDC and PTA, were included in the submission to the Millennium Commission. A technical assessment of the six finalists was undertaken by the Engineering Department of GMBC. Pictures of the six short-listed designs were published in the press and distributed to local residents so that they could express their opinions. The winner was selected by an independent panel chaired by the President of the Institution of Civil Engineers. The panel took account of technical merit, cost, fit with the design criteria and the comments from local residents. The panel's unanimous decision was that Gifford and Partners and Chris Wilkinson Architects had submitted the best design. This design had attracted 45 per cent of public support.

The possibility of attracting Millennium Commission funding was the catalyst that had prompted the Council to "take on" the project, but GMBC was very aware that the Commission would only fund 50 per cent of the project. The final bid in October 1997 estimated the total cost of the project would be £19,500,000. This was a much higher figure than GMBC's outline bid and at the request of the Millennium Commission it was re-examined and revised downward to £18,579,000. A grant of £9,289,500 by the Commission was announced on 12 November 1997. Subsequently, after a full financial analysis, GMBC decided to take on the inflation risk of £1,683,500.

A project timetable (see Table I) was drawn up and it was announced that the bridge would be completed by September 2000.

As a condition of the grant, GMBC was required to submit a Detailed Appraisal Report setting out when and by whom the bridge would be built. In July 1997 GMBC placed an advertisement in the *European Journal* for partners. A total of 16 British and one German Company lodged bids. A local firm, H&G (now Volker Stevin), was chosen as the main partner but binding contracts were not signed until May 1999.

2.1 The winning design

The now famous winning design is shown in Figure 1. The bridge consists of two arches, one curved in plan to provide the deck and the other supporting the deck by means of 18 stressed steel suspension rods. The arches pivot around their common springing points on hinge assemblies supported by reinforced end supports situated on the riverbed approximately 5 metres from each of the quaysides. Six hydraulic rams (three housed in each end support) push or pull against steel paddles attached to the hinges rotating the deck and its supporting arch so that as the overhead arch swings downwards, the deck moves up. When they are level they offer headroom of 25 m to allow vessels to pass underneath. As Figure 2 shows, this opening and closing procedure evokes the action of an eye slowly blinking.

At night, a complex lighting system illuminates the bridge without causing light pollution. The arch has multi-coloured programmable floodlights, the deck has marker lighting and the ribs on the underside of the deck are lit with white light that reflects on the river below.

2.2 Planning permission

In September 1997 the process of obtaining the many consents, permissions and licenses needed for the project began. First, local planning permission from TWDC and GMBC was sought and granted. Next, consents or permission were sought from the Environment Agency, MAFF, PTA and NCC and finally, in early 1998, solicitors acting for the Council proceeded with the main planning application for the bridge. This did not go smoothly. The solicitors had no past experience in obtaining planning permission for such an undertaking and initially made a submission under the

Table I.
Project timetable as drawn up in 1997

Task	Duration	Start date	End date
Design works			
Finalise design of quay wall	22 weeks	February 1998	July 1998
Finalise design of ship protection measures	22 weeks	February 1998	July 1998
Complete design of bridge	30 weeks	February 1998	August 1998
Riverworks licence			
Port of Tyne approve Riverworks Licence	4 weeks	July 1998	August 1998
Construction works			
Demolition and quaywall	8 weeks	August 1998	September 1998
Main contract	100 weeks	September 1998	September 2000
Baltic Square	12 weeks	September 2000	November 2000
Open to public		December 2000	

Figure 1.
The Gateshead Millennium Bridge

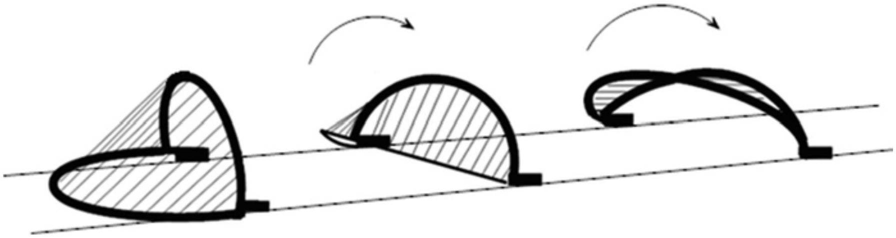


Figure 2.
Like the blinking of an eye

Highways Act 1980. Unfortunately, this had to be abandoned and replaced by one made under the Coast Protection Act 1949. This was unsuccessful so it was decided to seek an Order under the 1992 Transport and Works Act (TWA) from the Secretary of State. The work needed to do this was completed by May 1998 but it was then discovered that an application for an Order under the TWA required a resolution from a full Council meeting. This resolution had not been sought so a full Council meeting had to be called. Because this required 30 days clear notice it did not take place until 15 June 1998. Three days later a preliminary submission for the Order was to be made. The Secretary of State then required a period of notice to be allowed for objections and a further full Council meeting to be held to confirm the Order. The Council met on 20th July 1998 and immediately afterwards confirmed its request for an Order under the TWA.

The Government received 11 objections to the bridge; seven were withdrawn when the Council agreed to open the bridge 250 times a year at their own expense and to dredge out a new deepwater berth downstream of the proposed bridge on the Newcastle side of the river. One of the four objections that were not withdrawn concerned noise pollution that would be caused by equipment such as vibrating pile drivers and hammers while the bridge was under construction. This objection was perceived to be serious and there was a very real fear that a public inquiry would be called. It was believed that this, or any other further cause of delay, would dramatically increase the cost of the bridge. It was also feared that as the millennium drew nearer the demand for supplies and equipment created by other millennium projects that were underway would cause supply problems. The Council made a written representation to Secretary of State, setting out the arguments why this and the other objections should be over-ruled. Aware that the delay being experienced in obtaining planning permission was jeopardising the project, the Director of Engineering GMBC made repeated requests to the Secretary of State for a favourable decision over the TWA Order. He made numerous trips to London to lobby MPs. The Leader of GMBC, Councillor George Gill, also championed the project, assisting the Director of Engineering in his efforts to influence Parliament and ensuring that Gateshead residents were kept aware of the project through newsletters and articles in the local press.

On 9 April 1999 the TWA Order was finally approved but the difficulties in obtaining planning permission had delayed the project by nearly a year. GMBC announced a new target completion date of April 2001.

3. The chronological course of the project

Table II presents a chronological history of the project. This paper will expand upon just one or two aspects that are typical of the sorts of difficulties that need to be overcome during a large, complex and high profile project such as this. One of these, the vessel collision protection system, has only now reached a conclusion nearly a decade after the bridge was opened.

In January 1998 GMBC commenced an Archaeological Assessment of the area. During this assessment it was realised access to the proposed site (south side) was restricted by a Printing Works. GMBC therefore bought the site and re-located the business further up-river, thus fixing the location for the bridge between the Baltic Flour Mill and the proposed new music centre. This area had the best bank height and

1998
January - GMBC commenced Archaeological Assessment of site
14 January - GMBC officially awarded preferred contractor status to H&G but no binding contracts signed until May 1999. H&G appointed sub-contractors but again no binding contracts signed until May 1999
12 February - Site compound on south side established. Riverbed investigation commenced – numerous large rocks, poor bedrock and some mine workings revealed
18 February - Noise Level Measurements undertaken
March - First test bores drilled
April - Wind Tunnel Tests performed by the Boundary Layer Wind Tunnel Laboratory at the University of Western Ontario – minor changes to design required
June - Row between GMBC and NCC over name of bridge erupted. New requirements issued by PTA
15 June - Condition Survey of HMS Calliope undertaken
July - River wall on south side found to be in bad state and of low height. Environment Agency would not allow redevelopment until wall lifted to same height as north bank and land in-filled - wall demolished and rebuilt
29 July - Demolition of Printing Works commenced

1999
January - Problem of dumping of riverbed waste arose and electricity supply problems began.
February - GMBC realised that bridge would not be finished by 2000 as TWA Order had not been obtained. GMBC asked MC to agree change of date and also requested further funds – MC agreed date change but no further funds allowed
18 May -TWA Order came into force. Partnering contracts signed. Site compound on north side established. Drilling of riverbed commenced – unexpected number of large erratics found – a number of piles hit boulders causing piles to deflect – drilling delayed
June - A number of pile casings on north side of river hit disused railway line (presumably dumped in river when line running along north bank removed) – line pushed down into soft river bottom – divers hired to cut railway line out
13 August - Kvaerner Markham commenced manufacture (in Sheffield) of support hinge assemblies and electro-hydraulic actuation and control systems
16 August - Work on cofferdam for north caisson commenced
19 August - Work on cofferdam for south caisson and on placing of 16 channel markers commenced
August - Noise caused by hammering piles raised complaints from NCC – Environmental Health inspected site and ordered mobile sound absorbent hoardings and installation of noise and vibration metres
October - Cofferdams 60 per cent complete. Crane able to lift complete bridge became available - decision was made to fully assemble bridge at a yard 6 miles downstream in Wallsend and transport it up river in one piece. This change of plan was expected to take about the same amount of time and cost the same but involve less risk and avoid disruption to river traffic
18 October - Watson Steel commenced manufacture in Bolton of the 23 hollow box frames that made up the arch and deck
November - South cofferdam complete. Deepwater berth north side completed
7 December - First concrete pour in south caisson undertaken

2000
January - River wall down river from HMS Calliope started to collapse. Collapse blamed on vibrations arising from piling operation. H&G rebuilt wall
7 February - First concrete pour in north caisson undertaken
March - Fleet of lorries transported the 23 box sections to yard in Wallsend
3 April - Watson Steel commenced welding of 23 sections to form arch and deck
20 April - Vessel collision protection system completed
May - Gifford and Partners realised that extra stiffening plates would be required due to extra stress complexity on bridge during transportation (due to change of plan – see October 1999), extra internal stiffening added to box sections – conceptual 600 tonne structure grew to 850 tonnes

(*continued*)

Table II.
Chronological history of the project

June - Boom damaged
23 June - Foundation stone unveiled
August - Bridge arch lifted into vertical position at yard – bridge temporarily braced with spreader beam
13-27 September - Power packs installed on supports and cabled up ready for main power supply
24 October - Floating crane the Asian Hercules arrived at yard – entire lift, transportation and installation cycle to be completed in one working day, timing depended on shipping movements, weather and tide. Problem manoeuvring bridge round tight bend in river at St Anthony's in Walker (river 3 metres wider than crane at this point) appreciated, decision made for crane to carry bridge crossways
6 November - First attempt to lift bridge ready for transportation up river aborted due to gale force winds
8 November - Second attempt to lift bridge aborted due to high winds
9 November – Planned lift aborted - wind was too strong to attempt a lift
18 November - Asian Hercules attempted to lift the bridge but lift was aborted due to "foul weather"
19 November - Crane used one point lift to hoist bridge free of its temporary supports. Crane rotated bridge 90 in readiness for transport in sheerlegs" slings to main site
20 November - 7.30am crane transported bridge 6 miles up river. 10.30 am crane was on site - bridge was rotated by 90^{o} and placed in position but crane continued to bear weight of bridge
21 November - Crane continued to bear weight of bridge whilst final adjustments were made
22 November - Supporting cables released. Work on removing supporting strut (weighing 165 tonnes) commenced - floating crane removed main support strut
23 November - Floating crane departed
24 November - 11.00 pm - ten youths found sitting on bridge drinking
November/December - Bridge welded into place and attached to bearing plates. Members of the public made further attempts to reach bridge. GMBC decided to place security guard on the bridge every night
December - Installation of final metalwork undertaken
19 December - Lighting installation started

2001

January - Installation of six hydraulic rams and electric motors undertaken. Installation of handrails and seats started
26 January - Repairs to suspension rods undertaken – all paintwork "touched up" and cleaned
12 February to 20 April – A skin of concrete slabs was placed on end supports
March - Cabling for power supply to north end support fed though top arch and sub-station on south shore completed
12 March to 17 April - Glass panels fitted to end supports to form two large weatherproof pavilions
3 April - Testing and commissioning commenced
17 April to 12 May - Bridge surfaced
May - Small area (A 4 size) of bridge painted with experimental "smart paint" that would monitor vibrations throughout the lifetime of the structure. Control panel fitted to south pavilion. CCTV system fitted
June - All outer handrails finally welded into place. Computer software controlling rams fine tuned
28 June - First official full opening of bridge undertaken. Councillor Gill and a representative of the MC together with two local school children pushed the relevant button on the control panel that caused the bridge to tilt fully open. Two of the tallest yachts on the Tyne plus a number of cruisers carrying 200 Gateshead school children sailed under the open bridge
12 September - Fitting of central handrails and seats completed
14 September - The first public switch on of computerised lighting system undertaken
17 September - Official opening - 1pm party of dignitaries representing GMBC and other main partners together with representatives from the MC crossed the bridge from Gateshead to Newcastle and returned. Bridge then tilted open and closed to signal opening to public. 2.20 pedestrians and cyclists crossed over the Tyne using the bridge for the first time

2002

7 May - Queen officially opened bridge during visit to Newcastle (part of her Golden Jubilee tour).

Table II.

allowed the bridge to land on the Newcastle side directly opposite the Commemorative Steps that come down to the Quayside. However, it meant the landing on the Gateshead side would be immediately adjacent to the Royal Navy Reserve Training Centre, HMS Calliope. The owners of this expressed concern over the possibility of damage to their property during the demolition of the Printing Works and the bridge construction. The upshot of this was that GMBC agreed to fund an independent firm of chartered surveyors to carry out a condition survey of their building.

In June 1998 a row between GMBC and NCC over the name of bridge erupted. NCC objected to the original name, Baltic Millennium Bridge, and wanted to choose its name but GMBC responded by renaming the bridge "Gateshead Millennium Bridge". The row resulted in an ongoing feud between the two Councils. NCC would not allow the bridge supports on north side of river to be any higher than the north bank. Due to the fixed position of the bridge this meant the height of the supports would only be one metre above the highest recorded tide level. The architects amended the design to include extra precautions to protect mechanisms against risk of flood.

The PTA also introduced new requirements for the bridge during the course of the project. These included:

- Litter left on the bridge must be channelled to the side when the bridge opens so that it will not fall onto the ships passing underneath.
- The option of running the opening mechanism at a slower speed by only using two rams on each side instead of three.
- A system of stand-by generators for use in the case of power failure to be added, together with a hand winch system as a final backup measure
- Further measures including a closed-circuit television (CCTV) system and additional barriers to be implemented to ensure no one can be left on the bridge when it is opened.

One of the 11 consents, permissions and licenses that had to be obtained for the project was a River Works Licence from the PTA. When this was sought the Harbourmaster said he would not object to the license providing some form of vessel collision protection system was incorporated into the design for the bridge. As a result, GMBC commissioned a full vessel collision risk assessment. This concluded that the risk of major damage posed by existing river traffic to the bridge was "acceptably low". Indeed, it was judged to be less than the American Association of State Highway and Transportation Officials (AASHTO) threshold of 0.001 for "Regular Bridges". However, despite these findings, the PTA insisted that the design must incorporate some type of vessel collision protection system. The Council responded by commissioning two alternative plans. One was for an innovative under-water "soft" marker arrangement with submerged concrete piles to contain any ship impact (see Gifford and Partners, 1997) and the other was for a more conventional vessel collision protection system involving floating pontoons held by drag anchors. Neither of these designs proved acceptable to the PTA. The Harbourmaster announced that he required the protection system to be: proven; clearly visible at all states of the tide; and able to withstand a collision with two 4,000 dwt vessels travelling in succession, each at a speed of 4 knots. He favoured a design that consisted of two parallel rows of fixed piles placed at 20 metre centres to incorporate splayed back extensions at each end supporting floating booms. The PTA also insisted that floating booms be suspended between all the piles. GMBC then became concerned that the vessel collision protection system the PTA required would pose a real danger to small vessels, especially from the piles because they would be too strong to deform on impact. Despite these concerns the Council finally agreed that 16 highly visible fixed warning markers linked by booms would be built at a cost of £1.3 million (see Figure 3.).

When the piles and booms were in place it soon became obvious that the booms interrupted water flow on the north side of the river. As Figure 4 shows, this caused debris to collect behind them and between the end support and the quay wall.

Senior members of the project team suspected that the Harbourmaster was "trying to make a stand". They hoped that when the public became aware of the unsightly vessel collision protection system there would be an outcry for them to be removed. With this in mind, in January 1999 the Council published computer-generated images of how the bridge would look with the incorporation of the vessel collision protection system. This was taken up in a half-hearted manner by the local press (see, for example: Young, 1999; Richards, 1999) but no objections from the public were received.

There is no doubt that the bridge designers and the architects believed that the vessel collision protection system detracted greatly from the aesthetic design of the bridge. Indeed, a spokesman for the architects, Wilkinson Eyre, stated that "from an aesthetic point of view they undermine the finesse of the bridge" (Kendall, 2000) and the designers indicated they would have come up with a different design had they known at the start of the project that a vessel collision protections system was required (Carroll, 2000). The GMBC's Director of Engineering voiced his disapproval very clearly:

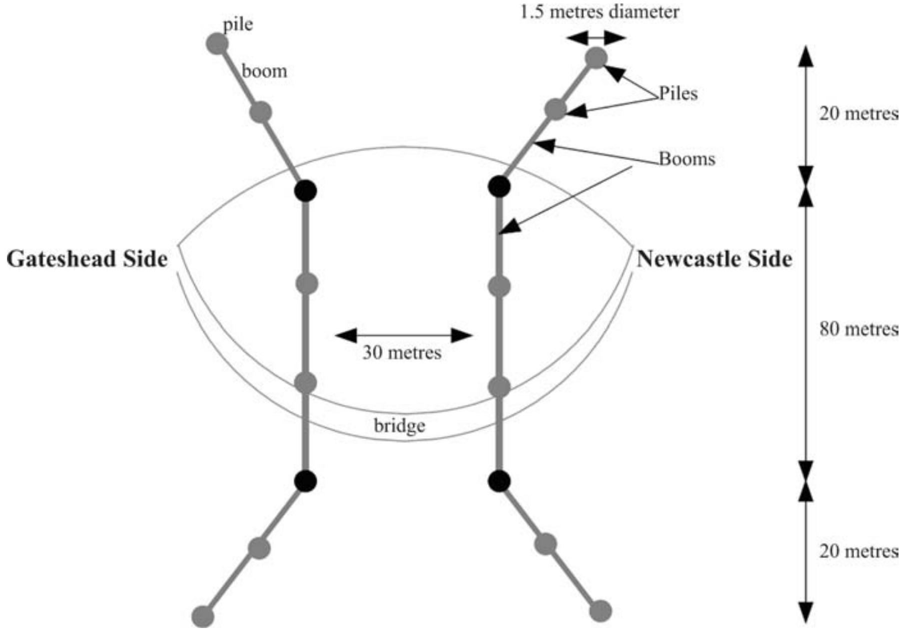


Figure 3.
The final arrangement of the vessel collision protection system

Figure 4.
Problems with the vessel collision protection system

> [. . .] they're horrendous and spoil the appearance totally. I think they ruin the appearance of the bridge and cost us a lot of money for no good reason. The likelihood of a ship hitting the bridge is very small because of the number of ships that come up the river that far. The Harbourmaster could have made certain they didn't come up in poor weather or could have used tugs to make sure that a risk that was minimal could be minimised even further [. . .] (Green, 2000).

Between February and June 2000 when it finally became evident to the public that the piles in the river were a permanent feature rather than part of the construction work, a number of articles and letters appeared in the press complaining about them. One, for example, asked why there were no markers around the Millennium Bridge on the Thames (*The Journal*, 2000a) and another (*The Journal*, 2000b) pointed out that the first class stamp commemorating the bridge did not have the markers. All the articles intimated that the PTA had made a mistake and was not admitting it had got it wrong. One article suggested that smaller boats could hit the piles and sink. Indeed, the Tyne Boat Race organised by Newcastle University had to be moved down river to avoid this perceived risk (Kendall, 2000). The *Financial Times* (Tighe, 2000) described the markers as looking like massive oil drums linked by tubing and christened them the "Harbourmaster's piles" whilst *The Independent* (Herbert, 2000) suggested that the "curse on millennium projects" had struck the bridge and stated:

> Gateshead Council has forwarded several proposals for more aesthetic navigational markers to the harbourmaster [name provided] during two years of negotiations, but to no avail [. . .]

More recently, the *Pevsner Architectural Guide* to Newcastle and Gateshead (McCombie, 2009, p. 96) judged the bridge to be "an elegant structure but somewhat disfigured by the piles sunk alongside into the river . . . "

However, despite the passage of the years the story was not over. The piles had been driven into sand to allow them to deform if a heavy vessel hit them so the opportunity to remove them easily without causing a major disruption on the river still existed. In 2009, with a different Harbourmaster in place, Gateshead Council (formerly GMBC) and Gifford and Partners decided to review the original vessel collision risk assessment. After taking account of current and predicted shipping movements on the Tyne they concluded that in view of the benefits removal would bring in terms of enhancing the setting of the bridge, the vessel collision protection system should go. A cost benefit analysis also showed an advantage, albeit a small one, in removing the system. Maintenance costs were calculated to be £662,000 over the design life of the bridge, whereas removal of the piles and booms would cost £650,000. At a meeting on 10th December 2009 Council members agreed that the Council should apply for an order under the Transport and Works Act 1992 for the removal of the bollards and booms. In September 2010 Gateshead Council advertised for a contractor to undertake work that would include:

> [. . .] the removal of the fenders and pile collars; the extraction of the steel piles and the installation of navigational markings to the bridge superstructure (Contract GCC-QTLE-89RGZT).

4. The management of the project – structure and processes

Historically, engineering projects undertaken by GMBC were put out to tender, the contract being awarded to the lowest bidder, but for the bridge project the Council decided to take a partnering approach. A partnering contract based on the Institution of Civil Engineers New Engineering Contract (ICE NEC) was advertised in the European Journal and the final choice of partner was H&G of Gateshead. GMBC believed that partnering with a local firm would be less risky, reasoning, according to the GMBC's Assistant Director of Engineering Services, that if problems arose "immediate decisions could be made at the highest level without having to go to another part of the United Kingdom to attend meetings, etc."

In consultation with GMBC, H&G selected over a dozen sub-contractors who would be responsible for constructing the bridge. The main sub-contractors are shown in Figure 5. In turn, the sub-contractors entered into relationships with over 101 suppliers. Two sub-contractors, Watson Steel and Kvaerner Markham entered into specialist sub-contractor partnerships also based on the ICE NEC. The majority of the other contracts were for a fixed price.

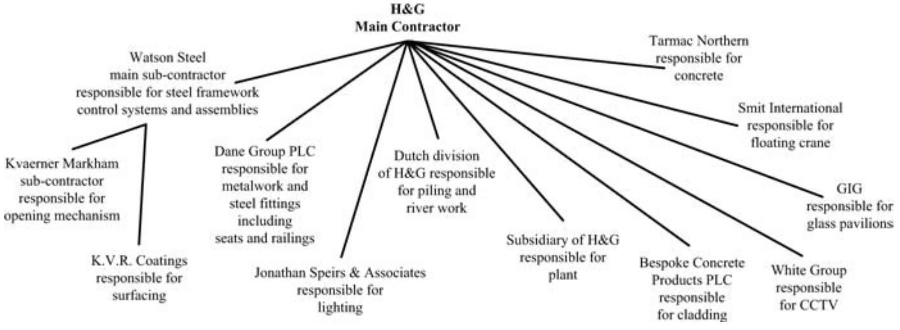


Figure 5.
Main contractor and sub-contractors for the Millennium Bridge

GMBC agreed that all project decisions would be taken by a team of four consisting of a representative from the main contractor (H&G), the bridge architects (Wilkinson Eyre), the consulting engineers (Gifford and Partners), and a member of the Council. Figure 6 shows the decision-making arrangement and Figure 7 shows the project organisation chart. The project had a “four headed” Project Director and a “four headed” Site Project Manager. In each case at least a 3:1 majority (of the “four heads”) was required before action was agreed. The Project Director was the main decision-maker. The “four heads” met on a monthly basis and had the final say on all decisions. Day-to-day decisions were taken on site by the “four headed” Site Project Manager. The “four heads” of the Site Project Manager met daily. The Project Director and the Site Project Manager (the “eight heads”) also met once a month. However, meetings could also be called at almost instant notice. It is interesting to note that interviewees claimed that throughout the 122 weeks of construction there was only one

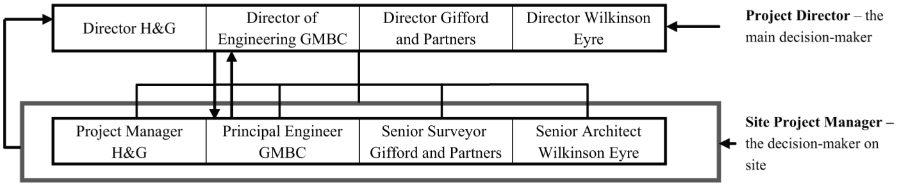


Figure 6.
The main decision-makers

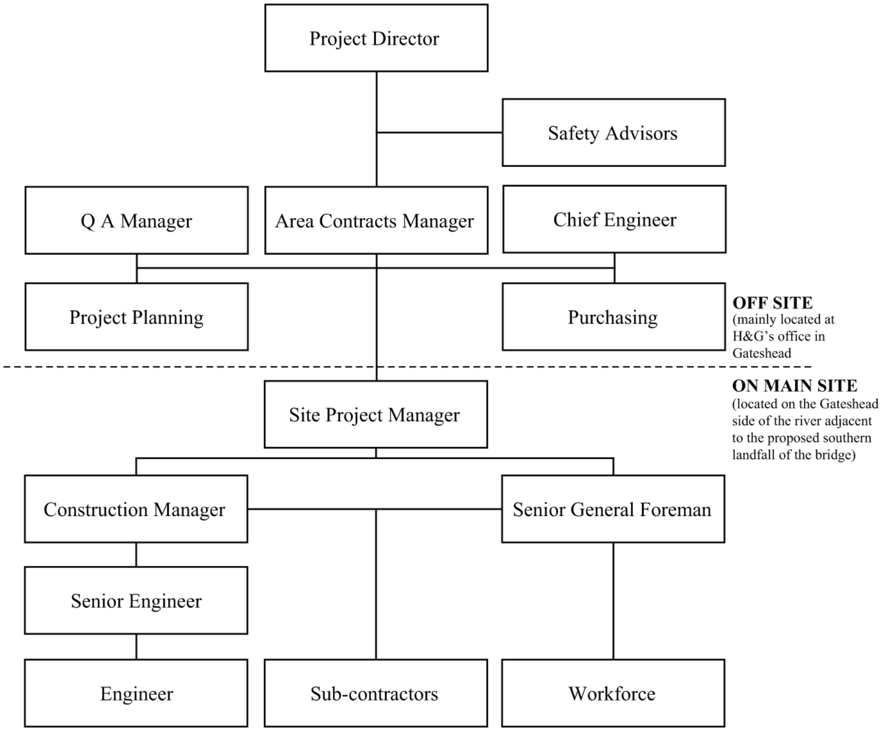


Figure 7.
Millennium Bridge organisation chart

acknowledged disagreement between the partners and even this dispute was quickly resolved with no ill feeling.

A number of computer software packages were used to help plan and manage the project, the main ones being LUSAS bridge analysis software and Pertmaster Professional Project Management Software. The former was used to plan and model the construction sequence and the opening and closing sequence. A total of 347 elements were modelled. The software allowed detailed analysis of buckling forces and displacement, wind loading and temperature effects and allowed the suspension rods to be tested for replacement or severance. It is interesting to note that all engineering drawings were not only calculated by computer but were also checked by hand, and lasers and (as an additional safety measure) the Global Positioning Satellite system were used for setting out points and for calculating angles. A Quantity Surveyor remained permanently on the main site.

Pertmaster Professional was used as a project management and risk analysis software tool. It used Monte Carlo simulations to analyse risks and allowed the Senior Engineer to see the potential effect on project costs, resources and expected finish date of any "what if" adjustments. Bar and Gantt charts were used to display progress and any tasks that had started late or were out of sequence were highlighted. The software also allowed the Senior Engineer to monitor time span and completeness of tasks by the use of precedence networks showing "leads and lags". Spending was monitored daily using both Pertmaster and Microsoft Excel spreadsheets.

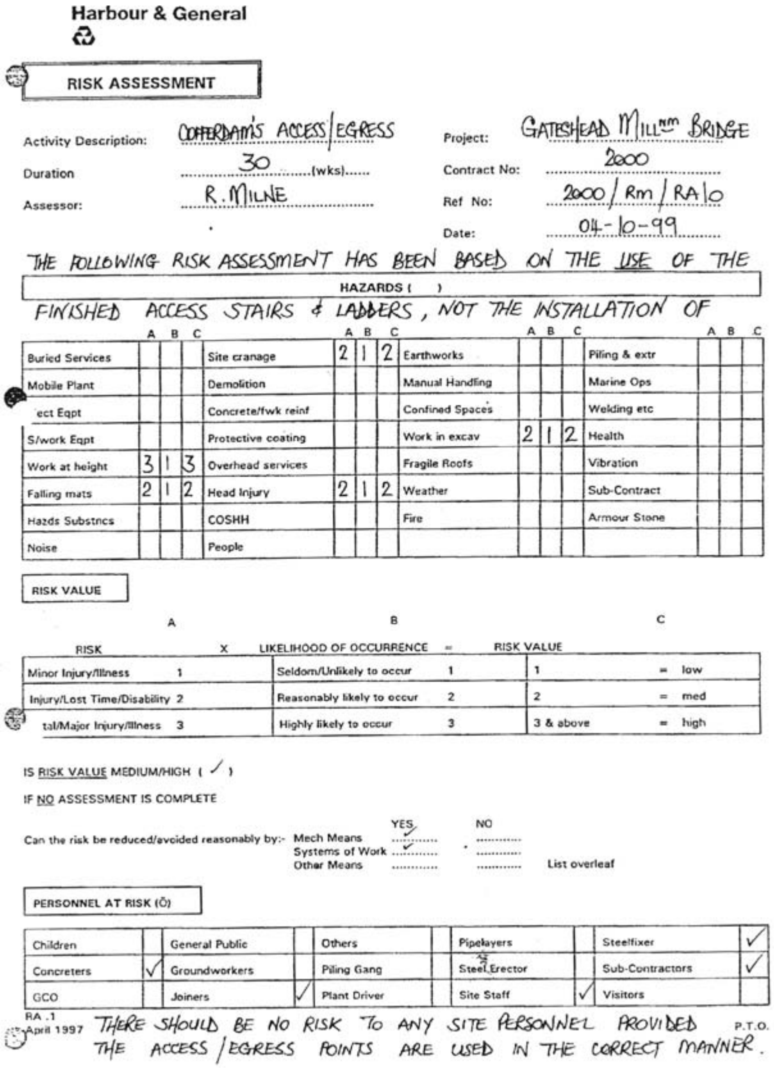
Project risks were also dealt with by the use of Method Statements and Risk Assessments. The construction of the bridge was divided up into separate tasks such as: concrete plug to cofferdams; cofferdams – access and egress; installation of scour protection; construction of levelling layer to plug and so on. For each task a Method Statement was drawn up. This described the sequence of construction for the relevant task and covered such items as Control of Substances Hazardous to Health (COSHH), welfare facilities and training. Assessments of all identifiable risks relevant to the task were then undertaken. A value was awarded to each risk. This was calculated by multiplying the level of risk by the likelihood of occurrence, a risk with a value over 1 was identified as requiring measures to be taken to reduce the risk. Personnel at risk also had to be identified and if necessary provided with special training. Figure 8 illustrates a section of a Risk Assessment of the risks inherent in using temporary ladders to gain access to the coffer dams during their construction.

In drawing up Method Statements, risks were examined by starting at the centre and then working out to consider the environment. For example:

> [. . .] in considering the risk of sending in divers to remove an old railway track, first the risks associated with the divers and their equipment were considered, then the effect of the procedure on the riverbed was assessed, next the effect the procedure might have on navigation was examined, then the effect a dive might have on the shore was studied, and so on out into the environment [. . .] (notes from interview with Project Manager H&G conducted March 2000).

5. Project performance

During an interview that took place in June 1998 the Assistant Director of Engineering Services GMBC stated that the aim of the project was to build a safe, high quality bridge that was acceptable to the general public, and that the building



Harbour & General

RISK ASSESSMENT

Activity Description: COFFERDAM'S ACCESS/EGRESS
Duration 30 (wks)
Assessor: R. MILNE

Project: GATESHEAD MILLnm BRIDGE
Contract No: 2000
Ref No: 2000/Rm/RA1o
Date: 04-10-99

THE FOLLOWING RISK ASSESSMENT HAS BEEN BASED ON THE USE OF THE FINISHED ACCESS STAIRS & LADDERS, NOT THE INSTALLATION OF

HAZARDS ( )

	A	B	C		A	B	C		A	B	C		A	B	C
Buried Services				Site cranage	2	1	2	Earthworks				Piling & extr			
Mobile Plant				Demolition				Manual Handling				Marine Ops			
ect Eqpt				Concrete/fwk reinf				Confined Spaces				Welding etc			
S/work Eqpt				Protective coating				Work in excav	2	1	2	Health			
Work at height	3	1	3	Overhead services				Fragile Roofs				Vibration			
Falling mats	2	1	2	Head Injury	2	1	2	Weather				Sub-Contract			
Hazds Substncs				COSHH				Fire				Armour Stone			
Noise				People											

RISK VALUE

A		B		C	
RISK	X	LIKELIHOOD OF OCCURRENCE	=	RISK VALUE	
Minor Injury/Illness	1	Seldom/Unlikely to occur	1	1	= low
Injury/Lost Time/Disability	2	Reasonably likely to occur	2	2	= med
tal/Major Injury/Illness	3	Highly likely to occur	3	3 & above	= high

IS RISK VALUE MEDIUM/HIGH (✓)

IF NO ASSESSMENT IS COMPLETE

Can the risk be reduced/avoided reasonably by:-

	YES	NO
Mech Means	✓	
Systems of Work	✓	
Other Means		

List overleaf

PERSONNEL AT RISK (Ö)

Children		General Public		Others		Pipelayers		Steelfixer	✓
Concreters	✓	Groundworkers		Piling Gang		Steel Erector		Sub-Contractors	✓
GCO		Joiners	✓	Plant Driver		Site Staff	✓	Visitors	

RA .1
April 1997

THERE SHOULD BE NO RISK TO ANY SITE PERSONNEL PROVIDED THE ACCESS/EGRESS POINTS ARE USED IN THE CORRECT MANNER.

P.T.O.

Note: Reproduced with permission from VolkerStevin (formerly Harbour and General)

Figure 8.
A section of a Risk Assessment

work should be completed without causing any major accidents, to plan, to budget and on time. He added that the criteria by which the success of the project would be judged were:

- completed to quality;
- completed to budget; and
- completed on time.

However, by March 1999 when work on the bridge had still not started, the success criteria appeared to have been downgraded significantly. The Director of Engineering Services GMBC stated that there was now only one success criterion: that the bridge should be completed "at some point in time". By March 2000 with work underway the three original criteria had been reinstated but their order had been revised to:

- completed on time;
- completed to quality; and
- completed to budget.

Time to completion had become very important because the bridge had to be finished by 2001 to qualify for Millennium Commission funds.

Although the Council had originally announced that the bridge would be completed by September 2000 it was not finished until September 2001. Table III shows the delays to the main contract. As has already been explained, the start of the contract was delayed by 35 weeks, but in addition to that the contract itself took 22 weeks longer than its planned 100 weeks duration. There were a number of reasons for this additional 22-week delay. One example where delay is concerned was the Electricity Board's requirement that two electricity sub-stations be built, one on each side of the river, to supply power to the adjacent set of rams. NCC stated that there was no space for a sub-station on the Newcastle Quayside so GMBC made arrangements to site a sub-station in a multi-storey car park close to the Newcastle Quayside. This agreement was provisional on GMBC agreeing to pay the cost of two parking bays for the life of the bridge. However, it soon emerged that the parking bays were further away than originally agreed and would thus require a larger cable to be installed. This, in turn, would increase costs.

By October 1999 it became clear that the sub-station in the car park was not practical and the Council then explored the possibility of placing the sub-station under some steps in a private property close to the Quayside. This option was eliminated in January 2000 and the possibility of running power cables under the river was the next option to be put forward. By January 2001 this plan had also been dismissed because it was not economically viable. Eventually a larger sub-station was built on the Gateshead side of the river immediately adjacent to the bridge. The power cables for the Newcastle side had to be run through the top arch of the bridge, as it was not possible to run them through the deck. Additional holes had to be drilled within the arch to take the cable thus adding to the cost of the bridge and causing further delays. Furthermore, the bridge was already in place at this stage, thus making the work more dangerous. The overall delay to the contract caused by these problems was over four weeks. Another example of delay was the late installation of the seats and handrails, these were only completed a week before the

Main contract – scheduled to run for 100 weeks	Date	Delay	Total delay
Originally due to start on:	15/09/1998		
Actually started on:	18/05/1999	35 weeks	
Due to complete on:	17/04/2001		
Actually completed on:	17/09/2001	22 weeks	57 weeks

Table III. Main contract – weeks delay bridge's official opening. However, the sub-contractor responsible bore the cost of the delay.

Even before construction work had started a number of difficulties had resulted in the cost of the bridge rising significantly to the point where the budgeted contingency money was all but committed. GMBC's Engineering Department were finding it increasingly difficult to convince Councillors that the target cost of the bridge was realistic whilst at the same time GMBC's Finance Department was finding it difficult to believe that the contingency figure could reduce so dramatically at this stage in project's life cycle. The consequence was disputes between the two departments.

Figure 9 shows that this total project cost was exceeded by nearly £3,000,000. (The "Published Total Cost" column shows how the total cost of the bridge continued to change.) Although numerous articles have stated that the total cost of the bridge amounted to £22 million (see, for example, *Evening Chronicle*, 2000), the "not revealed" unbudgeted costs suggest that this figure was exceeded. Indeed, in an article in the *Newcastle Journal* published in January 2001 the bridge was described as costing £23 million (Smith, 2001) and during informal conversations with key personnel from H&G it was intimated that the cost of the bridge "significantly" exceeded £22 million. Whatever the truth, there is no doubt that the cost of the bridge would have been considerably higher if the majority of the sub-contracts had not been "fixed cost".

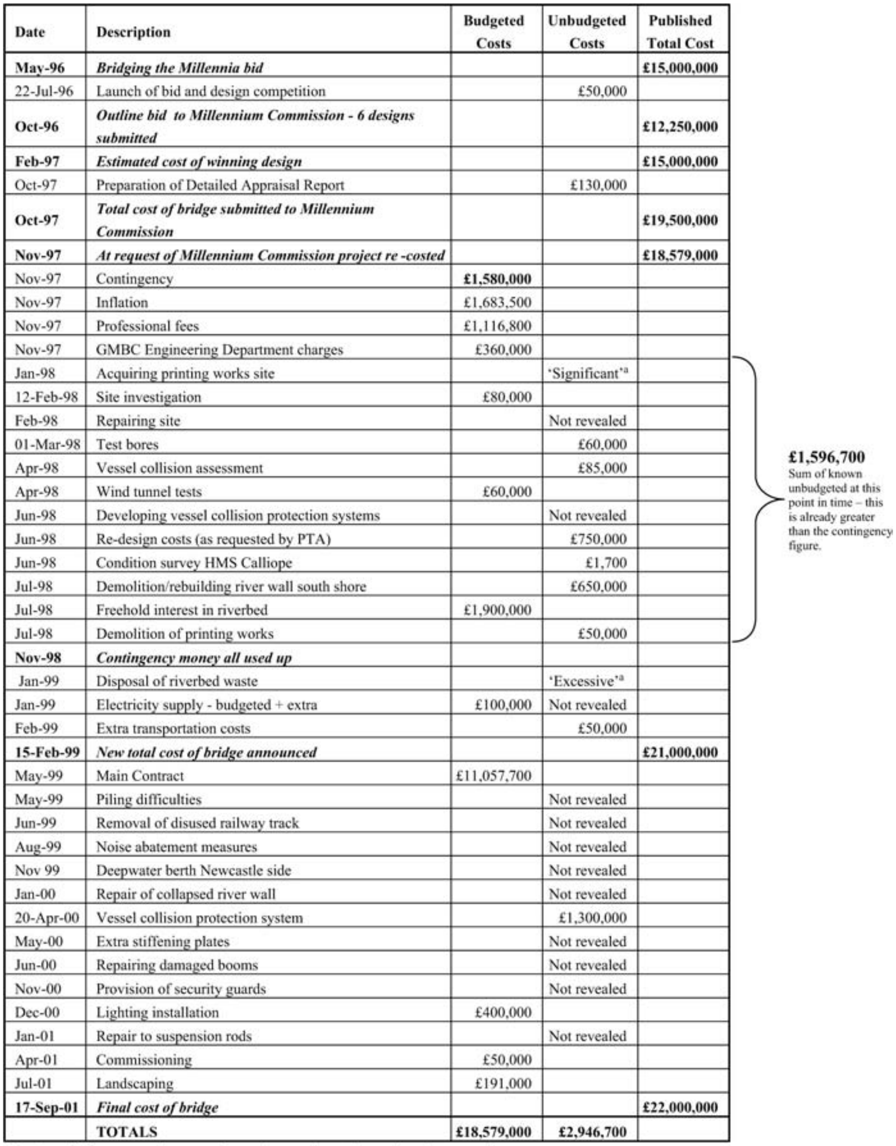
As Figure 9 shows, there were a number of reasons for the cost increases. One of them was related to a potential pollution problem. It was intended that the 5,000 tonnes of silt that would need to dredged from the riverbed before any piling work could commence would be dumped at sea. However, a licence from the Environment Agency was needed before dumping could begin and the Environment Agency requested tests on the riverbed waste before granting the licence. These tests revealed that the silt contained a high concentration of mercury and other heavy metals so at the last minute, a switch had to be made from sea dumping to offshore landfill. This increased the cost of the project considerably because the removal of the silt now involved dredging the waste using a long-reach excavator on a pontoon, storing the silt in hopper barges, and then transporting the silt to a number of makeshift lagoons that had to be built in haste at Spillers quay near the main site so that the waste could be left to dry before being removed to a landfill site.

On numerous occasions GMBC attempted to obtain further funds from the Millennium Commission but on every occasion the request for further funding was refused. However, the difference between the total cost of the bridge and the Millennium Commission's contribution was not borne by GMBC. It was made up from contributions from the Government's Single Regeneration Budget, the European Community's Regional Development Fund, English Partnerships and the private sector.

6. Evaluating the Gateshead Millennium Bridge project

In June 2001, in accordance with its standard procedure, H&G itself undertook a project post implementation review. Project data was sent back to the original estimators so that they could judge the accuracy of their original estimates. The following information was then filed for future use:

- cost changes since the original estimates;
- major changes to the plans;



Date	Description	Budgeted Costs	Unbudgeted Costs	Published Total Cost
May-96	***Bridging the Millennia bid***			**£15,000,000**
22-Jul-96	Launch of bid and design competition		£50,000	
Oct-96	***Outline bid to Millennium Commission - 6 designs submitted***			**£12,250,000**
Feb-97	***Estimated cost of winning design***			**£15,000,000**
Oct-97	Preparation of Detailed Appraisal Report		£130,000	
Oct-97	***Total cost of bridge submitted to Millennium Commission***			**£19,500,000**
Nov-97	***At request of Millennium Commission project re -costed***			**£18,579,000**
Nov-97	Contingency	**£1,580,000**		
Nov-97	Inflation	£1,683,500		
Nov-97	Professional fees	£1,116,800		
Nov-97	GMBC Engineering Department charges	£360,000		
Jan-98	Acquiring printing works site		'Significant'[a]	
12-Feb-98	Site investigation	£80,000		
Feb-98	Repairing site		Not revealed	
01-Mar-98	Test bores		£60,000	
Apr-98	Vessel collision assessment		£85,000	
Apr-98	Wind tunnel tests	£60,000		
Jun-98	Developing vessel collision protection systems		Not revealed	
Jun-98	Re-design costs (as requested by PTA)		£750,000	
Jun-98	Condition survey HMS Calliope		£1,700	
Jul-98	Demolition/rebuilding river wall south shore		£650,000	
Jul-98	Freehold interest in riverbed	£1,900,000		
Jul-98	Demolition of printing works		£50,000	
Nov-98	***Contingency money all used up***			
Jan-99	Disposal of riverbed waste		'Excessive'[a]	
Jan-99	Electricity supply - budgeted + extra	£100,000	Not revealed	
Feb-99	Extra transportation costs		£50,000	
15-Feb-99	***New total cost of bridge announced***			**£21,000,000**
May-99	Main Contract	£11,057,700		
May-99	Piling difficulties		Not revealed	
Jun-99	Removal of disused railway track		Not revealed	
Aug-99	Noise abatement measures		Not revealed	
Nov 99	Deepwater berth Newcastle side		Not revealed	
Jan-00	Repair of collapsed river wall		Not revealed	
20-Apr-00	Vessel collision protection system		£1,300,000	
May-00	Extra stiffening plates		Not revealed	
Jun-00	Repairing damaged booms		Not revealed	
Nov-00	Provision of security guards		Not revealed	
Dec-00	Lighting installation	£400,000		
Jan-01	Repair to suspension rods		Not revealed	
Apr-01	Commissioning	£50,000		
Jul-01	Landscaping	£191,000		
17-Sep-01	***Final cost of bridge***			**£22,000,000**
	TOTALS	**£18,579,000**	**£2,946,700**	

£1,596,700
Sum of known unbudgeted at this point in time – this is already greater than the contingency figure.

Note: [a]The words used to describe them by interviewees

Figure 9.
Project budget

- rates of work,
- sub-contractor problems;
- other problems identified; and
- risks not managed.

In this paper a systems approach based on the use of the project-specific version of the Formal System Model (FSM) is being used to evaluate the project. Further information on the development of this approach and its background can be found in White and Fortune (2009), Fortune and Peters (2001) and Fortune and Peters (2005).

The first stage in the application of this approach is to represent the project as a system. This has been done for the Gateshead Millennium Bridge project in Figure 10. Within the boundary are the components that make up the structure of the system and outside it, in the environment, are the components that influence the system and exert a degree of control over it but cannot be controlled by the system.

For the next stage of this evaluation the project-specific version of the Formal System Model (FSM), shown in Figure 11, has been used as a template. The FSM can be regarded as an "ideal-type". It represents a robust system that is capable of purposeful activity without failure so a project that mapped onto it exactly would itself be capable of purposeful activity without failure. The FSM comprises: a system (the Formal System); a wider system; and an environment in which the system operates. The wider system defines the system's purpose, sets objectives for it, monitors its performance and provides the resources that it needs in order to function. It also influences the decision takers within the system and monitors the performance of the system as a whole. The Formal System itself is made up of a decision-making subsystem, a performance-monitoring subsystem and a set of subsystems and elements, which undertake the project. The decision-making subsystem manages the system, deciding how the purposes of the system should be achieved and ensuring the resources that are needed are available. The performance monitoring subsystem reports to the decision-making subsystem because it is responsible for initiating any corrective actions that are needed.

The features of the FSM are:

- a decision-making subsystem;
- a performance-monitoring subsystem;
- a set of subsystems and elements which carry out the tasks of the system and thus effect its transformations by converting inputs into outputs;
- a degree of connectivity between the components;
- an environment with which the system interacts; and
- boundaries separating the system from its wider system and the wider system from the environment.

Figure 12 shows the bridge building system represented in the form of the project-specific version of the Formal System Model. A detailed comparison between Figure 11 and Figure 12 is undertaken in Table IV.

As Table IV shows, the project-specific version of the FSM successfully explains the outcome of the project and confirms that the project had very effective planning, monitoring, control and feedback systems, furthermore, clear lines of communication were established and there were sufficient resources. However, although many of the elements were in place, a number of important omissions and discrepancies exist. There was a clear failure to consider environmental influences or adequately take into account the viewpoints of those directly and indirectly affected by the project. It is suggested that these failures not only led to most of the problems experienced during

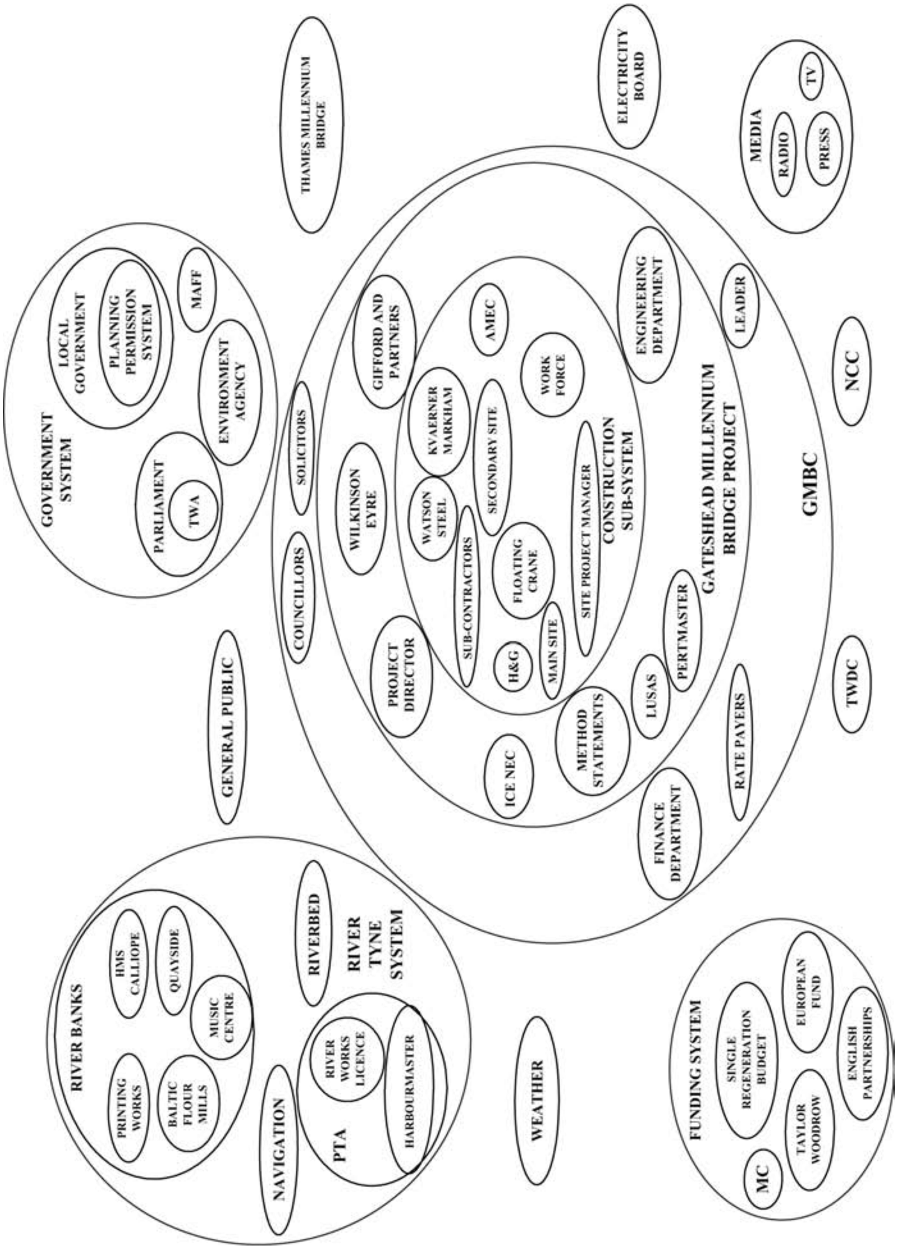


Figure 10.
A systems map of the Gateshead Millennium Bridge project management system

the project life cycle but caused the project to be late and over budget. For example, obtaining planning permission caused the project to be considerably delayed and the need to incorporate the unsightly vessel collision protection system increased its cost substantially.

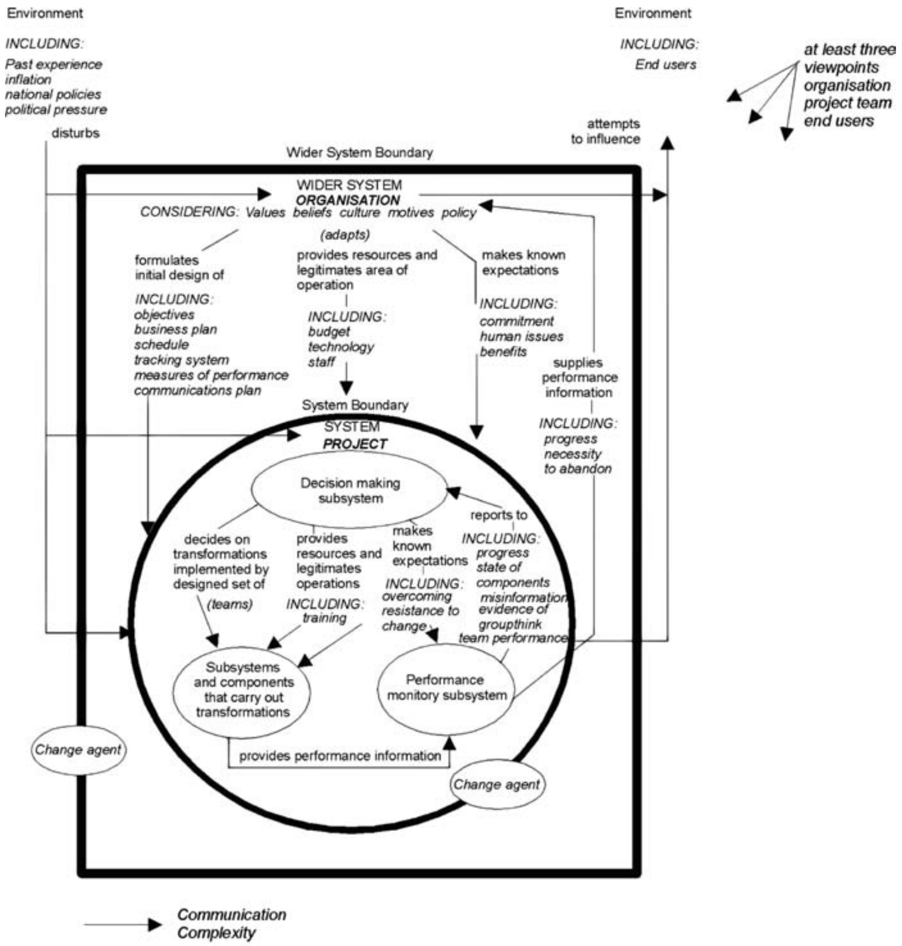


Figure 11.
Project-specific version of the Formal System Model

Source: White and Fortune (2009)

7. Conclusion

This paper has recounted the story of the building of the Gateshead Millennium Bridge. This innovative project involved the building of a spectacular curved bridge spanning the river Tyne between Newcastle and Gateshead. The bridge has a unique opening system that has been likened to the blinking of an eye.

The management of the project was based on the ICE NEC project management procedures and all main contractors signed partnering agreements. Most of the contracts were for a fixed price. The decision-making process was undertaken by two "four headed" decision-makers representing Gateshead Council, the designers, the engineers and the main contractor. This decision-making process proved to be very effective. However, the project was over budget and significantly late. Furthermore, the elegant design has been marred by the inclusion of a 16 piles emerging from the river beneath the bridge. The piles, part of a vessel collision protection system, were never

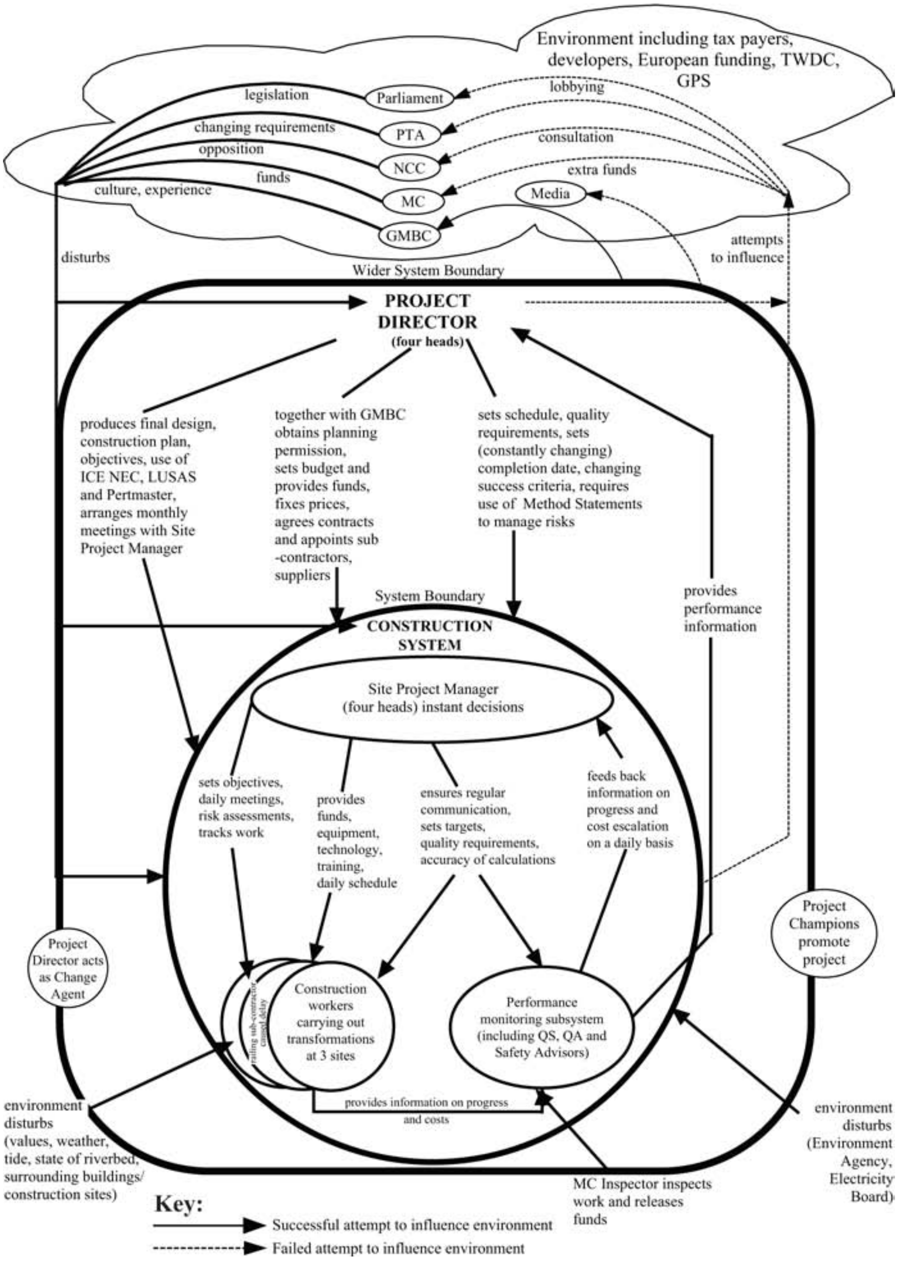


Figure 12.
Model of the Gateshead Millennium Bridge project management system

Table IV.
Discrepancies revealed by comparison with the developed FSM

Aspect of the developed FSM	Discrepancy or comments
Environment	The Wider System failed to consider most environmental influences adequately. For example the PTA requirements and the opposition to the bridge expressed by NCC were never envisaged. Furthermore, the Wider System failed to influence its environment, for example planning permission was obtained late and the media did not publicise the vessel collision protection system as extensively as the Wider System required. At the System level environmental influences were also not fully considered, for example the early inspection of the riverbed was not sufficient to reveal erratics and the disused railway track leading to extra expense and delays
Formulates initial design/decides on transformations	There were no discrepancies identified. Both the Wider System and the System set clear objectives and ensured that the subsystems carrying out the transformations understood what they had to do to construct the bridge
Provides resources	The Wider System and the System provided all the necessary resources to allow the project to progress at a satisfactory pace, however due to the failure to consider adequately the environment provision of an electricity supply for the bridge was delayed
Makes known expectations	Although the Wider System made clear its expectations, the success criteria changed during the project's life cycle and (due to environmental influences) a completion date was never firmly established at the start of the project. At the System level all expectations were made clear and a completion date for the construction work was set (100 weeks). Both the Wider System and the System established clear lines of communication between them (instigating a routine of weekly and monthly meetings)
Supplies performance information	No discrepancies – The System always provided adequate performance information to the Wider System
Decision-making subsystem	The "four headed" decision-making subsystem was extremely effective
Subsystems that carry out transformations	Most of the subsystems carried out the transformations as required, however the installation of the seats and railings was late, but the sub-contractor responsible bore the cost of the delay
Performance monitoring subsystem	At the System level there was a well-established monitoring system. The System was also monitored by the Millennium Commission inspector on a regular basis
Change agent	There was evidence that the Project Director was acting as a Change Agent, for example the change to the method of construction when a suitable crane became available, the change to the method of dumping waste when mercury was found in the riverbed or the installation of the "smart" paint. There was also clear evidence of two Project Champions promoting the project
Viewpoints	The viewpoints of those directly and indirectly affected by the project (in particular the proposed users of the bridge) were not adequately considered. Although consultation exercises took place, these came too late in the project's life cycle to be of real value

part of the original design but were added late in the project at the insistence of the PTA's Harbourmaster.

The analysis of the project indicated that the problems outlined above were caused by unforeseen environmental influences and the failure to appreciate the viewpoints of those directly and indirectly affected by the project. No two projects of this type and scale are ever alike but it is suggested that the lessons learned from investigating this project in real time can provide a valuable insight into understanding the challenges faced by similar projects.

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About the authors

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Professor Joyce Fortune has substantial experience in the development and use of systems approaches and in the gathering and analysis of case study data. Her particular expertise lies in the use of systems thinking to investigate and learn from failures and she has authored three books on systems failures. Her most recent papers have covered a wide range of topics including healthcare innovation, risk in project management, the design of crime and disorder reduction partnerships, emergence and systems approaches to failure. Joyce Fortune is the corresponding author and can be contacted at: j.fortune@open.ac.uk