Chapter 7
The Selection of a Bridge

7.1 Introduction

This chapter illustrates the use of the AHP for selecting the most appropriate bridge design in two different applications. The one recommended in the second application coincides with the decision that was actually made, demonstrating that the exclusion of an important, but hard to perceive actor, can alter the final decision. In this example we learn that decision making is not simply including multiple criteria in the decision, but more importantly the diverse people or groups who influence the outcome because of their own purposes.

By the close of the 1990s, the Golden Triangle Area in the City of Pittsburgh will once again be under construction to improve the flow of traffic into, out of, and through the city. The Mon Warf will be reconstructed, and the Fort Pitt Bridge will undergo rehabilitation. The Commonwealth Bridge Project is an effort by federal, state and local agencies to construct an alternative route across the Monongahela River to alleviate traffic congestion between the central business district of downtown Pittsburgh and Pittsburgh International Airport (Fig. 7.1). A new bridge, and a high occupancy vehicle (HOV) busway will be built to the Wabash Tunnel [3]. The bridge will consist of three HOV lanes and a lane for pedestrian traffic. The Port Authority and PennDOT want to begin construction by 1997, so that the new bridge will be open for use when the Fort Pitt Bridge is closed for rehabilitation. The cost of the entire busway project is estimated at $300 million, and estimates for the new bridge range from $30 to $40 million.

At the time of the writing of the two reports[1] on which this chapter is based, the bridge type had not been decided, although the second paper (a follow up on the first) did point to the bridge type that was chosen a few weeks later. The difference between the two approaches is the shift in emphasis among the stakeholders from

[1] See acknowledgments in the Preface.

T. L. Saaty and L. G. Vargas, *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*, International Series in Operations Research & Management Science 175,
DOI: 10.1007/978-1-4614-3597-6_7,

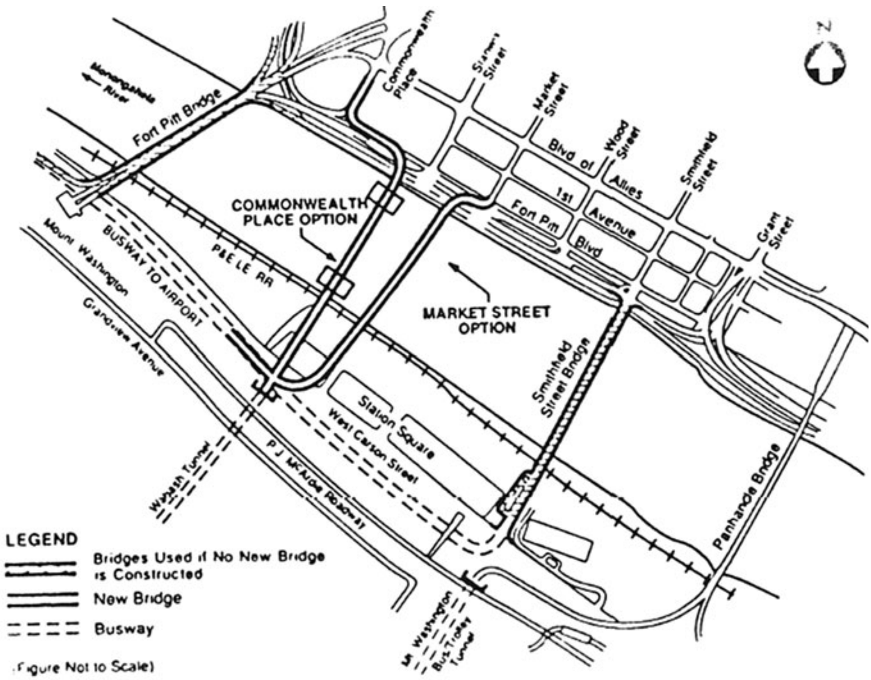

Fig. 7.1 Proposed commonwealth bridge location

the Public to the Coast Guard because of concern with safety and with the economic impact that the bridge would have on the area.

The bridge types considered by The Port Authority of Allegheny County (PAT) were: a Cable-stayed bridge, a Truss bridge, and a Tied-arch bridge.

7.2 Three Alternative Bridge Types

7.2.1 Cable-Stayed Bridges

Although the original concept of cable-stays dates back to Egyptian sailing ships, on which inclined ropes hanging from a mast were used to support a beam [1], it was not until the nineteenth century that the first cable-stayed bridge, the Roeblings bridge, at Niagara Falls New York, was constructed [4]. Built in 1855, it spanned 807 ft across a river gorge (Fig. 7.2).

Despite the fulfillment of this engineering feat, modern cable-stayed bridges were not considered feasible until shortly after World War II, when German engineers pioneered their development. The main hurdles were technology-based; the limitation of high strength materials, structural analysis and construction methods [2].

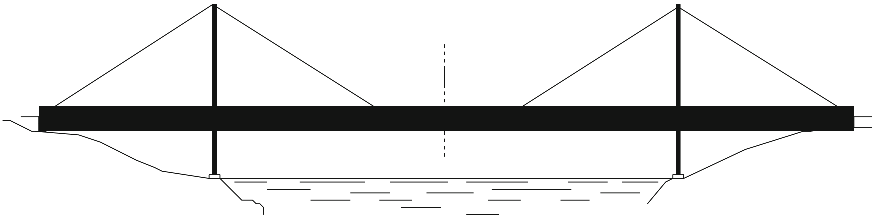

Fig. 7.2 The cable-stayed bridge

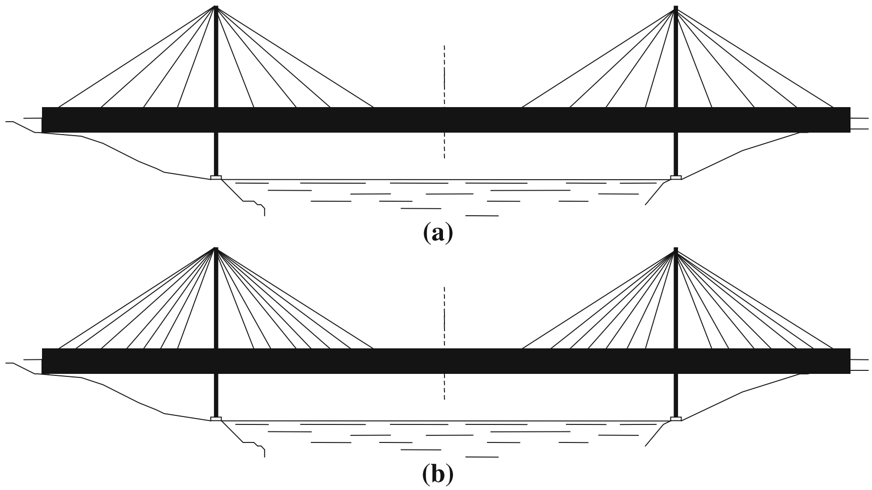

Fig. 7.3 **a** Cable-stay bridge with several cables. **b** Cable-stay bridge with cable separation reduced

To overcome design limitations, only cables with very high tensile strength are used. This minimizes beam deflection which becomes increasingly important as the span increases. Moreover, adding several stay cables allows the use of more slender deck beams (Fig. 7.3a) which require less flexural stiffness. By decreasing the cable spacing supports (Fig. 7.3b), local bending moments in the girders are also reduced.

The second presupposition for the success of cable-stayed bridge types is the simplification of the deck cross-section. Simple double-edge girders supporting transverse floor beams and top slabs provide a synergistic reinforcing action. As a result, the deck structure acts as a unit over intermediate supports.

Because of their aesthetically pleasing form, cable-stayed bridges can be found in almost all modern cities. The early cable-stayed bridges in North America were mostly constructed from steel because that was the traditional method at the time.

However, due to the high cost of material and labor the all-steel bridge has been losing competitiveness. To address this decline, modern designers have developed an orthotopic composite deck, a concrete deck slab supported by steel framing. Today, virtually all cable-stayed bridges contain an orthotopic deck.

The economic viability and aesthetic appeal of the cable-stayed bridge make it the most popular bridge type for spans ranging between 650 and 1650 ft. In North America there were 25 cable-stayed bridges constructed or under development in the 20 years between 1971 and 1993.

7.2.2 Truss Bridges

Truss bridges have been used in North America for decades. A truss may be described as a triangulated assembly of straight members. The design of the truss structure [2] allows applied loads to be resisted primarily by axial forces in its straight truss members; the truss proper is loaded only at the nodes or intersection of straight members. It is a very efficient and sturdy design.

Figure 7.4 shows five main types of trusses, each providing a slight variation in load distribution. Also included in this figure is a general illustration of the Warren Truss bridge. The two most common are the Pratt and the Warren designs. Bridge design is typically performed on a case-by-case basis considering variables such as traffic, durability, and dependability.

A truss bridge has two major structural advantages [2]: (a) The primary member forces are axial loaded; (b) the open web system permits the use of a greater overall depth than for an equivalent solid web girder. Both factors lead to economy in material and a reduced dead weight. Increased depth results in reduced deflections, and a more rigid structure. These advantages are achieved at increased fabrication and maintenance costs.

The conventional truss bridge is typically most economical for medium spans (500–1,500 ft). Traditionally it has been used for spans intermediate between the plate girder and the stiffened suspension bridge designs. Modern construction techniques have tended to increase the economical span of both steel and concrete girders. Thus the steel truss bridge is a direct competitor to the cable-stayed for intermediate spans. The relative lightness of a truss bridge is advantageous because it can be assembled part-by-part using lifting equipment of small capacity. Alternatively, the number of field connections may be supplanted by pre-assembly.

From an architectural perspective the truss bridge rarely possesses aesthetic beauty. This is partly due to the complexity of the intersection of its load bearing component. In bridges of moderate span, it appears best to provide a simple and regular structure. For this reason, the Warren truss usually looks better than other forms.

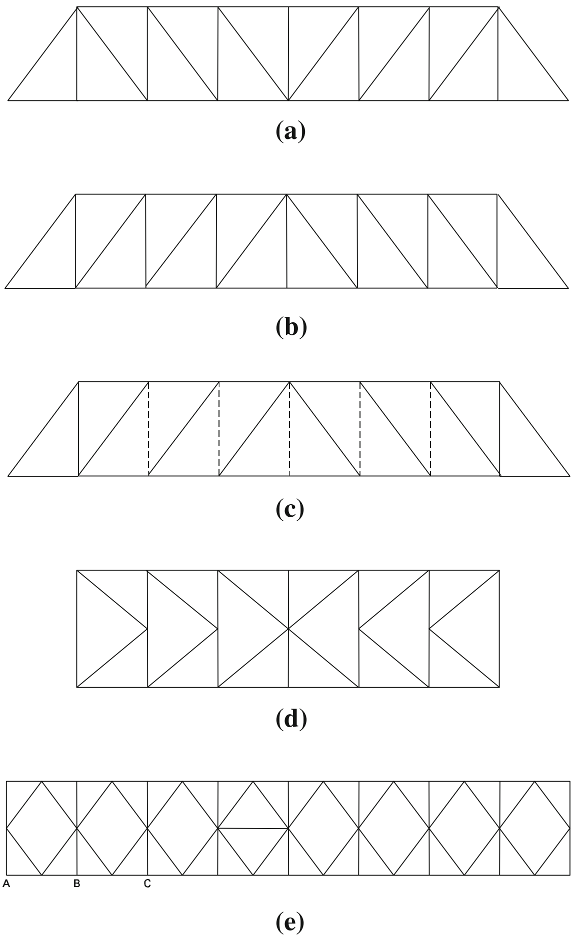

Fig. 7.4 Five of the most common truss type bridges **a** Pratt truss, **b** Howe truss, **c** Warren truss, **d** K-bracing system, **e** Diamond bracing system

7.2.3 Tied-Arch Bridges

The structural form of the arch has been used for its architectural beauty and outstanding strength for centuries. Because of the manner in which it distributes the applied load [2], with the aid of inward-acting horizontal components, the arch is capable of distributing loads both above and below its structure. In a tied arch design, the horizontal reactions to the arch rib are supplied by a tie at deck level. Figure 7.5 illustrates common tied-arch bridge types.

Some of the distinguishable features of the tied-arch are that it reduces bending moments in the superstructure and is fairly economical to construct relative to an equivalent straight, simple supported girder or truss [2].

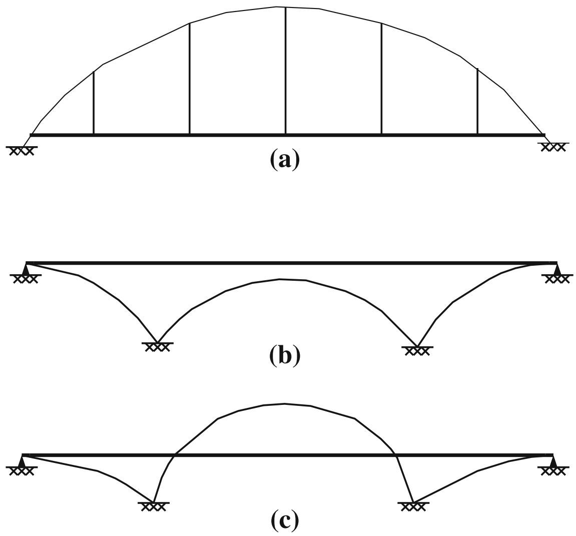

Fig. 7.5 Three common tied-arch bridge types

Aesthetically, the arch has been the most appealing of all bridge types. Its appearance is familiar and expressive. The curved shape is always pleasing to view.

The disadvantages of the tied-arch are probably its high relative fabrication and building costs. The conventional curved arch rib usually entails the highest expense. Building problems vary with structure type, with the least problematic structure being the cantilever-arch and the tied-arch possibly being the most difficult. The difficulty with the latter arises from the fact that the horizontal reactions are not available until the deck is completed.

7.3 The Decision Making Process

The most desirable bridge type would conceivably be the one which brings the most satisfaction to the greatest number of stakeholders. Using this goal, a hierarchy (see Fig. 7.6) was developed with major stakeholders at the second level, the driving criteria at the third level and the three alternative bridge types at the fourth level.

7.3.1 Stakeholders

Published reports have estimated the number of stakeholders involved in this project to be in the hundreds. The most important stakeholders were aggregated into seven broad groups. Commonality within the groups was maintained. The identifiable groups are: a federal agency, the commercial business district, the public, state

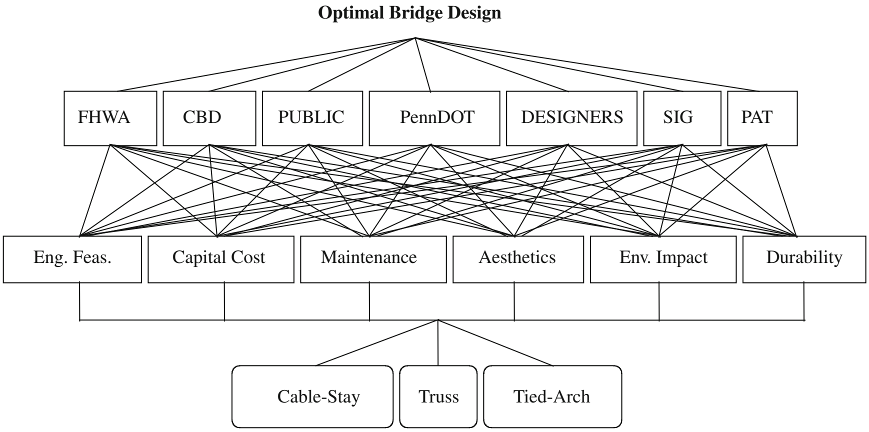

Fig. 7.6 Bridge selection hierarchy

agencies, the Port Authority Transit, the designers, and special interest groups such as concrete suppliers, steel manufacturers, environmentalists and others.

A Federal Agency (FHWA) represents an array of federal departments. They are a key financier of the project and will have dictates with respect to the engineering integrity of any bridge type.

The Commercial Business District (CBD) broadly represents the businesses in downtown Pittsburgh. However, with respect to bridge type it is suggested that Station Square is the dominant entity because of the interest in maintaining the historical appearance of the site.

The Public represents the population of Pittsburgh which would use the new service (and the bridge itself).

The Pennsylvania Department Of Transportation (PennDOT) represents the complex interest of the state. These interests are financial (as the state provides part of the capital), political, technical and environmental.

The Designers represent engineers, architects and planners and their representative professional organizations. It is recognized that designers provide crucial technical input and, as such, are strategically positioned to influence the decision making process.

The Port Authority Transit (PAT) is the ultimate project owner. They are responsible for all management issues from conception to construction, as well as subsequent maintenance. This makes them a premier stakeholder.

Special Interest Groups (SIG) is a very broad category with diverse and possibly conflicting interests. With regard to the bridge type the three most significant special interest groups are likely to be: concrete suppliers, steel manufacturers and environmentalists. The indigenous steel industry of Pittsburgh has declined in size and influence in recent times; however, the concrete industry remains strong. Environmentalists are active and sometimes vocal.

7.3.2 Criteria

In the level below the stakeholders are the criteria which drive the decision making process. The most important criteria are:

Engineering Feasibility (EF): The technical knowledge and experience of both the designers and contractors in regard to the bridge type.

Capital Cost (CC): Necessary funding.[2] Because the costs were committed, low costs are included in the overall benefits hierarchy as one the criteria.

Maintenance (MA): General cleaning, painting and inspection vary dramatically with bridge type.

Aesthetics (AE): Architectural attractiveness.

Environmental Impact (EI): The ecological and historical adjustments that must be compromised.

Durability (DU): The life of the bridge and the potential major repairs over and above routine maintenance.

7.4 Judgements and Decisions

To find the most desirable bridge design, the actors were compared to determine their relative influence (Table 7.1). The stakeholder ranking, as suggested by the authors in order of importance, is PAT (0.337), CBD (0.221), Federal Agency (0.136), State Agencies (0.136), Designers (0.085), Special Interests (0.056) and the Public (0.029). The criteria were then compared according to each actor and the composite relative priorities calculated (Table 7.2). Finally, the alternatives were compared according to the criteria and the final priorities computed.

This information was synthesized to yield the most desirable bridge type which was determined to be the Truss type bridge.

The priorities of the three alternatives are:

Truss bridge	0.371
Tied-arch bridge	0.320
Cable-stayed bridge	0.309

[2] The cable-stayed bridge type is very efficient in terms of section sizes and material used. However, there is limited experience with their use in the State of Pennsylvania. As a result, the capital costswould vary greatly depending on the tender procedureused (statewide, nationwide or international).

Table 7.1 Actors' comparisons

	FHWA	CBD	Public	PennDOT	Designers	SIG	PAT
FHWA	1	2	1/5	1	1/2	1/3	3
CBD	1/2	1	1/6	1/2	1/3	1/4	2
Public	5	6	1	5	4	3	7
PennDOT	1	2	1/5	1	1/2	1/3	3
Designers	2	3	1/4	2	1	1/2	4
SIG	3	4	1/3	3	2	1	5
PAT	1/3	1/2	1/7	1/3	1/4	1/5	1

Table 7.2 Priorities of the criteria

	0.135 FHWA	0.221 CBD	0.029 Public	0.136 PennDOT	0.085 Designers	0.056 SIG	0.337 PAT	Priorities
EF	0.117	0.048	0.037	0.216	0.313	0.033	0.260	0.173
CC	0.340	0.048	0.297	0.082	0.197	0.357	0.100	0.147
MA	0.069	0.116	0.297	0.052	0.118	0.097	0.260	0.154
AE	0.069	0.401	0.074	0.216	0.136	0.224	0.061	0.174
EI	0.202	0.270	0.114	0.352	0.117	0.224	0.061	0.181
DU	0.202	0.116	0.182	0.082	0.118	0.064	0.260	0.171

7.5 Bridge Selection Revisited

The analysis just presented was prepared by MBA students. Several months following the foregoing analysis another MBA student revisited the decision and sought validation with two individuals closely involved in the bridge selection process. The hierarchy developed in this second approach is given in Fig. 7.7 and the results are provided in Table 7.3. Note that the hierarchy used is similar to the one given in Fig. 7.6. However, the elements in the levels are not identical to the ones in the first approach. The major difference between the two approaches is the addition of a new stakeholder, the U.S. Coast Guard, and the deletion of The Public.

United States Coast Guard (USCG): River transportation has a significant impact on the economy of Pittsburgh and the surrounding area in Western Pennsylvania. Since there will be three bridges in close proximity to one another (Smithfield Street, Monongahela River, and Fort Pitt), ample room must be maintained for river traffic. The Coast Guard will also want to minimize the impact of the bridge construction on river traffic.

Tied-arch bridge:	0.471
Cable-stayed bridge:	0.328
Truss bridge:	0.201

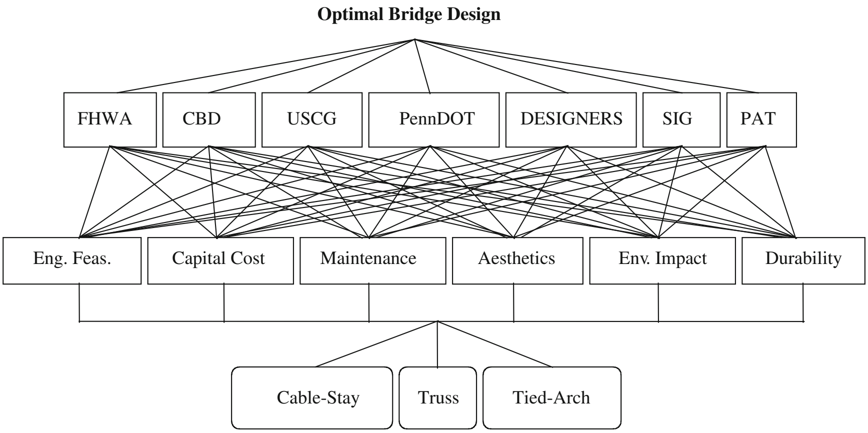

Fig. 7.7 Hierarchy for the revised bridge decision

Table 7.3 Priorities of the criteria for the revisited bridge decision

	0.173 FHWA	0.087 CBD	0.118 USCG	0.173 PennDOT	0.036 Designers	0.051 SIG	0.361 PAT	Priorities
EF	0.218	0.048	0.214	0.220	0.346	0.228	0.230	0.212
CC	0.354	0.137	0.043	0.344	0.248	0.100	0.121	0.195
MA	0.053	0.083	0.161	0.053	0.070	0.046	0.230	0.132
AE	0.073	0.400	0.067	0.114	0.155	0.432	0.121	0.146
EI	0.189	0.249	0.383	0.191	0.129	0.148	0.070	0.170
DU	0.112	0.083	0.123	0.078	0.052	0.046	0.230	0.142

The priorities of the three alternatives are now:

It must be noted that another important difference between the two approaches, in addition to the ones mentioned above, is the group of decision makers providing the judgments. Although in both occasions judgments were provided by people with good information on the project, the second time the judgments were given by the two individuals close to the committee that made the final recommendation of the tied-arch type bridge.

7.6 Conclusion

The AHP was used to select the best alternative (the Tied-arch type bridge) from among closely competing alternatives. It also facilitated the learning process and gave users a more thorough understanding of the competing factors in a complex decision making environment. It illustrates the sensitivity of the outcome to what factors one chooses to include. It is certain that so far major public works divisions have not been as thorough and comprehensive as may be needed to ensure the success and longevity of an important project. More examples of such applications need to be brought to the attention of authorities for better value and longer lasting performance.

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