Multi-criteria Decision-making Approach for Selecting a Bridge Superstructure Construction Method

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Abstract Selection of an effective construction method of bridge superstructure is critical to the success of the bridge project. Multiple criteria and the relative importance among them are involved in the process of decision-making. These criteria and their relative importance lead to vague and complex situation in the selection process. In order to tackle this complex situation, a mathematical methodology is required. Analytical Hierarchy Process (AHP) is a popular method that is used for solving Multi-Criteria Decision-Making (MCDM) problems. Every construction method of bridge superstructure has its own advantages and disadvantages. The challenge is to select the correct one for the prevailing circumstances. In this paper, the different methods of bridge construction are explained and are compared using their advantages, disadvantages and their suitability to different criteria and constraints associated with a bridge construction. The criteria weights and priorities are collected from experienced professionals of different point of view, i.e. Client, Designer and Contractor using questionnaire survey. Using this comparison, a decision support model is developed along with suitability ranking using AHP in order to simplify the process of selection of the appropriate method of bridge superstructure construction.

Keywords Bridge · Superstructure · Pairwise comparisons · AHP · MCDM

1 Introduction

Continuous progress in materials technology and calculation methods have led to the development and usage of prestressed, precast concrete and continuous beam structural systems. These methods have given rise to new forms of erection like span by span erection, balanced cantilever erection, full span erection, etc. Each method has its own advantages and disadvantages. This means that older form of construction like cast in-situ still exists.

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B. B. Das et al. (eds.), *Recent Trends in Civil Engineering*, Lecture Notes in Civil Engineering 105, https://doi.org/10.1007/978-981-15-8293-6_41

Currently, bridges have evolved into segmental construction, use newer technologies like precasting, prestressing and continuous spans have been adopted. Erection is useful in negating the topographical conditions, in increasing mechanization, decreasing time required and flow disruption and for bringing better economy into construction. Precasting is useful in maintaining good quality of concrete, increasing speed of construction, negating weather conditions, reducing labour requirement, etc. While precasting has gained lot of prominences, it still cannot match the versatility of in-situ construction. Cast in-situ methods are generally simpler, cost-effective and can be adjusted to suit any circumstances and technical requirements [1, 2].

2 Need of This Study, Scope and Objectives

Selection of methods currently is done by designers using some predominant characteristics of the bridge and the site conditions and based on experience. This may lead to vague and complex situations due to clashing of the deciding criteria. Based on factors such as application conditions, construction surroundings, project driving factor and other requirements the correct method of construction should be chosen to bring upon economic benefits into bridge construction.

Every construction method has its own advantages and challenges. The evaluation of the best possible alternative construction method is a difficult task when we lack the list of particular requirements that make one solution immediately preferable to the others. Comparisons based on the quantities of materials are the most common practice, which consider only one of the various components of the construction method of a bridge. There are various other factors involved and should be considered.

The aim of this study is to compare the different methods of superstructure construction across different criteria and to prepare a decision support model using a multi-criteria decision-making method so as to be able to use the most appropriate one at the right place and right time for a given set of circumstances [4–8].

To achieve the scope of the study, the following objectives have been set up:

- Comparing the construction methods across multiple criteria using a multi-criteria decision-making approach for different parties involved in bridge construction.
- Developing a model in order to facilitate the selection process.

3 Correlation Among the Bridge Types and Construction Methods

Bridges can be classified into various categories based on different parameters. It can be classified as precast and cast in-situ based on the construction and concrete casting technique. To suit the various types of bridges listed above, there are a variety of machines and equipment which are falsework, launching girders,

Table 1 Correlating various bridge classifications to methods of construction

	Construction Methods	Cast in-situ	Precast	Span by span	Full span	Balanced cantilever	Long span	Short span
Machine/Equipment	Launching girder		✓	✓	✓	✓	✓	✓
	Lifting frames		✓			✓	✓	✓
	Movable scaffolding system	✓			✓			✓
	Form traveller	✓				✓	✓	✓
	Falsework	✓	✓	✓				✓
	Push launching		✓		✓		✓	✓
	Stay supported launching		✓			✓	✓	✓
	Crane		✓	✓	✓	✓	✓	✓

movable scaffolding systems, form travellers, lifting frames, incremental launching, cable/stay supported launching etc. The bridge classifications have been correlated to construction methods and summarized in the Table 1.

The highlighted boxes that correspond to the five different methods are used in our Questionnaire Survey.

4 Research Methodology

In this research, we have considered Qualitative comparison using AHP from the various MCDM techniques. The details of the methodology have been discussed thoroughly.

4.1 Qualitative Comparison

While comparing different methods, a quantitative approach is generally preferred as it gives better insights, relative differences among methods and clarity. But in the case of bridge construction, there are a lot of factors which affect the final delivery. These factors cannot always be compared quantitatively directly for a universal comparison.

The numbers fluctuate a lot based on the design conditions due to the methods having limits in both their advantages and disadvantages.

The problems with quantitative comparison of cost and time of bridge construction:

- Current data available for methods (Example from L&T Project) are data for a predefined and predesigned setup—load, span, width, design strategy, etc. Getting data for similar setups but using different methods will be a problem.
- A real comparison would require us to design all the methods for a similar setup then simulating it. But this would require extensive design background and is out of scope of this research.
- Absence of any data to normalize or model different superstructures.
- A method can be designed for different performance and efficiency levels based on the availability of technology and capital.

Due to these problems, we will adopt a qualitative approach which would not need raw numbers and is not very data intensive.

4.2 Multi-Criteria Decision-Making (MCDM)

'Multi criteria decision making is an umbrella term used to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter' (Valerie and Theodor, 2003).

Numerical scores are calculated to represent degree of preference for decision options in value measurement methods. This includes methods like AHP (Analytical Hierarchy Process), MAUT (Multi-Attribute Utility Theory), weighted sum and product model.

Both value measurement models and outranking models can be used in our case. But the easy to use and lesser data-intensive AHP are preferred to the more complex methods (Fig. 1).

4.3 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is an approach for multi-criteria decision-making, which was introduced by Saaty (1977 and 1994). The AHP is a supporting tool for decision-making, which can be used to reduce the complexity of the decision-making problems and solve it. A multi-level hierarchical structure of objectives is used. Also, different criteria, sub-criteria, and alternatives are incorporated in that structure. We used a set of pair-wise comparisons for deriving the pertinent data. To calculate the weights of importance of the decision criteria, these comparisons are

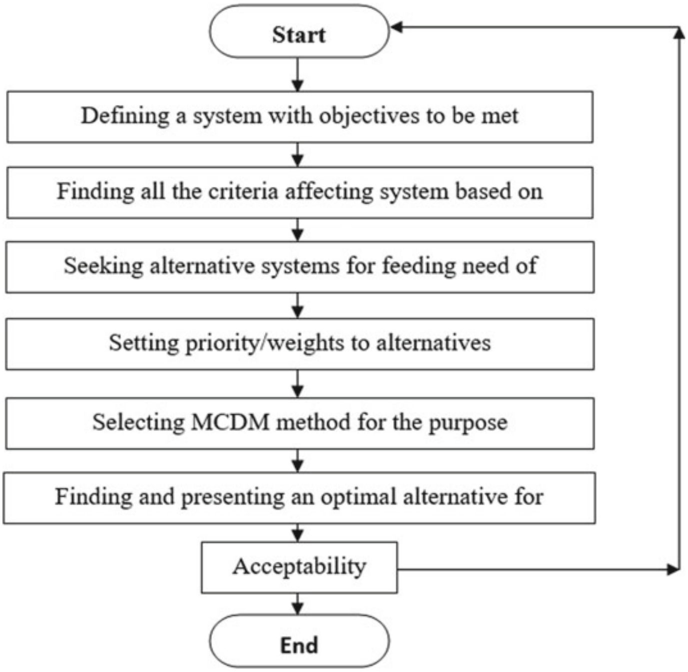

Fig. 1 Procedure for MCDM analysis

used. Moreover, in terms of each individual decision criterion, the relative performance measures of the alternatives are obtained. It has proved its usefulness in various areas of construction management.

For the pair-wise comparisons, we formed a scale of numbers that indicates how good or important one element is over another. The following exhibits the scale generally used for all process using AHP Table 2.

Table 2 Rating scale to compute criteria weights and compare alternatives

Rating	Meaning
1	Equally good
3	Moderately preferred
5	Strongly preferred
7	Very strongly preferred
9	Extremely preferred
2,4,6,8	In between values

Table 3 Random matrix consistency index

n	1	2	3	4	5	6	8	7	9	10
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

4.3.1 Consistency

The judgements need to be checked for consistency. In order to limit the inconsistency AHP, concepts of consistency ratio (CR), consistency index (CI) and random matrix consistency index (RI) were presented by Saaty. Saaty [3] has provided the calculated RI for different matrix sizes and has been shown in the Table 3.

The consistency ratio is calculated using the formula *CR* = *CI/RI*. CI is calculated using

$$CI = \frac{Amax^{-n}}{n-1} \tag{1}$$

where A is the max eigenvalue of the matrix and n is the dimension of the matrix. Saaty [3] has shown that a consistency ratio of 0.10 is acceptable for analysis. If the consistency ratio is more than 0.1 then the judgements must be revised.

4.3.2 Aggregating Judgements

Since there are multiple individual participants in the judgement process, we need to aggregate the information. The two most commonly used methods are aggregation of individual judgements (AIJ) and aggregation of individual priorities (AIP). In this research, the responses have already been divided into different homogeneous groups (clients, contractors and designers). This along with the need for getting consistent responses without too much rework led to the selection of AIJ using the geometric mean of a small group of experts as the preferred method of analysis of the judgements.

4.3.3 Calculation of Priority

Alessio and Markus (2006) found out that when the matrix size is relatively small, and the inconsistency is low then there is very less difference between the methods. The number of rank contradictions was low between the eigenvalue method and mean of normalized and geometric mean method. The eigenvalue method is difficult to execute on a simple excel worksheet. So, for this research mean of normalized method and geometric mean will be selected as the methods to derive priority.

Table 4 List of constraints used for the different parties

Client	Contractor	Designer
Initial cost	Initial cost	Cost efficiency
Erection and indirect cost	Erection and indirect cost	Rate of construction
Rate of construction	Rate of construction	Safety
Safety	Weather susceptibility	Quality
Quality	Safety	Topography
Process efficiency	Quality	Curve
Maintenance efficiency	Topography	Process efficiency
	Curve	Maintenance
	Manpower	
	Process efficiency	

4.4 The Criteria

For an overall comparison of the methods, they will be compared across multiple criteria. Different parties have different preferences and requirements. In order to satisfy all the parties (contractor, client and designer) involved in the construction, different criteria are selected. These criteria may have different meaning for different parties and not all criteria will be used for the three parties. These criteria will be divided into sub-criteria in order to make it easier to give a clear rating to each. The criteria used here are not exhaustive and there are other ones which have not been considered here Table 4.

4.5 The Constraints

The criteria alone cannot decide on the appropriate method. A method can be very good in most criteria but can be severely lacking in one or two criteria. If those criteria turn out to be basic constraints, then the method should not be considered. In order to take this into consideration, some basic conditions are taken as constraint inputs during the analysis. The constraints are selected and rated for each bridge using a basic understanding of the construction method Table 5.

The Y stands for the method being able to work despite the constraint and N stands for the methods inability to contend with the constraint.

Table 5 Relation between different methods and constraints

Construction Method	Weather	Ground	Water	Curves	Span length
Balanced cantilever	Y	Y	Y	Y	Y
Crane and falsework	Y	N	N	Y	Y
Cast in-situ with falsework	N	N	N	Y	Y
Span by span using overhead LG	Y	Y	Y	N	N
Span by span using underslung LG	Y	Y	Y	Y	N

4.6 Questionnaire Survey

The methods will be compared by collecting data of pair-wise comparisons using questionnaire survey in the construction industry.

Design of survey—Questionnaire surveys will be used to obtain ratings for the methods. The rating can be based on ranking or rating (ordinal scales i.e. it will measure a variable in terms of rank). Using pairwise comparisons, we can get a more accurate picture about the methods. But the pair-wise comparisons themselves suffer from a disadvantage.

- As the number of alternatives and criteria increase the total number of pairwise comparisons gets too heavy and cumbersome. For our case of five alternative methods and 10 criteria, it will lead to 100 pair-wise comparisons ('$n * (n - 1) * m/2'$, where n is the number of alternatives available and m is the no of criteria) and 45 pair-wise comparisons for the criteria importance. For our objective to be achieved, a ranking system is too inadequate hence we will go with pair-wise comparisons and AHP.
- Getting responses—Responses will be received from small groups of clients, designers and contractors. In order to get homogeneous replies, the groups are instructed to work together to agree on a rough common hierarchy before they can work on aggregating their responses. For this research, we have collected five responses from the Client, five responses from the Contractor and six responses from the Designer.
- Analysing the results—The results are analysed using AHP. The judgements are aggregated using geometric method and priority will be derived by mean of normalized values and geometric mean method.

4.7 Analysing Survey Responses and Calculations

Responses were taken from engineers with experience as either a client or designer or a contractor in the bridge construction industry. The aggregation of results is done by taking geometric mean of product of all the responses. The MNV method utilizes normalizing the column first. Then the mean of the row is taken to obtain the priority values. The lambda value is obtained by using eigenvalue and vector equation. In the geometric mean method, all the judgements across a row are multiplied and their geometric mean is taken. The geometric mean values are then normalized.

The consistency check is done to ensure the judgements have not exceeded the allowable levels of inconsistency. Consistency index is calculated using the formula.

$$CI = (A - n)\Big/(n - 1) \tag{2}$$

Where lambda is the eigenvalue calculated in the previous step and n is the matrix size. The random average index is obtained from the table illustrated before. The consistency ratio is obtained by dividing the consistency index by the random average index,

$$CR = CI/RI \tag{3}$$

5 Decision-Making Model

The next step in the AHP decision-making process is obtaining the relative priorities for different criteria. The priorities keep changing with place, preferences, driving goals, etc. Thus, the priorities will be taken as an input in order to get the method more suitable for those conditions. A pair-wise comparison criteria are created similar to previous matrices but for the different criteria. The user will input the pair-wise preferences. The priority and lambda values will be calculated as done in the previous chapters using MNV and GM method. Consistency check is done in order to obtain consistent preferences. Then constraints will be taken in as input in order to filter methods further. Overall priority is calculated as a sum of product of the criteria priority and method priority for those criteria.

5.1 Client's Selection Model

A hypothetical case is taken in order to illustrate the model. In our example, we assume bridge construction in a busy city. The general order of preference of criteria is assumed as safety/quality, time/initial cost followed by maintenance/erection cost and process efficiency. The overall priorities for each criterion are calculated and the sum of the priorities across criteria gives the methods final priority.

The methods are given an initial ranking based on their priorities. Then the constraints are used to filter methods feasibility. And based on the criteria method, a method either passes or gets disqualified. A final ranking is generated where the disqualified method does not feature Table 6.

For the given set of preferences and constraints, the model concludes that erection using crane and falsework is the most suitable method.

Table 6 Ranking table of client's selection model

Type	Initial ranking		Final ranking	
	WSM	GMM	Qualified	Final
Balanced cantilever erection	5	5	5	4
Cast in-situ construction	4	4	NA	NA
Crane and falsework	1	1	1	1
Overhead LG	3	3	3	3
Underslung LG	2	2	2	2

Table 7 Ranking table of contactor's selection model

Type	Initial ranking		Final ranking	
	WSM	GMM	Qualified	Final
Balanced cantilever erection	3	3	3	2
Cast in-situ construction	5	5	5	3
Crane and falsework	1	1	1	1
Overhead LG	2	2	NA	NA
Underslung LG	4	4	NA	NA

5.2 Contractor's Selection Model

A similar case is taken for contractor's selection model and similar calculations are done for the initial and final ranking according to the priorities Table 7.

For the given set of preferences and constraints, the model concludes that erection using crane and falsework is the most suitable method.

6 Designer's Selection Model

A similar case is taken for contractor's selection model and similar calculations are done for the initial and final ranking according to the priorities Table 8.

For the given set of preferences and constraints, the model concludes that erection using underslung LG is the most suitable method.

Table 8 Ranking Table of Designer's Selection Model

Type	Initial ranking		Final ranking	
	WSM	GMM	Qualified	Final
Balanced cantilever erection	5	5	5	2
Cast in-situ construction	2	2	NA	NA
Crane and falsework	1	1	NA	NA
Overhead LG	3	3	NA	NA
Underslung LG	4	4	4	1

7 Conclusion

Accurately choosing a bridge construction method is vital for the success of the bridge project. With multiple factors and interested parties at play, we need a robust mathematical and analytical system to arrive at a suitable choice. Multi-criteria decision-making methods are an elegant way to solve this problem. This project work presents an AHP-based model in order to simplify the process of method selection.

The model is divided into three models based on the different parties involved in the construction process. Each model considers the same alternatives across different relevant criteria. The model takes in expert opinions as the major input in form of pair-wise comparisons. The comparisons also tend to be lengthy and repetitive. Due to this, it is crucial that the expert has enough knowledge and expertise.

Hypothetical cases were considered, and they were analysed using the developed model to illustrate the model's capability and effectiveness. This shows the steps involved and explains the process so that by using that the parties can evaluate their options better.

The proposed model is not restricted to either the five methods used, or the different criteria used for different parties. The methods were selected just based on being the commonly used methods in the Indian construction industry. The list of criteria is also not exhaustive. In future studies, more construction methods may be considered along with changing the criteria in order to introduce newer and different methods into the Indian construction industry.

A qualitative comparison does not always convey the same information which is conveyed by raw numbers. A quantitative comparison is arguably more helpful in deciding. The lack of data availability with respect to simulating the methods is across a given set. Future studies can look into simulating design and construction for different methods in order to make better decisions.

References

1. Saaty TL (2008) Decision making with the analytic hierarchy process. Int J Serv Sci 1(1)
2. Ishizaka A, Lusti M (2006)How to derive priorities in AHP: a comparative study. CEJOR 14(4):387–400
3. Saaty TL (2012) A new approach to the middle east conflict: the analytic hierarchy process. J Multi-Criteria Decis Anal 19(5–6), 201–225
4. Valerie B, Theodor SJ (2003) Multiple criteria decision analysis: an integrated approach
5. Forman E, Peniwati K (1998) Aggregating individual judgments and priorities with the analytic hierarchy process. Eur J Oper Res 108:165–169
6. Triantaphyllou E, Mann SH (1995) Using the analytic hierarchy process for decision making in engineering applications: some challenges. Int J Ind Eng: Appl Pract 2(1):35–44
7. Chaphalkar NB, Shirke PP (2013) Application of multi criteria decision making techniques for bridge construction. Int J Innovative Res Sci Eng Technol 2(8)
8. Hwang C-L, Yoon K (1981) Multiple attribute decision making. Springer.