Correlative Study of Accra Water Supply Project

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Abstract. Accra Water Supply Project adopted TOPSIS method which is based on Multiple-attribute Decision Making Theory to establish decision making model. After sorting based on distance measure, the best scheme was recommended, which met the requirements of comprehensive comparison proposed by the proprietor.

Keywords: Water delivery scheme, integrated comparison, TOPSIS, distance measure.

1. Introduction
Accra water Supply Project was a large foreign-related urban water supply project constructed by Chinese contractors. It adopted the PDB mode of FIDIC provisions in 1999. According to the long-term design, water intake capacity was 353,000 tons/day, and the first-phase equipment installation was constructed at 196,000 tons/day. It was the largest water supply project in Ghana so far. The project diagram is shown in Figure 1.

Figure 1. Schematic Diagram of Accra Water Supply Project

1 -- Water intake head; 2 - Lifting pump station; 3 - Water treatment plant; 4 - Clear pool and high level pool; 5 - Lifting pump station; 6 - Water main pipe; 7 - Water distribution network; 8 - Terminal pool

The feasibility study of the project began in 2004, and in 2009 the project entered the implementation phase. The rapid development of the rapidly developing cities around the capital city of Ghana led to the redesign of the original pumping stations and pipelines.
2. Overview of water delivery scheme design

Before the implementation of the project, the contractor redesigned the water delivery scheme according to the owner’s comments on the project. There are three types of construction schemes which can achieve the aim of water delivery.

In terms of the layout of the structures along the way, the first type is the water conveyance scheme in the original contract, that is, the arrangement of the high water tank (HWT) behind the lifting pump station (LPS). The water flow in the scheme enters the mid-way lifting pump station after it comes out from the water treatment plant pump station, and is transferred to the high water tank by pressurization through the lifting pump station, after that, it flows to the terminal water tank of Accra due to gravity. The second type is the plan of layout lifting pump station after the high water tank. This plan delivers water to the high water tank through the secondary pump station in the water treatment plant, and then retains it to the lifting pump station. The third type is the plan of joint construction with the pump station after the high water tank is moved down.

In terms of route selection, route 1 is the original design of water transmission direction, which has the shortest water transmission distance, and availability of the original water distribution network is higher, but more old towns and villages are influenced. Route 2 is the route recommended by the proprietor. The route is arranged along the newly built highway, which can serve the new community and government buildings. Route 3 is relatively remote, with fewer villages and towns and roads running through, and less construction interference.

The nine alternative water delivery schemes after combining different lines and structure arrangements are shown in Table 1.

| Route     | LPS+HWT | HWT+LPS | Combination of HWT& LPS |
|-----------|---------|---------|-------------------------|
| Route 1   | Scheme 1| Scheme 2| Scheme 3                |
| Route 2   | Scheme 4| Scheme 5| Scheme 6                |
| Route 3   | Scheme 7| Scheme 8| Scheme 9                |

3. The decision-making process of the original comparison evaluation and the existing problems

The original comparison evaluation decision adopted method of comparing all kinds of index in recommendation proposal. It was found that Scheme 3 and 6 have stronger feasibility compared with the original scheme. Scheme 6 has a good performance on time limit and land requisition amount. Scheme 3 performed well on the cost, line length and the reliability. Finally the general contractor recommended scheme 3 to the proprietor.

Although the general contractor compared and analyzed the alternatives with different indicators, the consulting engineer still raised a lot of questions:

First evaluation criteria is not considerate, while considering the different preference, such as time limit reflects the owner wishes, cost reflects the interests of the contractor, but they were failed to reflect on the same type indicator, such as in economic indicators, in addition to the cost index reflecting the interests of the contractor, the owners should also consider operation periods of management fees, etc.

However, the elimination of other schemes is too hasty. Although the shorter the time limit of the water conveyance project is, the better the realization of the water supply target can be, the 40-months time limit is not required by the contract. In fact, all the alternatives have not exceeded the contract target, and they still have excellent performance in other indicators.

Finally, it is believed that the importance of the index is not the same, and the final scheme cannot be determined simply by the number of the optimal index, so the elimination of the scheme recommended by the owner is not convincing. Therefore, the comprehensive decision-making method is adopted to carry out comparative study on the water supply scheme.
4. Application of the Integrated decision method in Ghana project

The multi-objective comprehensive decision method is designed and calculated by setting various constraints and using mathematical programming and other methods on the premise of no alternative scheme, and the solution is the optimal one. The commonly used integrated decision-making methods are the multi-objective decision-making evaluation method designed by Sadek S., Kaysi I. and others, which is based on GIS software [1]; AHP, genetic algorithm and other methods which are used by Jonj.c. and Schonfeld P.; and other methods [2], and TOPSIS method proposed by Hwang and Yoon. TOPSIS method is a multi-attribute integrated decision-making method which comprehensively applies Euclidean distance measure which was proposed in 1980s. This method uses the data from different dimensions of each scheme to construct decision-making model and ideal scheme, calculates Euclidean distance between each alternative and ideal scheme in Euclidean space, and finally analyzes the distance comprehensively side by side to get the optimal scheme [3].

The first step of integrated comparison decision is complement indicators on the basis of the existing information, which solved the problem of the inconsiderate evaluation index. The supplementary economic indicators included running costs, utilization of old pipe network along the route. The supplementary technical indexes included road crossing length. The supplementary social efficiency index is the population of service quantity.

The index values for the nine alternatives are shown in Table 2.

Table 2. A list of alternative index values

| Alternatives | i1 Time Limit (mon) | i2 Cost (mil) | i3 Ten year operating expenses (m) | i4 Primary pipeline utilization rate | i5 route Length (km) | i6 service population (Ten thousand) | i7 Land requisition (ha) | i8 crossing length (m) | i9 reliability |
|--------------|---------------------|--------------|-----------------------------------|-----------------------------------|---------------------|--------------------------------------|------------------------|----------------------|---------------|
| S1           | 43.9                | 124.2        | 42.6                              | 35%                               | 65.58               | 44                                    | 85.25                  | 297                  | 0.9708        |
| S2           | 43.2                | 123.3        | 46.6                              | 30%                               | 65.27               | 44                                    | 84.85                  | 307                  | 0.9712        |
| S3           | 39.7                | 118.5        | 43.3                              | 30%                               | 63.88               | 38                                    | 76.66                  | 254                  | 0.9744        |
| S4           | 42.7                | 122.3        | 43.9                              | 25%                               | 68.73               | 41                                    | 81.28                  | 198                  | 0.9704        |
| S5           | 42.2                | 121.2        | 48.7                              | 23%                               | 68.43               | 41                                    | 80.92                  | 211                  | 0.9707        |
| S6           | 39.4                | 119.4        | 44.1                              | 25%                               | 65.19               | 36                                    | 73.82                  | 163                  | 0.9738        |
| S7           | 41.3                | 122.6        | 43.1                              | 10%                               | 67.94               | 38                                    | 83.68                  | 174                  | 0.9702        |
| S8           | 41.2                | 122.4        | 45.0                              | 12%                               | 67.76               | 38                                    | 83.45                  | 186                  | 0.9704        |
| S9           | 39.1                | 121.3        | 44.3                              | 5%                                | 66.19               | 34                                    | 78.23                  | 165                  | 0.9729        |

4.1. Comparison and selection of European distance proximity method

Step 1: Establish a standardized decision matrix

Establish the original matrix according to the index value of the alternative:

\[
\begin{bmatrix}
43.9 & 124.2 & 42.6 & 0.35 & 65.58 & 44 & 85.25 & 297 & 0.9708 \\
43.2 & 123.3 & 46.6 & 0.3 & 65.27 & 44 & 84.85 & 307 & 0.9712 \\
39.7 & 118.5 & 43.3 & 0.3 & 63.88 & 38 & 76.66 & 254 & 0.9744 \\
42.7 & 122.3 & 43.9 & 0.25 & 68.73 & 41 & 81.28 & 198 & 0.9704 \\
42.2 & 121.2 & 48.7 & 0.23 & 68.43 & 41 & 80.92 & 211 & 0.9707 \\
39.4 & 119.4 & 44.1 & 0.25 & 65.19 & 36 & 73.82 & 163 & 0.9738 \\
41.3 & 122.6 & 43.1 & 0.1 & 67.94 & 38 & 83.68 & 174 & 0.9702 \\
41.2 & 122.4 & 45 & 0.12 & 67.76 & 38 & 83.45 & 186 & 0.9704 \\
39.1 & 121.3 & 44.3 & 0.05 & 66.19 & 34 & 78.23 & 165 & 0.9729
\end{bmatrix}
\]

Step 2: Determine the weighted standardized decision matrix

The original decision matrix A was transformed into the standard decision matrix B, and the index was weighted based on both main and objective factors. The comprehensive weight coefficient is shown in the table below:
\[ \omega = (0.177 \ 0.148 \ 0.121 \ 0.078 \ 0.092 \ 0.078 \ 0.093 \ 0.093 \ 0.12) \]

Step 3: Establish a weighted standardized decision matrix, \( C = \omega B \)
\[
C = \begin{bmatrix}
0.063 & 0.078 & 0.000 & 0.047 & 0.006 & 0.055 & 0.035 & 0.062 & 0.014
\end{bmatrix}
\]

Step 4: Observe the matrix \( C \) and determine the ideal solution.
Positive ideal solution:
\[
r^+ = (0.177 \ 0.148 \ 0.121 \ 0.078 \ 0.092 \ 0.078 \ 0.093 \ 0.093 \ 0.12)
\]
Negative ideal solution:
\[
r^- = (0.00 \ 0.00 \ 0.00 \ 0.00 \ 0.00 \ 0.00 \ 0.00 \ 0.00 \ 0.00)
\]

Step 5: Calculate closeness degree, sort the above calculation results, and sort the alternatives in the order of the size of the paste progress. The results are shown in Table 3.

| closeness degree | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 |
|------------------|----|----|----|----|----|----|----|----|----|
| \( D^+ \)        | 0.081 | 0.071 | 0.007 | 0.055 | 0.057 | 0.007 | 0.051 | 0.049 | 0.024 |
| \( D^- \)        | 0.031 | 0.018 | 0.091 | 0.025 | 0.021 | 0.087 | 0.032 | 0.025 | 0.064 |
| \( C \)          | 0.275 | 0.207 | 0.928 | 0.315 | 0.265 | 0.925 | 0.385 | 0.341 | 0.731 |
| Rank             | 7   | 9   | 1   | 6   | 8   | 2   | 4   | 5   | 3   |

According to the sorting results, scheme 3 > scheme 6 > scheme 9 > scheme 7 > scheme 8 > scheme 4 > scheme 1 > scheme 5 > scheme 2, therefore, scheme 3 is the best scheme.

5. Conclusion
Through the integrated comparison study on Accra water supply project, this thesis enables the application of the multiple attribute decision theory applied to the international general contracting project. The result of the decision also confirms the reliability of the recommended by the contractor, which shows the vital significance of winning the trust of the owner and expanding Ghana construction market, meanwhile, it also provides a reference for decision-making research.

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