Data Article

Data and calculation approach of the fuzzy AHP risk assessment of a large hydroelectric project

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A B S T R A C T

This data article employs the Fuzzy Analytic Hierarchy Process (FAHP) to perform the project risk assessment in a phase of the construction of a large hydroelectric project. The list of service packs and risk events was extracted from in-depth interviews and content analysis with experts. Such qualitative data were used to identify the relevant service pack and risk event indicators for two groups – the owner’s and the builder’s representatives – required to specify the model. FAHP was used to calculate the relative importance of such indicators in two stages. First the relevance of the service packs was measured through paired comparisons and then weighted. Next, the relevance of the risk events associated with each service pack was assessed through the same method. A complete method of calculation for one of the respondents is presented. At the end, the average weights for the risk events of the two groups are calculated. For further information it is recommended to read the article entitled “Multi-criteria risk assessment: Case study of a large hydroelectric project” (Ribas et al., 2019).

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2352-3409© 2019 Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
1. Data

A subjective assessment was conducted with the experts of two groups of stakeholders - the owner consortium and the builder consortium [1]. They were asked to fill out a paired comparison form divided into two parts: paired comparison between service packs and between risk events from the point of view of each service pack. In this way, for each combination of two service packs, the expert indicates which has the highest impact, and then assigned a score, according to the nominal scale proposed by Saaty [2], whose odd scores range from 1 to 9, to estimate the level of importance. This was repeated until the exhaustion of the number pairs. Second, each service pack was compared to the pairwise risks. Likewise, the procedure was repeated for each service pack until the last pairwise comparison of risk events. The spreadsheets containing data extracted from these interviews and the calculation procedure are stored in a zip file available at https://data.mendeley.com/datasets/xcm524mppx/2.

The experts in the owner consortium were the technical manager (P.1), proprietary engineering manager (P.2) and health and safety engineer (P.3). The representatives of the builder consortium were the project manager (C.1), contracts and civil works manager (C.2), electromechanical equipment manager (C.3), electromechanical assembly manager (C.4), contract administration manager (C.5) and environmental manager (C.6).

The service packs were: contractual modality (CM), interpreted as referring to the type of contract, which was lump-sum, covering delivery of the work with the default specifications at a fixed price; river management (RM), achieved by the combination of ecological and sustainability principles with the construction engineering techniques and procedures; electromechanical assembly (EA), involving the installation and commissioning of the hardware; civil works (CW), which include the construction of the dam itself; and workforce (WF), including all the human resources hired to execute the works.

The identified risk events were: hydrological cycle (HC), related to the seasonality of the existing flow in the Amazon River and the planning and construction of engineering works in this region;
product specification (PS), referring to the management of materials, parts, components, and equipment manufactured by different vendors; quality of service (QS), regarding the ability, qualification and coordination of services, control and organization; interface (IN), interpreted as the management of different teams working on steps that complement each other, resulting in a complete product; stoppages (ST), arising out of strikes, poor planning of labor allocation, and various problems faced by suppliers.

For each respondent, filling out the paired comparison form generated an array of importance of service packs and another for risk events applicable to a specific service pack. To demonstrate the calculation method, the present article reports the scores for service packs indicated by the respondent identified as C.2 in Table 1, the contracts and civil works manager of the builder consortium. The respondent was asked to make the paired comparisons corresponding to the cells located above the main diagonal, being the cells below reciprocals of his choices.

2. Experimental design, materials and methods

A fuzzy number characterized by a triangular membership function (TMF) assumes values in the interval [1,9], and for the reciprocals, values in the interval [1/9,1]. The fuzzy number $M_{ij} = \{l_{ij}; m_{ij}; u_{ij}\}$ is a TMF with a fuzzification degree $\delta$, set as equal to 1 in this study, therefore:

$$M_{ij} = \{l_{ij} = m_{ij-1}; m_{ij}; u_{ij} = m_{ij+1}\}$$  \hspace{1cm} (1)

The results of equation (1) are shown in Tables 2a and 2b for the five service packs, each comprising three columns: “l” for minimum, “m” for modal and “u” for maximum. These tables contain the arguments of equation (2). Sum[j] in the last line of both tables corresponds to $\sum M_{ij}$. The three last columns Sum[l], Sum[m] and Sum[u] of Table 2b correspond to $\sum \sum M_{ij}$. The three cells located at the bottom right of Table 2b correspond to $\sum \sum \sum M_{ij}$ [3].

$$S_i = \sum_{j=1}^{n} M_{ij} \otimes [\sum_{i=1}^{n} \sum_{j=1}^{n} M_{ij}]^{-1}$$  \hspace{1cm} (2)

| Table 1 |
|---|
| Scores of service packs indicated by C.2 |
| | CM | RM | EA | CW | WF |
| Contractual modality | CM | 1 | 1/7 | 1/7 | 1/5 | 1/7 |
| River management | RM | 7 | 1 | 1/7 | 1/3 | 1/9 |
| Electromechanical assembly | EA | 7 | 7 | 1 | 7 | 1/5 |
| Civil works | CW | 5 | 3 | 1/7 | 1 | 1/5 |
| Workforce | WF | 7 | 9 | 5 | 5 | 1 |

| Table 2a |
|---|
| Fuzzified values of the service packs (part I). |
| | CM.l | CM.m | CM.u | RM.l | RM.m | RM.u | EA.l | EA.m | EA.u |
| CM | 1 | 1 | 1 | 1/8 | 1/7 | 1/6 | 1/8 | 1/7 | 1/6 |
| RM | 6 | 7 | 8 | 1 | 1 | 1 | 1/8 | 1/7 | 1/6 |
| EA | 6 | 7 | 8 | 6 | 7 | 8 | 1 | 1 | 1 |
| CW | 4 | 5 | 6 | 2 | 3 | 4 | 1/8 | 1/7 | 1/6 |
| WF | 6 | 7 | 8 | 8 | 9 | 10 | 4 | 5 | 6 |
| Sum[j] | 23.00 | 27.00 | 31.00 | 17.13 | 20.14 | 23.17 | 5.38 | 6.43 | 7.50 |
Applying equation (2) with the arguments as mentioned above, we have the results for the fuzzy synthetic extent \((S_i)\) as shown in Table 3:

Comparing two convex fuzzy numbers \(S_1\) and \(S_2\), the degree of possibility must be one of the following values, as shown in equations (3)–(5), where \(hgt\) is the ordinate of the highest intersection point between \(S_1\) and \(S_2\), here represented by \(d\) in Equation (4).

\[
V(S_1 \geq S_2) = 1 \text{ iff } m_1 \geq m_2
\]  

(3)

\[
V(S_2 \geq S_1) = hgt(S_1 \cap S_2) = d = \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} \text{ iff } d \geq 0
\]  

(4)

\[
\text{if } d < 0 \Rightarrow V(S_2 \geq S_1) = 0
\]  

(5)

The degrees of possibility for the paired comparisons between convex fuzzy numbers are shown in Table 4. For one specific convex fuzzy number \(S_j\) being greater than the remaining \(S_i\), then in equation (6) using the \(\min\) operator yields:

\[
V(S_j \geq S_i) = d_j = \min(S_j \geq S_i), \ i = 1...n, i \neq j
\]  

(6)

The weight vector (7) and the normalized weight vector (8) are:

### Table 2b
Fuzzified values of the service packs (part II).

|        | CW.l | CW.m | CW.u | WF.l | WF.m | WF.u | Sum[l] | Sum[m] | Sum[u] |
|--------|------|------|------|------|------|------|--------|--------|--------|
| CM     | 1/6  | 1/5  | 1/4  | 1/8  | 1/7  | 1/6  | 1.54   | 1.63   | 1.75   |
| RM     | 1/4  | 1/3  | 1/2  | 1/9  | 1/9  | 1/8  | 7.49   | 8.59   | 9.79   |
| EA     | 6    | 7    | 8    | 1/6  | 1/5  | 1/4  | 19.17  | 22.20  | 25.25  |
| CW     | 1    | 1    | 1    | 1/6  | 1/5  | 1/4  | 7.29   | 9.34   | 11.42  |
| WF     | 4    | 5    | 6    | 1    | 1    | 1    | 23.00  | 27.00  | 31.00  |
| Sum[j] | 11.42| 13.53| 15.75| 1.57 | 1.65 | 1.79 | 58.49  | 68.76  | 79.21  |

### Table 3
Fuzzy synthetic extent of the service packs.

|        | CM.l   | CM.m   | CM.u   | RM.l   | RM.m   | RM.u   | EA.l   | EA.m   | EA.u   |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| CM     | 0.0195 | 0.0237 | 0.0299 | 0.0945 | 0.1249 | 0.1674 | 0.2420 | 0.3229 | 0.4317 |
| CW     | 0.0921 | 0.1359 | 0.1952 | 0.2904 | 0.3927 | 0.5300 |        |        |        |

### Table 4
Degrees of possibility, weights and normalized weights of the service packs.

|       | RM | EA | CW | WF | W | W' |
|-------|----|----|----|----|---|----|
| CM    | 0  | 0  | 0  | 0  | 0 | 0  |
| RM    | 1  | 0  | 0.8727 | 0 | 0 | 0  |
| EA    | 1  | 1  | 1   | 0.6694 | 0.6694 | 0.4010 |
| CW    | 1  | 1  | 0   | 0  | 0 | 0  |
| WF    | 1  | 1  | 1   | 1  | 1 | 0.5990 |
The weight vector calculated by equation (6) and the normalized weight vector calculated by equation (8) are shown in the last two columns of Table 4.

The same set of equations is used to calculate the risk events normalized weight vector associated with each of the five service packs. The tables for the risk events associated with one of the service packs, in this case the contractual modality (CM), were initially indicated by respondent C.2 in Table 5 and are shown in Table 6a, Table 6b, Table 7 and Table 8, where W and W' stand for Weight and Normalized Weight, respectively.

The calculation of the risk events' weights associated with each of the service packs is repeated. The degrees of possibility, weights and normalized weights of the risk events associated with the service packs are shown in Table 9.

### Table 5
Scores of risk events associated with the contractual modality as indicated by C.2

|                              | HC     | PS     | QS     | IN     | ST     |
|------------------------------|--------|--------|--------|--------|--------|
| Hydrological cycle           | HC     | 1      | 1/7    | 1/7    | 1/5    | 1/9    |
| Product specification        | PS     | 7      | 1      | 1      | 3      | 1/3    |
| Quality of service           | QS     | 7      | 1      | 1      | 3      | 1/3    |
| Interfaces                   | IN     | 5      | 1/3    | 1/3    | 1      | 1/5    |
| Stoppages                    | ST     | 9      | 3      | 3      | 5      | 1      |

### Table 6a
Fuzzi fied values of the risk events associated with the contractual modality (part I).

|      | HC.l | HC.m | HC.u | OS.l | OS.m | OS.u | QS.l | QS.m | QS.u |
|------|------|------|------|------|------|------|------|------|------|
| HC   | 1    | 1    | 1    | 1/8  | 1/7  | 1/6  | 1/8  | 1/7  | 1/6  |
| PS   | 6    | 7    | 8    | 1    | 1    | 1    | 1    | 1    | 1    |
| QS   | 6    | 7    | 8    | 1    | 1    | 1    | 1    | 1    | 1    |
| IN   | 4    | 5    | 6    | 1/4  | 1/3  | 1/2  | 1/4  | 1/3  | 1/2  |
| ST   | 8    | 9    | 9    | 2    | 3    | 4    | 2    | 3    | 4    |
| Sum[j]| 25.00| 29.00| 32.00| 4.38 | 5.48 | 7.67 | 4.38 | 5.48 | 7.67 |

### Table 6b
Fuzzi fied values of the risk events associated with the contractual modality (part II).

|      | IN.l | IN.m | IN.u | ST.l | ST.m | ST.u | Sum[l] | Sum[m] | Sum[u] |
|------|------|------|------|------|------|------|--------|--------|--------|
| HC   | 1/6  | 1/5  | 1/4  | 1/9  | 1/9  | 1/8  | 1.53   | 1.60   | 1.71   |
| OS   | 2    | 3    | 4    | 1/4  | 1/3  | 1/2  | 10.25  | 12.33  | 15.50  |
| QS   | 2    | 3    | 4    | 1/4  | 1/3  | 1/2  | 10.25  | 12.33  | 15.50  |
| IN   | 1    | 1    | 1    | 1/6  | 1/5  | 1/4  | 5.67   | 6.87   | 8.25   |
| ST   | 4    | 5    | 6    | 1    | 1    | 1    | 17.00  | 21.00  | 24.00  |
| Sum[j]| 9.17 | 12.20| 15.25| 1.78 | 1.98 | 2.38 | 44.69  | 54.13  | 64.96  |

### Table 7
Fuzzy synthetic extent of the risk events associated with the contractual modality.

|      | HC.l | HC.m | HC.u | OS.l | OS.m | OS.u | QS.l | QS.m | QS.u |
|------|------|------|------|------|------|------|------|------|------|
| 0.0235| 0.0295| 0.0382| 0.1578| 0.2278| 0.3468| 0.1578| 0.2278| 0.3468|
| 0.0872| 0.1269| 0.1846| 0.2617| 0.3880| 0.5370|
The last column of Table 4, containing the normalized weights of the service packs, is multiplied by the content of Table 9, resulting in the final risk event weights of respondent C.2 (see Table 10). The risk events weights for the respondents of the owner consortium are calculated in the same way. Their results and the corresponding average are shown in Table 11. The same is done with the risk event weights for the respondents of the builder consortium in Table 12.

Table 8
Degrees of possibility and weights of the risk events associated with the contractual modality.

|     | CM   | RM   | EA   | CW   | WF   | W    | W'   |
|-----|------|------|------|------|------|------|------|
| CM  | 0    | 0.3839 | 0.5903 | 0    | 0    | 0.9337 | 0.3621 |
| RM  | 0.2049 | 0    | 0.5903 | 0    | 0    | 0    | 0    |
| EA  | 0.2049 | 0    | 0.5903 | 0.2980 | 0    | 0    | 0    |
| CW  | 0    | 0.2116 | 0    | 0    | 0.0070 | 0.6451 | 0.2502 |
| WF  | 0.5093 | 0.5903 | 0.2262 | 0.2702 | 0.5903 | 1    | 0.3878 |

Table 9
Degrees of possibility and weights of the risk events associated with the service packs.

|     | MC    | MR    | ME    | OC    | MO    |
|-----|-------|-------|-------|-------|-------|
| CM  | 0.3839 | 0.5903 | 0     | 0     | 0     |
| EP  | 0     | 0     | 0.5903 | 0     | 0     |
| QS  | 0.2116 | 0    | 0.5903 | 0.2980 | 0    |
| IN  | 0     | 0     | 0     | 0.0071 | 0    |
| PA  | 0.5903 | 0.2262 | 0.2702 | 0.5903 | 0.5903 |

Table 10
Risk events normalized weights of respondent C.2.

| Risk events | Normalized weights | Ranking order |
|-------------|--------------------|---------------|
| CH          | 0                  | 4th           |
| EP          | 0.2049             | 2nd           |
| QS          | 0.2049             | 2nd           |
| IN          | 0                  | 4th           |
| PA          | 0.5903             | 1st           |

Table 11
Weights of risk events for the owner consortium.

|                        | P.1   | P.2   | P.3   | Average | Order |
|------------------------|-------|-------|-------|---------|-------|
| Hydrological cycle     | 0.0010 | 0      | 0     | 0.0003  | 5th   |
| Product specification  | 0.5223 | 0.4777 | 0.1688 | 0.4525  | 2nd   |
| Quality of service     | 0.7108 | 0.2980 | 0.2502 | 0.2502  | 1st   |
| Interfaces             | 0.0681 | 0.0227 | 0.0125 | 0.0125  | 3rd   |
| Stoppages              | 0.7151 | 0.4083 | 0.1896 | 0.1896  | 4th   |
| Standard deviation     | 0.3338 | 0.2454 | 0.2634 | 0.2634  | 5th   |

Table 12
Weights of risk events of the builder consortium.

|                        | C.1    | C.2    | C.3    | C.4    | C.5    | C.6    | Average | Order |
|------------------------|--------|--------|--------|--------|--------|--------|---------|-------|
| Contractual modality   | 0.7096 | 0.0000 | 0.6458 | 0.0000 | 0.3829 | 0.0000 | 0.2897  | 2nd   |
| River management       | 0      | 0.2049 | 0      | 0      | 0      | 0.4047 | 0.1016  | 4th   |
| Electromechanical assembly | 0.2904 | 0.2049 | 0.3542 | 0.2881 | 0      | 0      | 0.1986  | 3rd   |
| Civil works            | 0      | 0      | 0      | 0      | 0.0408 | 0.0048 | 0.0076  | 5th   |
| Workforce              | 0      | 0.5903 | 0      | 0.7119 | 0.5762 | 0.5906 | 0.4115  | 1st   |
| Standard Deviation     | 0.2785 | 0.2156 | 0.2617 | 0.2792 | 0.2368 | 0.2500 | 0.1411  | 1st   |
Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dib.2019.104294.

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