Evaluation on Functions of Urban Waterfront Redevelopment Based on Proportional 2-Tuple Linguistic

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Received 1 August 2013
Accepted 7 January 2014

Abstract

As a planning strategy, “connectivity” has been used to promote the functions of Urban Waterfront space to revitalize the city. By analyzing the hierarchy of functions of Urban Waterfront, namely ecological function, social function and context function, an index system of assessing its functions is proposed. In order to overcome the drawbacks which are only used numerical scales or simple linguistic values in the traditional expert evaluation for the functions of Urban Waterfront, a proportional 2-tuple linguistic representation model is introduced. Some proportional 2-tuple linguistic aggregation operators are proposed, such as PTWA, PTOWA, PTHA operators. A group decision making procedure to evaluate the functions of urban waterfront by the proposed proportional 2-tuple linguistic operators is developed. A case study of two typical redevelopment projects in West Lake Waterfront of Hangzhou of China is also provided.

Keywords: Function; Urban waterfront redevelopment; Assessment index system; proportional 2-tuple linguistic; group decision making.

1. Introduction

Accompanied by old city reconstruction and new zone development, China’s urban waterfront redevelopment has been coming into a new stage of landscape design & planning in recent years. Besides promoting the ecological harmony and the environment beautification, the profound meaning of the evolution of urban waterfront landscape begins to receive attention. Oakley 1 proposed that the transformation of urban waterfront policy has induced a particular urban form from industrial and maritime landscape to consumption landscape, which signified a radical reconstitution of place identity, economic function and social relations. Hoyle 2 discussed the urban waterfront redevelopment in port city from the perspective of globalization, which was a kind of city link occurs at the problematic and controversial interface between port function and urban environment that has reflected varied changes involving community attitudes, environmental sensitivities, urban change and transport evolution. Norcliffe et al. 3 analyzed that in the influence of postmodern culture the new urban wat-
erfront had five main groups of overlapping activities: employment, housing, recreation, hospitality industries, culture and heritage, which present a complex landscape and land-use in urban waterfront. The problem of complexity in urban waterfront has caused many interests for research. But most researches focused solely on 'cause and effect' analyses on the complex and fluid connections in society and nature with their production of complexity of scale in planning and development in urban waterfront. Sairinen and Kumpulainen proposed that new researches approach to view urban waterfronts as subjective, open, and constantly changing areas, which tended to use an embrace of scalar analyses. Thus, as a planning strategy, “connectivity” in urban waterfront has been used to redevelop the urban waterfront space in order to improve the functions of urban waterfront to meet the requirement of the urban industry and social transformation.

In the 1980s, the concept of connectivity was introduced to the category of landscape ecology, which was one of the key factors of protecting biological diversity and maintaining the stability and integrity of the ecosystem. Researches on urban waterfront connectivity were mainly focused on “landscape connectivity” analysis, which evaluated the impacts of human waterfront activities on biodiversity from an ecological point of view. The indexes could only characterize the extent of disturbances of human waterfront activity on waterfront natural environment, but could not reflect the needs of human social activities by using waterfront space. Moreover, as a planning strategy, researches on connectivity were mainly focused on the qualitative description on its realization ways, which also showed that there was a lack of a set of normative methods for evaluating the functions of urban waterfront redevelopment project. Da proposed an assessment index system of the three-dimensional connectivity of Urban Waterfront. We will further study the quantitative evaluation method for functions of urban waterfront redevelopment in this paper.

To assess the urban waterfront functions, some of the methods use the numerical values, others use the linguistic variables. When linguistic variables are used, most of the methods transform the linguistic variables into triangular fuzzy numbers. Some other methods just transform the linguistic values into discrete numerical values. For instance, \( L = \{ l_1 = \text{very poor(VP)}, l_2 = \text{poor (P)}, l_3 = \text{medium(M)}, l_4 = \text{good(G)}, l_5 = \text{very good(VG)} \} \) are used to evaluate functions of urban waterfront, the experts only gave his/her evaluations based on the five linguistic variables. After all the experts have finished their evaluation, the decision maker then collects all the evaluations, and transforms the linguistic values into numerical values, i.e., 5 denotes that the score is very good, 4 is good, and so on. Finally, the decision maker gets the whole score for each alternative and selects the best one according to the highest value. When the linguistic variables are transformed into triangular fuzzy numbers, the results may be loss of information and hence lack of precision. When linguistic variables are transformed into numerical values, the results have lost their original semantic. In both approaches, the results do not exactly match any of the initial linguistic terms. In order to overcome these drawbacks, Herrera and Martínez developed a new fuzzy linguistic representation model called 2-tuple, composed by a linguistic term and a number. Xu developed the virtual linguistic variables and practical methods for group decision making with linguistic preference relations. Dong et al. showed that the 2-tuple linguistic label and the virtual linguistic label are similar to each other, and they are only using different representation formation. The 2-tuple linguistic and virtual linguistic models have been received great attention since they emerged. However, when rating certain indicator, the experts mostly believe that the score of the alternative is between very good and good. In this situation, numerical and the above linguistic values can not be used expressed the information. Wang and Hao introduced a new linguistic representation model called proportional 2-tuple linguistic terms, to express the above linguistic information provided by the experts. In the model, linguistic information is represented by proportional 2-tuples, such as \((0.2, 0.8, 0.3)\) for the case when some expert gives that the evaluation of the alternative is distributed as 20% good and 80% very good. Considering that the experts always give the proportional linguistic variables when evaluating urban waterfront functions, in this paper, we adopt the proportional 2-tuple linguistic model. In order to obtain the overall evaluation scores for the alternatives, aggregation method is an effective method to do it. However, as far as we know, there are rarely research which concentrate on how to aggregate the proportional 2-tuple linguistic information. Therefore, in this paper, we present some new proportional 2-tuple aggregation method.
operators, such as proportional 2-tuple weighted average (PTWA) operator, proportional 2-tuple ordered weighted average (PTOWA) operator which is based on the 2-tuple and OWA operator. We also develop a proportional 2-tuple hybrid linguistic operator (PTHA) which generalizes the PTWA and PTOWA operators. Based on the PTWA operator and PTHA operator, we propose a practical procedure for group decision making to evaluate functions of Urban Waterfront with proportional 2-tuple linguistic information.

In order to do this, the rest of the paper is organized as follows. Section 2 develops the evaluation index system of functions of Urban Waterfront. Section 3 introduces the basic concepts of proportional 2-tuple linguistic representation model, and develops some new proportional 2-tuple linguistic aggregation operators, such as PTWA, PTOWA, PTHA operators. Section 4 develops a procedure for group decision making to evaluate functions of Urban Waterfront based on the proposed operators. In Section 5, a case study is provided. The paper is concluded in Section 6.

2. Assessment index system of Functions of Urban Waterfront

In the paper “"Connectivity" in Urban Rivers: Conflict and Convergence between Ecology and Design”, Rachel has revealed the meaning and conflict between the ecology, social function and context in urban waterfront redevelopment, which is a theoretical basis that we evaluate the urban waterfront functions in this paper. By increasing the connections of ecology, social function and context, we can enhance the respective functions in urban waterfront redevelopment.

(1) Ecological function

From an ecological point of view, the urban waterfront should be regarded as a riparian ecosystem located in the river ecosystem and terrestrial ecosystem communities coupling zone. The ecological function of urban waterfront is associated with species and flow characteristic, which not only involved in the green patch of urban green space system connection in traditional waterfront planning & design, but also involved in the waterfront hydrological connection. By considering that the urban waterfront is the joint action zone of nature and urban area, we believe that the significance of urban waterfront ecological function not only is limited to the role of water and green space in waterfront ecosystem, but also includes the eco-environment effects of the combination of water and green space with all kinds of landscape architecture and facilities.

(2) Social function

In social functional level, the urban waterfront redevelopment is concerned with how to use the open space in urban waterfront to release people’s mental pressure in high-density urban environment as well as to recreate and organize the public life in urban waterfront. The public recreational demand of urban waterfront is changed from landscape and ecology to culture and socialization.

(3) Context function

The context function is concerning with the cultural interactions between residence and water which are hidden in the phenomena of a variety of construction in urban waterfront. Therefore, from a contextual perspective, the context connection in urban waterfront reflects the continuity and succession in urban waterfront development, so as to increase sense of place. The establishment of high-level cognitive connection, which can reflect the history and natural succession process, becomes a way of shaping the landscape environment in waterfront redevelopment. The context function in waterfront is concerned with the historical features reconstruction and cultural significance convey. We believe that the water ecology implication and cultural implication in different kinds of landscape recovery and reconstruction are the way to enhance the context function.

Up to this point, we have presented the ecological, social and context functions in urban waterfront redevelopment. So the first grade indexes of an assessment system of the functions of Urban Waterfront Redevelopment are the ecological ($X_1$), social ($X_2$) and context ($X_3$) functions.

Moreover, considering that the versatility of urban waterfront has gotten widely attention in the urban planning field and others, which can be concluded to nine categories, such as ecological effects, environmental beautification, athletic sports, leisure and recreation, cultural entertainment, trade, business and living, transportation, culture implications, we regard ecological effects and culture implications as the evaluation of the first grade assessment indexes called ecological ($X_1$) and context ($X_3$) functions, respectively, and use the rest seven functions as the secondary assessment indexes of social function ($X_2$).
According to the relevant provision of Technical Criterion for Eco-environmental Status Evaluation (HJ/T192-2006) (Chinese National Standard), the first grade assessment index of ecological function (X1) can be divided into its two secondary assessment indexes which are ecological environment (X11) and environment safety of waterfront (X12), concerning with whether it is helpful to improve the waterfront environment of biodiversity, vegetation coverage, water system density, pollution and land deterioration.

Urban Waterfront Redevelopment has formed a set of mature mixed redevelopment model, namely, shopping, exhibition, conference, leisure, entertainment, tourism, local office, residential, hotel and etc. By means of functional type diversification, the urban waterfront recreation diversification can be achieved. So for social function (X2) can be divided into its 7 secondary assessment indexes, see Fig. 1. Therefore its secondary assessment indexes are focused on the occupational standards in urban planning and the principles of urban waterfront construction.

By taking into account that the urban waterfront should have the function of cultural implications, the secondary indexes of X3 are mainly on whether the human’s regression and nostalgia in urban waterfront are reflected, the historical and natural processes are visible and the processes could be explained clearly in design & planning projects. Therefore the historical evolution (X31) and waterfront cultural cognition (X32) become the secondary assessment indexes of X3.

In conclusion, we have set up an assessment index system of functions of Urban Waterfront Redevelopment, which consists of 3 first grade indexes and 11 second grade indexes (see Fig. 1).

3. Proportional 2-tuple fuzzy linguistic representation model

Linguistic variables provide means to approximate human activities (fuzzy reasoning) and human decisions. The concept of a linguistic variable was first introduced by Zadeh. Afterwards, the use of linguistic information is used for modeling preference intensities and performance evaluation. The linguistic terms are ordered. For simplicity of notation, an ordered linguistic term set \( L = \{ l_1, l_2, \ldots, l_n \} \) with \( l_1 < l_2 < \ldots < l_n \) is used to represent the linguistic variables. For example, one may uses an ordered linguistic term set \( L = \{ l_1 = \text{none}, l_2 = \text{bad}, l_3 = \text{medium}, l_4 = \text{good}, l_5 = \text{perfect} \} \), which has granularity 5 to represent a linguistic variable. However, when we need to express the linguistic information such as “between good and excellent”, the above discrete linguistic terms are not enough to capture the information. Thus, Wang and Hao introduced proportional 2-tuple linguistic model. In the following, we shall make a brief review of some concepts of the proportional 2-tuple which will be used in the whole paper.

**Definition 1**  . Let \( L = \{ l_1, l_2, \ldots, l_n \} \) be an ordinal term set, \( n \) is an odd number, \( i = [0, 1] \) and \( IL = L \times L = \{(a, l_i) : a \in [0, 1] \text{ and } i = 1, 2, \ldots, n\} \). Let a pair \( (l_i, l_{i+1}) \) be two successive ordinal terms in \( L \), any two elements \((a, l_i)\) of \( IL \) is called a symbolic proportion pair, where \( a, \beta \) are called a pair of symbolic proportions of the pair \((l_i, l_{i+1})\) such that \( a + \beta = 1 \). A symbolic proportion pair \( (l_i, l_{i+1}) \) will be denoted by \( (l_i(1-\alpha)l_{i+1}) \), and the set of all the symbolic proportion pairs is denoted by \( \bar{L} \), i.e., 
\[
\bar{L} = \{(l_i(1-\alpha)l_{i+1}) , a \in [0, 1] \text{ and } i = 1, 2, \ldots, n-1\}.
\]

**Remark 1** . Ordinal term \( l_i \) can be represented by \((0l_i, 1l_i)\) or \((1l_i, 0l_i)\) in \( \bar{L} \), where \( i = 2, \ldots, n-1 \). Wang and Hao 
 called the set \( \bar{L} \) the ordinal proportional 2-tuple set generated by \( L \), and the members of \( \bar{L} \) ordinal proportional 2-tuples.

The notion of proportional 2-tuple allows experts to express their opinions not just using one ordinal in the normally case, but spreading that opinion by two adjacent ordinals. To operate ordinal information under proportional 2-tuple contexts, Wang and Hao expanded the computational techniques for ordinals to proportional 2-tuple in the following.

**Comparison of Proportional 2-Tuples** : The comparison of ordinal information represented by proportional 2-tuples is carried out as follows: Let \( L = \{ l_1, l_2, \ldots, l_n \} \) be an ordinal term set and \( \bar{L} \) be the ordinal proportional 2-tuple set generated by \( L \). For any \((a, l_i) \) and \((\beta, l_{i+1}) \) \( \in \bar{L} \), define
\[
(a, l_i) < (\beta, l_{i+1}) \iff a \in (1-\alpha)(i+1) < \beta j + (1-\beta)(j+1) \iff i + (1-\alpha) < j + (1-\beta).
\]
Thus, for any two proportional 2-tuples \((a, l_i) \) and \((\beta, l_{i+1}) \), we obtain
1) if \( i < j \), then
   a) \((a, l_i) < (\beta, l_{i+1}) \) represents the same information when \( i = j - 1 \) and \( a = \alpha, \beta = 1 \);
   b) \((a, l_i) < (\beta, l_{i+1}) \) otherwise;
2) if \( i = j \), then

Fig. 1. The assessment index system of functions of Urban Waterfront Redevelopment
a) if $a=b$ then $(a_l, (1-a)l_{i+1})$, $(b_l, (1-b)l_{j+1})$ represents the same information;

b) if $a<b$ then $(a_l, (1-a)l_{i+1})$, $(b_l, (1-b)l_{j+1})$;

c) if $a>b$ then $(a_l, (1-a)l_{i+1})$, $(b_l, (1-b)l_{j+1})$.

3) The usual Negation Operator of a Proportional 2-Tuple: \( \text{Neg}(a_l, 1-a)l_{i+1}) \) is called proportional 2-tuple weighted averaging (PTWA) operator, where \( a_l \in \{1,2,\ldots,n-1\} \).

Especially, if \( w=(1/n,1/n,\ldots,1/n)^T \), then PTWA is reduced to the proportional 2-tuple averaging (PTA) operator.

Definition 4. Let \( \{(l_1, l_{i+1}) (l_2, l_{i+1}), \ldots, (l_n, l_{i+1})\} \) be a set of proportional 2-tuples in \( \overline{L} \), and \( w=(1/n,1/n,\ldots,1/n)^T \) be their associated \( \text{weighting vector such that } 0 \leq w_i \leq 1, \text{ for } i=1,2,\ldots,n \), then \( \text{PTWA}_w((l_1, l_{i+1}), (l_2, l_{i+1}), \ldots, (l_n, l_{i+1})) \) is called proportional 2-tuple OW A operator, where \( (l_0,l_1), (l_2, l_{i+1}) \) is the \( j \)th largest value of \( (l_1, l_{i+1}), (l_2, l_{i+1}), \ldots, (l_n, l_{i+1}) \), and \( a_l \in \{1,2,\ldots,n\} \).

Definition 5. Let \( \{(l_1, l_{i+1}), (l_2, l_{i+1}), \ldots, (l_n, l_{i+1})\} \) be a set of proportional 2-tuples in \( \overline{L} \), and \( \eta=(\eta_1, \eta_2, \ldots, \eta_n)^T \) be their associated \( \text{weighting vector such that } 0 \leq \eta_i \leq 1, \text{ for } i=1,2,\ldots,n \), then \( \text{PTHA}_{\alpha, \eta}((l_1, l_{i+1}), (l_2, l_{i+1}), \ldots, (l_n, l_{i+1})) \) is called proportional 2-tuple hybrid averaging (PTHA) operator, where \( (l_0,l_1), (l_2, l_{i+1}) \) is the \( j \)th largest of the proportional 2-tuple linguistic weighted argument \( (l_1, l_{i+1}), (l_2, l_{i+1}), \ldots, (l_n, l_{i+1}) \), \( i=1,2,\ldots,n \), \( \omega=(\omega_1, \omega_2, \ldots, \omega_n)^T \) is the \( \text{weighting vector of the } (l_1, l_{i+1}), (l_2, l_{i+1}), \ldots, (l_n, l_{i+1}) \), with \( \omega_j \in [0, 1] \), \( \sum_{i=1}^{n} \omega_i=1 \), \( n \) is the \( \text{balancing coefficient and } \omega_j \in \{1,2,\ldots,n\} \).

Example 1. Assume \( \omega=(0.2,0.3,0.1,0.4)^T \), \( \eta=(0.3,0.2,0.3,0.2)^T \), and \( (0.75l_1, 0.25l_2), (0.3l_3, 0.7l_4), (0.6l_4, 0.4l_3), (0.8l_3, 0.2l_4) \) By Definition 5, we have

\[
\begin{align*}
\text{PTA}_{\alpha, \eta}((l_1, l_{i+1}), (l_2, l_{i+1}), \ldots, (l_n, l_{i+1})) &= \left(1 - \frac{4 \omega_1}{1 + (1 - \alpha) l_{i+1}} \right) l_{i+1} \\
\text{PTA}_{\alpha, \eta}((l_1, l_{i+1}), (l_2, l_{i+1}), \ldots, (l_n, l_{i+1})) &= 0.6l_1 + 0.4l_4, \\
\text{PTA}_{\alpha, \eta}((l_1, l_{i+1}), (l_2, l_{i+1}), \ldots, (l_n, l_{i+1})) &= 0.56l_4 + 0.44l_3, \\
\text{PTA}_{\alpha, \eta}((l_1, l_{i+1}), (l_2, l_{i+1}), \ldots, (l_n, l_{i+1})) &= 0.24l_1 + 0.76l_2.
\end{align*}
\]
Theorem 1. The PTWA operator is a special case of the PTHA operator.

Proof. Let \( \eta = (1/n, 1/n, \ldots, 1/n)^T \), then
\[
\text{PTHA}_{\eta, q}((\lambda_i'_{a_j}, 1-\lambda_i'_{a_j+1}), \ldots, (\lambda_n'_{a_j}, 1-\lambda_n'_{a_j+1}))
\]
\[
= \pi^{-1}\left(\frac{1}{n} \sum_{j=1}^{n} \eta_j \pi(\lambda_i'_{a_j}, 1-\lambda_i'_{a_j+1})\right)
\]
\[
= \pi^{-1}\left(\frac{1}{n} \sum_{j=1}^{n} \lambda_i'_{a_j} \pi(\lambda_i'_{a_j}, 1-\lambda_i'_{a_j+1})\right)
\]
which completes the proof of Theorem 1. \( \square \)

Theorem 2. The PTOWA operator is a special case of the PTHA operator.

Proof. Let \( \omega = (1/n, 1/n, \ldots, 1/n)^T \), then
\[
(\lambda_i'_{a_j}, 1-\lambda_i'_{a_j+1}) = \lambda_i'_{a_j}, 1-\lambda_i'_{a_j+1}
\]
This completes the proof of Theorem 2. \( \square \)

4. A procedure to evaluate the functions of Urban Waterfront

Based on the proposed assessment index system of functions of Urban Waterfront and the concepts of proportional 2-tuple linguistic representation model, in the following, a procedure is proposed to solve how to evaluate the functions of Urban Waterfront by proportional 2-tuple linguistic representation model. In this paper, we consider the evaluation problem with group decision making.

For the functions of Urban Waterfront evaluation hierarchy decision problem, let \( A = \{A_1, A_2, \ldots, A_n\} \) be a discrete set of alternatives, let \( X = \{X_1, X_2, \ldots, X_m\} \) be a set of criteria, let \( \omega = (w_1, w_2, \ldots, w_m)^T \) be the weight vector of the criteria, where \( w_i \geq 0, \quad i = 1, 2, \ldots, m, \quad \sum_i w_i = 1, \quad w_i \geq 0, \quad i = 1, 2, \ldots, m \), and \( \omega = (w_1, w_2, \ldots, w_m)^T \) be the weight vector of \( X_i \), let \( E = \{E_1, E_2, \ldots, E_q\} \) be a set of experts, \( \omega = (\omega_1, \omega_2, \ldots, \omega_q)^T \) be the weight vector of experts, where \( \omega_j \geq 0, \quad j = 1, 2, \ldots, q, \quad \sum_j \omega_j = 1 \). For each alternative \( A_i (i = 1, 2, \ldots, n) \), the expert \( E_j \in \mathcal{E} \) gives his proportional 2-tuple linguistic evaluation values \( \omega_{ij} \) for the sub-criteria \( X_k(i = 1, 2, \ldots, m, \quad k = 1, 2, \ldots, n_i, \quad j = 1, 2, \ldots, q) \), and constructs the decision matrix \( R_{\omega} \).

The procedure based on the PTWA and PTHA operators for the hierarchy problem is described as follows:

Step 1. For each decision matrix \( R_{\omega} = (r_{ij})_{n \times m} \) for each criteria \( X_i \) by PTWA operator, where
\[
\begin{align*}
\overline{r}_{ij} &= \text{PTWA}_{\omega_i}((\lambda_i'_{a_j}, 1-\lambda_i'_{a_j+1}), \ldots, (\lambda_n'_{a_j}, 1-\lambda_n'_{a_j+1})) \\
&= \pi^{-1}\left(\frac{1}{m} \sum_{k=1}^{m} w_i k \pi(\lambda_i'_{a_j}, 1-\lambda_i'_{a_j+1})\right)
\end{align*}
\]
Step 2. For the integrated decision matrix \( \overline{R} = (\overline{r}_{ij})_{n \times m} \), calculate the group collective decision matrix \( \overline{R} = (\overline{r}_{ij})_{n \times m} \) for each criteria \( X_i \) by the PTHA operator:
\[
\overline{r}_{ij} = \text{PTHA}_{\omega_i}((\lambda_i'_{a_j}, 1-\lambda_i'_{a_j+1}), \ldots, (\lambda_n'_{a_j}, 1-\lambda_n'_{a_j+1}))
\]
where \( \omega = (\omega_1, \omega_2, \ldots, \omega_q)^T \) be the weight vector of experts, with \( \omega_j \geq 0, \quad j = 1, 2, \ldots, q, \quad \sum_j \omega_j = 1 \), \( \eta = (\eta_1, \eta_2, \ldots, \eta_q)^T \) is the weighting vector of the PTHA operator, with \( \eta_j \geq 0, \quad j = 1, 2, \ldots, q, \quad \sum_j \eta_j = 1 \).

Step 3. For the group collective decision matrix \( \overline{R} = (\overline{r}_{ij})_{n \times m} \), calculate the overall aggregated values \( r^* \) for each alternative \( A_i (i = 1, 2, \ldots, n) \) by the PTWA operator, where
\[
\begin{align*}
r^* &= \text{PTWA}_{\omega}((\lambda_i'_{a_j}, 1-\lambda_i'_{a_j+1}), \ldots) \\
&= \pi^{-1}\left(\frac{1}{m} \sum_{k=1}^{m} w_i k \pi(\lambda_i'_{a_j}, 1-\lambda_i'_{a_j+1})\right)
\end{align*}
\]
Step 4. Rank the alternatives or select the desired one(s) according to the values \( r^* \) for each alternative \( A_i (i = 1, 2, \ldots, n) \) by the comparison rules of proportional 2-tuple linguistic values.

Step 5. End

5. A case study

West Lake in Hangzhou, China, one of the world’s most romantic places, has been designated by the United Nations as one of the World Cultural Heritage Sites. As
a famous scenic, flourished in Song Dynasty, West Lake is located to the west of the city, which is surrounded by hills in north, south and west, and was close to the ancient city by its east side. Nowadays, the city that served ancient emperors is still a cultural center and an important tourist destination in China, for the famous West Lake, with over 30 million visitors a year. The West Lake urban waterfront refers to the east shore of the lake, which is adjacent to the city center (see Fig. 2).

As the city economy growing, by the influence of modern urban planning, there built a highway to ease the urban traffic congestion in urban waterfront. Nanshan Rd. and Hubin Rd. were ones of the multilane highways that border the scenic lake grew out of scale and became a significant barrier to access to the lakefront. Just a narrow strip of land was available for public use and benefited only the owners of property facing the water. In a concerted effort to ameliorate this obstacle and to revitalize the urban waterfront, different types of urban waterfront redevelopment projects were carried out to improve its connectivity. Two typical redevelopment projects in West Lake Waterfront are chosen to be the research objects, which are “South-line conformity project” along Nanshan Rd.42 and “Hubin commerce & tourism district” along Hubin Rd.43 (see Fig. 3). The former project is committed to build a series of linear parks in the foreshore to perfect the urban waterfront recreation functions by landscape restoration. The latter one is for urban design project that is aimed to develop the mix use of commerce & tourism district to unite the history and inherent beauty of West Lake with the Hangzhou’s historic city center. By analyzing the difference on the functions of urban waterfront, it can be explained that which way is the best way to improve the functions of Urban Waterfront Redevelopment, which has long been perplexed in theory circle.

In order to evaluate the functions of above redevelopment projects in West Lake Urban Waterfront, four experts are invited to assess on the two alternatives. The weight vector of the four experts is \( \omega=(0.3, 0.2, 0.3, 0.2)^T \). The experts evaluate each project of West Lake Urban Waterfront Redevelopment using the linguistic term set

\[ L=\{l_1=\text{very poor (VP)}, l_2=\text{poor}, l_3=\text{medium (M)}, l_4=\text{good (G)}, l_5=\text{very good (VG)} \} \]

Each expert gives his proportional 2-tuples linguistic values (PTLVs) for each sub-criteria for the two alternatives. The weights of all the criteria and their sub-criteria and the preference values are given by the experts directly and are listed in Tables 1 and 2, respectively.
Table 1. The group decision matrix $R^1$ for South-line conformity project using PTLVs

<table>
<thead>
<tr>
<th>$X_1(w_1=0.3)$</th>
<th>$X_2(w_1=0.5)$</th>
<th>$X_3(w_2=0.2)$</th>
<th>$X_4(w_2=0.5)$</th>
<th>$X_5(w_2=0.2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_1(w_1=0.3)$</td>
<td>$X_2(w_1=0.5)$</td>
<td>$X_3(w_2=0.2)$</td>
<td>$X_4(w_2=0.5)$</td>
<td>$X_5(w_2=0.2)$</td>
</tr>
<tr>
<td>$(0.3 l_60.7 l_9)$</td>
<td>$(0.6 l_60.4 l_9)$</td>
<td>$(0.9 l_60.1 l_9)$</td>
<td>$(0.9 l_60.3 l_9)$</td>
<td>$(0.3 l_60.5 l_9)$</td>
</tr>
<tr>
<td>$(0.2 l_60.8 l_9)$</td>
<td>$(0.3 l_60.7 l_9)$</td>
<td>$(0.9 l_60.2 l_9)$</td>
<td>$(0.9 l_60.1 l_9)$</td>
<td>$(0.3 l_60.7 l_9)$</td>
</tr>
</tbody>
</table>

Table 2. The group decision matrix $R^2$ for Hubin commerce & tourism district using PTLVs

<table>
<thead>
<tr>
<th>$X_1(w_1=0.3)$</th>
<th>$X_2(w_1=0.5)$</th>
<th>$X_3(w_2=0.2)$</th>
<th>$X_4(w_2=0.5)$</th>
</tr>
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<tr>
<td>$X_1(w_1=0.3)$</td>
<td>$X_2(w_1=0.5)$</td>
<td>$X_3(w_2=0.2)$</td>
<td>$X_4(w_2=0.5)$</td>
</tr>
<tr>
<td>$(0.2 l_60.8 l_9)$</td>
<td>$(0.6 l_60.4 l_9)$</td>
<td>$(0.9 l_60.1 l_9)$</td>
<td>$(0.9 l_60.3 l_9)$</td>
</tr>
<tr>
<td>$(0.3 l_60.7 l_9)$</td>
<td>$(0.4 l_60.6 l_9)$</td>
<td>$(0.9 l_60.1 l_9)$</td>
<td>$(0.6 l_60.4 l_9)$</td>
</tr>
</tbody>
</table>

Table 3. The integrated decision matrix $R^{11}$ using PTLVs

<table>
<thead>
<tr>
<th>$X_1(w_1=0.3)$</th>
<th>$X_2(w_1=0.5)$</th>
<th>$X_3(w_2=0.2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_1(w_1=0.3)$</td>
<td>$X_2(w_1=0.5)$</td>
<td>$X_3(w_2=0.2)$</td>
</tr>
<tr>
<td>$(0.75 l_60.25 l_9)$</td>
<td>$(0.3 l_60.7 l_9)$</td>
<td>$(0.6 l_60.4 l_9)$</td>
</tr>
<tr>
<td>$(0.45 l_60.55 l_9)$</td>
<td>$(0.32 l_60.68 l_9)$</td>
<td>$(0.27 l_60.73 l_9)$</td>
</tr>
<tr>
<td>$(0.3 l_60.7 l_9)$</td>
<td>$(0.25 l_60.75 l_9)$</td>
<td>$(0.55 l_60.45 l_9)$</td>
</tr>
</tbody>
</table>

Table 4. The integrated decision matrix $R^{21}$ using PTLVs

<table>
<thead>
<tr>
<th>$X_1(w_1=0.3)$</th>
<th>$X_2(w_1=0.5)$</th>
<th>$X_3(w_2=0.2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_1(w_1=0.3)$</td>
<td>$X_2(w_1=0.5)$</td>
<td>$X_3(w_2=0.2)$</td>
</tr>
<tr>
<td>$(0.75 l_60.25 l_9)$</td>
<td>$(0.5 l_60.5 l_9)$</td>
<td>$(0.2 l_60.8 l_9)$</td>
</tr>
<tr>
<td>$(0.21 l_60.79 l_9)$</td>
<td>$(0.27 l_60.73 l_9)$</td>
<td>$(0.16 l_60.84 l_9)$</td>
</tr>
<tr>
<td>$(0.35 l_60.65 l_9)$</td>
<td>$(0.25 l_60.75 l_9)$</td>
<td>$(0.5 l_60.5 l_9)$</td>
</tr>
</tbody>
</table>

Table 5. The functions degree using PTLVs

<table>
<thead>
<tr>
<th>South-line conformity project</th>
<th>Hubin commerce &amp; tourism district</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_1$</td>
<td>$(0.408 l_60.592 l_9)$</td>
</tr>
<tr>
<td>$X_2$</td>
<td>$(0.0652 l_60.9348 l_9)$</td>
</tr>
<tr>
<td>$X_3$</td>
<td>$(0.204 l_60.796 l_9)$</td>
</tr>
<tr>
<td>Overall aggregated value</td>
<td>$(0.0918 l_60.9042 l_9)$</td>
</tr>
</tbody>
</table>
Table 6. The group decision matrix $R_1$ for South-line conformity project using NVs

<table>
<thead>
<tr>
<th>$X_i(w_1=0.3)$</th>
<th>$E_1$</th>
<th>$E_2$</th>
<th>$E_3$</th>
<th>$E_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{11}(w_{11}=0.5)$</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>$X_{12}(w_{12}=0.5)$</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>$X_{21}(w_{21}=0.2)$</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>$X_{22}(w_{22}=0.1)$</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>$X_{23}(w_{23}=0.2)$</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>$X_{24}(w_{24}=0.1)$</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>$X_{25}(w_{25}=0.1)$</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>$X_{26}(w_{26}=0.1)$</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>$X_{27}(w_{27}=0.2)$</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>$X_{31}(w_{31}=0.5)$</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>$X_{32}(w_{32}=0.5)$</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 7. The group decision matrix $R_2$ for Hubin commerce & tourism district using NVs

<table>
<thead>
<tr>
<th>$X_i(w_1=0.3)$</th>
<th>$E_1$</th>
<th>$E_2$</th>
<th>$E_3$</th>
<th>$E_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{11}(w_{11}=0.5)$</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>$X_{12}(w_{12}=0.5)$</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>$X_{21}(w_{21}=0.2)$</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>$X_{22}(w_{22}=0.1)$</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>$X_{23}(w_{23}=0.2)$</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>$X_{24}(w_{24}=0.1)$</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>$X_{25}(w_{25}=0.1)$</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>$X_{26}(w_{26}=0.1)$</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>$X_{27}(w_{27}=0.2)$</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>$X_{31}(w_{31}=0.5)$</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>$X_{32}(w_{32}=0.5)$</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 8. The integrated decision matrix $\tilde{R}_1$ using NVs

<table>
<thead>
<tr>
<th>$X_i(w_1=0.3)$</th>
<th>$E_1$</th>
<th>$E_2$</th>
<th>$E_3$</th>
<th>$E_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{1}(w_{1}=0.3)$</td>
<td>4.5</td>
<td>3.5</td>
<td>3.5</td>
<td>4</td>
</tr>
<tr>
<td>$X_{2}(w_{2}=0.5)$</td>
<td>3.8</td>
<td>3.7</td>
<td>3.8</td>
<td>3.9</td>
</tr>
<tr>
<td>$X_{3}(w_{3}=0.2)$</td>
<td>3</td>
<td>3</td>
<td>2.5</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 9. The integrated decision matrix $\tilde{R}_2$ using NVs

<table>
<thead>
<tr>
<th>$X_i(w_1=0.3)$</th>
<th>$E_1$</th>
<th>$E_2$</th>
<th>$E_3$</th>
<th>$E_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{1}(w_{1}=0.3)$</td>
<td>4.5</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>$X_{2}(w_{2}=0.5)$</td>
<td>3.1</td>
<td>3.7</td>
<td>3.5</td>
<td>3.7</td>
</tr>
<tr>
<td>$X_{3}(w_{3}=0.2)$</td>
<td>3</td>
<td>3</td>
<td>2.5</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 10. The functions degree using NVs

<table>
<thead>
<tr>
<th></th>
<th>South-line conformity project</th>
<th>Hubin commerce &amp; tourism district</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_1$</td>
<td>3.9</td>
<td>4.15</td>
</tr>
<tr>
<td>$X_2$</td>
<td>3.8</td>
<td>3.46</td>
</tr>
<tr>
<td>$X_3$</td>
<td>2.85</td>
<td>2.65</td>
</tr>
</tbody>
</table>

Overall aggregated value

|       | 3.69                          | 3.505                            |

**Remark 2.** Here, the weights of all criteria are given by the decision makers directly. There are so many methods to generate weights, such as AHP method, linguistic quantifier, etc.

**Step 1.** For each decision matrix $R_1$, $R_2$, calculate the integrated matrix $\tilde{R}_1$, $\tilde{R}_2$ for each sub-criteria $X_i$ by PTWA operator. For instance, the integrated value $\tilde{r}_{11}$ of the criteria $X_1$ for the South-line conformity project is:
\[ \pi_1 = \pi^{-1}(0.5 \times \pi((0.3l_4, 0.7l_5)) + 0.5 \times \pi((0.2l_3, 0.8l_4)) = \pi^{-1}(4.25) = (0.75l_4, 0.25l_5) \]

In the same way, we can get all the integrated values for the two alternatives which are listed in Tables 3 and 4, respectively.

**Step 2.** Calculate the group collective decision matrix \( \hat{R} = (\hat{r}_{ij})_{3 \times 1} \) for each criteria \( X_i \) \((i=1,2,3)\) by the PTHA operator (let \( \eta=(0.3,0.4,0.2,0.1)^T \)), which are listed in Table 5.

**Step 3.** Calculate the overall aggregated value for the two alternatives, respectively, which are listed in the last line in Table 5.

From Table 5, we can see that the functions degree of the two alternatives can be expressed by proportional 2-tuple linguistic variables. The ecological function \( X_1 \) degrees of the two alternatives are somewhat different: the score of South-line conformity project is \((0.408 l_4, 0.592 l_5)\), which means that the group experts think that for South-line conformity project, its ecological function 40.8% is good, and 59.2% is very good; while for Hubin commerce & tourism district only 71.8% is good, and 28.2% is very good. The social function \( X_2 \) of the two alternatives are different, as for South-line conformity project, 6.52% is medium, and 93.48% is good; and for Hubin commerce & tourism district, 88.72% is good, and 11.28% is very good. The context function \( X_3 \) of the two alternatives are almost same, i.e., 20.4% of South-line conformity project is poor, 79.6% is medium; while 19.4% of Hubin commerce & tourism district is poor, 80.6% is medium. The whole aggregated values of the functions of the two alternatives are almost same, 9.18% is medium, 90.42% is good for South-line conformity project; and 9.78% is medium, 90.22% is good for Hubin commerce & tourism district.

In order to show the advantages of the proposed method, in the following, comparative analysis with the traditional methods are provided. Here, we suppose that the experts evaluate each project of West Lake Urban Waterfront Redevelopment using the linguistic term set

\[ L=\{l_1=very \ poor \ (VP), l_2=poor \ (P), l_3=medium \ (M), l_4=good \ (G), l_5=very \ good \ (VG)\} \]

then, these linguistic evaluation values are transformed into numerical values (NVs). i.e., 5 denotes that the score is very good, 4 is good, and so on. Here, we show the experts' numerical evaluation values directly which are listed in Tables 6 and 7. The weights of criteria and experts are the same as in Tables 1 and 2 respectively.

In order to get the overall scores of each alternatives. The following steps are involved.

**Step 1.** For each decision matrix \( R^1, R^2 \), calculate the integrated matrix \( \hat{R}^1, \hat{R}^2 \) for each sub-criteria \( X_i \) by WA operator. For instance, the integrated value \( \pi_{i1} \) of the criteria \( X_1 \) for the South-line conformity project is:

\[ \pi_{i1} = 0.5 \times 5 + 0.5 \times 4 = 4.5 \]

Similarly, we can get the integrated values for the two alternatives which are listed in Tables 8 and 9.

**Step 2.** Calculate the group collective decision matrix \( \hat{R} = (\hat{r}_{ij})_{3 \times 1} \) for each criteria \( X_i \) \((i=1,2,3)\) by the WA operator, which are listed in Table 10.

**Step 3.** Calculate the overall aggregated value for the two alternatives, respectively, which are listed in the last line in Table 10.

Compared with the proposed method in this paper, the method has the following drawbacks. First, the experts could use the linguistic variables to denote his scores for each alternative with respect to each criteria. However, the experts could not give his scores by proportional 2-tuples linguistic variables, this does not meet the facts, as the experts may think one score is between good and very good. Second, the final scores are still in numerical values. From Table 10, we see that the overall aggregated value of South-line conformity project is 3.69. The meaning of the value is not clear. While our proposed values are still in the form of proportional 2-tuple linguistic values. The decision maker knows the linguistic value. From Table 5, we know that the final aggregated value of South-line conformity project is \((0.0918 l_3, 0.9042 l_4)\), which denotes that the value is between medium and good, the proportional of them is 9.18% and 90.42%, approximate to good.

6. Conclusions

A standard assessment index system for urban waterfront functions is built in this paper. It is based on the traditional experts evaluation of waterfront design & planning, and is a kind of comprehensive quantization in projects evaluation results, providing a systematic analysis methods for improving the functional and structural connection in urban waterfront. In order to overcome the drawbacks which the evaluation for urban waterfront functions is only used numerical scales or simple linguistic values in the current researches, this paper introduces the proportional 2-tuple linguistic representation model. The model can express the
linguistic information more clearly and without loss of information, and the final results are also expressed by the proportional 2-tuple linguistic variables. We also develop a group decision making procedure to evaluate functions of Urban Waterfront by the proposed proportional 2-tuple linguistic model. A case study for the two typical redevelopment projects in West Lake Urban Waterfront of Hangzhou of China and comparative analysis are provided.

Acknowledgement

The authors are very grateful to Editor-in-Chief, Associate Editor and the four anonymous reviewers for their constructive comments and suggestions that have helped to improve the quality of this paper. This work was partly supported by the National Natural Science Foundation of China (NSFC) under Grant 71101043.

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