International Journal of Computational Intelligence Systems, Vol. 7, No. 4 (August 2014), 796-808

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

Ting Da
School of Landscape Architecture, Beijing Forestry University, Beijing,100083, PR China

Yejun Xu [1,2*]
[1]State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing, 210098, PR China
[2]Business School, Hohai University, Jiangning, Nanjing, 211100, PR China
E-mail: xuyejohn@163.com

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-

---

* Corresponding author. Tel. +86-25-68514612
E-mail address: xuyejohn@163.com (Y-J. Xu)

Co-published by Atlantis Press and Taylor & Francis

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[4]. Sairinen and Kumpulainen [5] proposed that new researches approach to view urban waterfronts as subjective, open, and constantly changing areas, which tended to use an embracement 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[6]. 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[7,8]. The indexes could only characterize the extent of the 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[9,10], which also showed that there was a lack of a set of normative methods for evaluating the functions of urban waterfront redevelopment project. Da[11] 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 [12-16]. Some other methods just transform the linguistic values into discrete numerical values. For instance, $L=\{l_1=$*very poor*(VP), $l_2=$ *poor* (P), $l_3=$ *medium*(M), $l_4=$*good*(G), $l_5=$*very good*$(VG)\}$ [17-20] 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 above approaches, the results do not exactly match any of the initial linguistic terms. In order to overcome these drawbacks, Herrera and Martíze[21,22] developed a new fuzzy linguistic representation model called 2-tuple, composed by a linguistic term and a number. Xu[23-25] developed the virtual linguistic variables and practical methods for group decision making with linguistic preference relations. Dong *et al.*[26,27] 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[19,28-33]. 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[34,35] 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 $(0.2\ l_4, 0.8\ l_5)$ 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 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[36]. 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[10] 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[37]. 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[38], 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[39].

(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 perpective, the context connection in urban waterfront reflects the continuity and succession in urban waterfront development[40], so as to increase sense of place. The establishment of high-level cognitive connection[10], 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[9,38-40], 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 (X_1) can be divided into its two secondary assessment indexes which are ecological environment (X_{11}) and environment safety of waterfront (X_{12}), 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[9]. By means of functional type diversification, the urban waterfront recreation diversification can be achieved. So for social function (X_2) 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 X_3 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 (X_{31}) and waterfront cultural cognition (X_{32}) become the secondary assessment indexes of X_3.

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[41]. 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. $L=\{l_1=none,\ l_2=bad,\ l_3=medium,\ l_4=\text{good},\ l_5=perfect\}$, 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[34] 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[34]. Let $L=\{l_1,l_2,\ldots,l_n\}$ be an ordinal term set, n is an odd number, $I=[0,1]$ and $IL\equiv I\times L=\{(\alpha,l_i)$: $\alpha\in[0,1]$ and $i=1,2,\ldots,n\}$. Let a pair (l_i,l_{i+1}) be two successive ordinal terms in L, any two elements $(\alpha l_i, \beta l_{i+1})$ of IL is called a symbolic proportion pair, where α, β are called a pair of symbolic proportions of the pair (l_i,l_{i+1}) such that $\alpha+\beta=1$. A symbolic proportion pair $\alpha l_i,(1-\alpha)l_{i+1}$ will be denoted by $(\alpha l_i,(1-\alpha)l_{i+1})$, and the set of all the symbolic proportion pairs is denoted by $\overline{L}$, i.e., $\overline{L}=\{(\alpha l_i,(1-\alpha)l_{i+1}),\ \alpha\in[0,1]$ and $i=1, 2,\ldots,n-1\}$.

Remark 1. Ordinal term l_i can be represented by $(0l_{i-1}, 1l_i)$ or $(1l_i,0l_{i+1})$ in $\overline{L}$, where $i=2,\ldots,n-1$. Wang and Hao[34] called the set $\overline{L}$ the ordinal proportional 2-tuple set generated by L, and the members of $\overline{L}$ 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[34] 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 $\overline{L}$ be the ordinal proportional 2-tuple set generated by L. For any $(\alpha l_i,(1-\alpha)l_{i+1})$, $(\beta l_j,(1-\beta)l_{j+1})\in\overline{L}$, define

$$(\alpha l_i,(1-\alpha)l_{i+1})<(\beta l_j,(1-\beta)l_{j+1})\Leftrightarrow$$
$$\alpha i+(1-\alpha)(i+1)<\beta j+(1-\beta)(j+1)\Leftrightarrow$$
$$i+(1-\alpha)<j+(1-\beta)\ .$$

Thus, for any two proportional 2-tuples $(\alpha l_i,(1-\alpha)l_{i+1})$ and $(\beta l_j,(1-\beta)l_{j+1})$, we obtain

1) if $i<j$, then

a) $(\alpha l_i,(1-\alpha)l_{i+1})$, $(\beta l_j,(1-\beta)l_{j+1})$ represents the same information when $i=j-1$ and $\alpha=0$, $\beta=1$;

b) $(\alpha l_i,(1-\alpha)l_{i+1})<(\beta l_j,(1-\beta)l_{j+1})$ otherwise;

2) if $i=j$, then

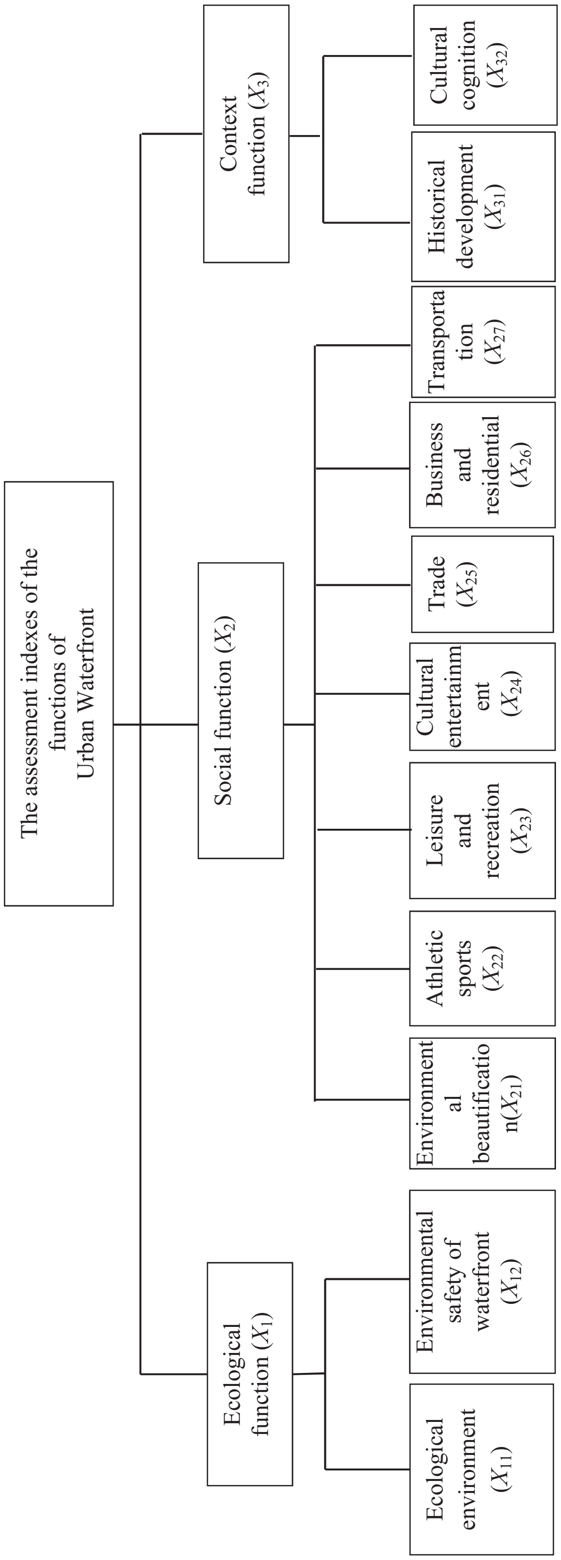

Fig. 1. The assessment index system of functions of Urban Waterfront Redevelopment

a) if $\alpha=\beta$ then $(\alpha l_i,(1-\alpha)l_{i+1})$, $(\beta l_j,(1-\beta)l_{j+1})$ represents the same information;

b) if $\alpha<\beta$ then $(\alpha l_i,(1-\alpha)l_{i+1})>(\beta l_j,(1-\beta)l_{j+1})$;

c) if $\alpha>\beta$ then $(\alpha l_i,(1-\alpha)l_{i+1})<(\beta l_j,(1-\beta)l_{j+1})$.

3) The Usual Negation Operator of a Proportional 2-Tuple: $Neg((\alpha l_i,(1-\alpha)l_{i+1}))=((1-\alpha)l_{n-i},\alpha l_{n+1-i}))$, where n is the cardinality of L, $L=\{l_1,l_2,\ldots,l_n\}$.

The aforementioned two computation techniques can be characterized by position indices of proportional 2-tuples which are defined in the following.

Definition 2[34]. Let $L=\{l_1,l_2,\ldots,l_n\}$ be an ordinal term set and $\overline{L}$ be the ordinal proportional 2-tuple set generated by L.

Define $\pi:\overline{L}\to[1,n]$ by

$$\pi((\alpha l_i,(1-\alpha)l_{i+1}))=i+(1-\alpha),$$

where $i=1,2,\ldots,n-1$ and $\alpha\in[0,1]$.

π is called the position index function of ordinal 2-tuples.

Note that, under the identification convention which was remarked after Definition 1, the position index function π becomes a bijection from $\overline{L}$ to $[1,n]$ and its inverse $\pi^{-1}:[1,n]\to\overline{L}$ is $\pi^{-1}(x)=((1-\beta)l_i,\beta l_{i+1})$, where $i=E(x)$, E is the integral part function, $\beta=x-i$ and $(1l_n,0l_{n+1})\equiv(0l_{n-1},1l_n)$.

Thus, for any $(\alpha l_i,(1-\alpha)l_{i+1})$, $(\beta l_j,(1-\beta)l_{j+1})\in\overline{L}$

$$(\alpha l_i,(1-\alpha)l_{i+1})<\beta l_j,(1-\beta)l_{j+1})\Leftrightarrow$$
$$\pi((\alpha l_i,(1-\alpha)l_{i+1}))<\pi((\beta l_j,(1-\beta)l_{j+1}))$$

and

$$Neg((\alpha l_i,(1-\alpha)l_{i+1}))$$
$$=\pi^{-1}(n+1-(\pi((\alpha l_i,(1-\alpha)l_{i+1})))).$$

Meanwhile, one can develop aggregation operators of proportional ordinal 2-tuples through their position indices.

Definition 3. Let $\{(\lambda_1 l_{\alpha_1},(1-\lambda_1)l_{\alpha_1+1}),(\lambda_2 l_{\alpha_2},(1-\lambda_2)l_{\alpha_2+1}),\ldots,(\lambda_n l_{\alpha_n},(1-\lambda_n)l_{\alpha_n+1})\}$ be a set of proportional 2-tuples in $\overline{L}$, and $w=(1/n,\ldots,1/n)^T$ be their associated weighting vector, such that $0\le w_i\le 1$, for $i=1,2,\ldots,n$, and $\sum_{i=1}^n w_i=1$, then

$$\mathrm{PTWA}_w((\lambda_1 l_{\alpha_1},(1-\lambda_1)l_{\alpha_1+1}),\ldots,(\lambda_n l_{\alpha_n},(1-\lambda_n)l_{\alpha_n+1}))$$
$$=\pi^{-1}\left(\sum_{j=1}^n w_j(\pi(\lambda_j l_{\alpha_j},(1-\lambda_j)l_{\alpha_j+1}))\right)$$

is called proportional 2-tuple weighted averaging (PTWA) operator, where $\alpha_j\in\{1,2,\ldots,n-1\}$.

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 $\{(\lambda_1 l_{\alpha_1},(1-\lambda_1)l_{\alpha_1+1}),(\lambda_2 l_{\alpha_2},(1-\lambda_2)l_{\alpha_2+1}),\ldots,(\lambda_n l_{\alpha_n},(1-\lambda_n)l_{\alpha_n+1})\}$ be a set of proportional 2-tuples in $\overline{L}$, and $w=(1/n,\ldots,1/n)^T$ be their associated weighting vector such that $0\le w_i\le 1$, for $i=1,2,\ldots,n$, and $\sum_{i=1}^n w_i=1$, then

$$\mathrm{PTOWA}_w((\lambda_1 l_{\alpha_1},(1-\lambda_1)l_{\alpha_1+1}),\ldots,(\lambda_n l_{\alpha_n},(1-\lambda_n)l_{\alpha_n+1}))$$
$$=\pi^{-1}\left(\sum_{j=1}^n w_j(\pi(\lambda_{(j)}l_{(j)},(1-\lambda_{(j)})l_{(j)+1}))\right)$$

is called proportional 2-tuple OWA operator, where $(\lambda_{(j)}l_{(j)},(1-\lambda_{(j)})l_{(j)+1})$ is the jth largest value of $(\lambda_j l_{\alpha_j},(1-\lambda_j)l_{\alpha_j+1})\}$, and $\alpha_j\in\{1,2,\ldots,n-1\}$.

Definition 5. Let $\{(\lambda_1 l_{\alpha_1},(1-\lambda_1)l_{\alpha_1+1}),(\lambda_2 l_{\alpha_2},(1-\lambda_2)l_{\alpha_2+1}),\ldots,(\lambda_n l_{\alpha_n},(1-\lambda_n)l_{\alpha_n+1})\}$ be a set of proportional 2-tuples in $\overline{L}$, and $\eta=(\eta_1,\eta_2,\ldots,\eta_n)^T$ be their associated weighting vector, such that $0\le\eta_i\le 1$, for $i=1,2,\ldots,n$, and $\sum_{i=1}^n\eta_i=1$, then

$$\mathrm{PTHA}_{\omega,\eta}((\lambda_1 l_{\alpha_1},(1-\lambda_1)l_{\alpha_1+1}),\ldots,(\lambda_n l_{\alpha_n},(1-\lambda_n)l_{\alpha_n+1}))$$
$$=\pi^{-1}\left(\sum_{j=1}^n\eta_j(\pi(\lambda_{(j)}l_{(j)},(1-\lambda_{(j)})l_{(j)+1}))\right)$$

is called proportional 2-tuple hybrid averaging (PTHA) operator, where $(\lambda_{(j)},l_{(j)},(1-\lambda_{(j)})l_{(j)+1})$ is the jth largest of the proportional 2-tuple linguistic weighted argument $\overline{(\lambda_i l_{\alpha_i},(1-\lambda_i)l_{\alpha_i+1})}$ $\left(\overline{(\lambda_i l_{\alpha_i},(1-\lambda_i)l_{\alpha_i+1})}=\pi^{-1}(n\omega_i\pi(\lambda_i l_{\alpha_i},(1-\lambda_i)l_{\alpha_i+1}))\right)$, $i=1,2,\ldots,n$, $\omega=(\omega_1,\omega_2,\ldots,\omega_n)^T$ is the weighting vector of the $(\lambda_i l_{\alpha_i},(1-\lambda_i)l_{\alpha_i+1})$ with $\omega_j\in[0,1]$, $\sum_{j=1}^n\omega_j=1$, n is the balancing coefficient and $\alpha_j\in\{1,2,\ldots,n-1\}$.

Example 1. Assume $\omega=(0.2,0.3,0.1,0.4)^T$, $\eta=(0.3,0.2,0.3,0.2)^T$, and $(0.75l_4,0.25l_5)$, $(0.3l_3,0.7l_4)$, $(0.6l_4,0.4l_5)$, $(0.8l_4,0.2l_5)$

By Definition 5, we have

$$\pi^{-1}(4\times0.2\times\pi(0.75l_4,0.25l_5))=(0.6l_3,0.4l_4),$$
$$\pi^{-1}(4\times0.3\times\pi(0.3l_3,0.7l_4))=(0.56l_4,0.44l_5),$$
$$\pi^{-1}(4\times0.1\times\pi(0.6l_4,0.4l_5))=(0.24l_1,0.76l_2),$$

$$\pi^{-1}(4\times 0.4\times \pi(0.8l_4,0.2l_5))=(0.28l_6,0.72l_7)\,,$$

thus,

$$\begin{aligned}&\mathrm{PTHA}_{\omega,\eta}((0.75l_4,0.25l_5),(0.3l_3,0.7l_4),\\&\qquad(0.6l_4,0.4l_5),(0.8l_4,0.2l_5))\\&=\pi^{-1}(0.3\times\pi(0.28l_6,0.72l_7)+0.2\times\pi(0.56l_4,0.44l_5)\\&\quad+0.3\times(0.6l_3,0.4l_4)+0.2\times 0.24l_1,0.76l_2))\\&=(0.724l_4,0.276l_5)\end{aligned}$$

Theorem 1. *The PTWA operator is a special case of the PTHA operator.*

Proof. Let $\eta=(1/n,1/n,...,1/n)^T$, then

$$\begin{aligned}&\mathrm{PTHA}_{\omega,\eta}((\lambda_1 l_{\alpha_1},(1-\lambda_1)l_{\alpha_1+1}),...,(\lambda_n l_{\alpha_n},(1-\lambda_n)l_{\alpha_n+1}))\\&=\pi^{-1}\left(\sum_{j=1}^{n}\eta_j(\pi(\lambda_{(j)}l_{(j)},(1-\lambda_{(j)})l_{(j)+1}))\right)\\&=\pi^{-1}\left(\tfrac{1}{n}\sum_{j=1}^{n}(\pi(\lambda_{(j)}l_{(j)},(1-\lambda_{(j)})l_{(j)+1}))\right)\\&=\pi^{-1}\left(\sum_{j=1}^{n}\omega_j\pi(\lambda_j l_{\alpha_j},(1-\lambda_j)l_{\alpha_j+1})\right)\end{aligned}$$

which completes the proof of Theorem 1. □

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

Proof. Let $\omega=(1/n,1/n,...,1/n)^T$, then

$$\overline{(\lambda_j l_{\alpha_j},(1-\lambda_j)l_{\alpha_j+1})}=\lambda_j l_{\alpha_j},(1-\lambda_j)l_{\alpha_j+1}$$

This completes the proof of Theorem 2. □

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 $w=(w_1,w_2,\ldots,w_m)^T$ be the weight vector of the criteria, where $w_i\geq 0$, $i=1,2,\ldots,m$, $\Sigma_{i=1}^{n}w_i=1$, let $X_i=\{X_{i1},X_{i2},\ldots,X_{iu_i}\}$ be the sub-criteria of the criteria X_i ($i=1,2,\ldots,m$), and $w_i=(w_{i1},w_{i2},\ldots,w_{iu_i})^T$ be the weight vector of X_i, where $w_{ik}\geq 0$, $k=1,2,\ldots,u_i$, $\Sigma_{ik=1}^{u_i}w_{ik}=1$, 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 $\omega_j\geq 0$, $j=1,2,\ldots,q$, $\Sigma_{j=1}^{q}\omega_j=1$. For each alternative A_σ ($\sigma=1,2,\ldots,n$), the expert $E_i\in E$ gives his proportional 2-tuple linguistic evaluation values r_{ikj}^{σ} for the sub-criteria X_{ik} ($i=1,2,\ldots,m$, $k=1,2,\ldots,u_i$, $j=1,2,\ldots,q$), and constructs the decision matrix. $R^\sigma=(r_{ikj}^{\sigma})$ The procedure based on the PTWA and PTHA operators for the hierarchy problem is described as follows:

Step 1. For each decision matrix $R^\sigma=(r_{ikj}^{\sigma})(\sigma=1,\ldots,n)$, calculate the integrated decision matrix $\overline{R}^\sigma=(\overline{r}_{ij}^{\sigma})_{m\times n}$ for each criteria X_i by PTWA operator, where

$$\begin{aligned}\overline{r}_{ij}^{\sigma}&=\mathrm{PTWA}_{w_i}((\lambda_1 l_{\alpha_1},(1-\lambda_1)l_{\alpha_1+1}),...,\\&\qquad(\lambda_{u_i}l_{\alpha_{u_i}},(1-\lambda_{u_i})l_{\alpha_{u_i}+1}))\\&=\pi^{-1}\left(\sum_{k=1}^{u_i}w_{ik}(\pi(\lambda_k l_{\alpha_k},(1-\lambda_k)l_{\alpha_k+1}))\right)\end{aligned}$$

Step 2. For the integrated decision matrix $\overline{R}^\sigma=(\overline{r}_{ij}^{\sigma})_{m\times n}$, calculate the group collective decision matrix $\dot{R}^\sigma=(\dot{r}_i^{\sigma})_{m\times 1}$ for each criteria X_i ($i=1,2,\ldots,m$) by the PTHA operator:

$$\begin{aligned}\dot{r}_i^{\sigma}&=\mathrm{PTHA}_{\omega,\eta}((\lambda_1 l_{\alpha_1},(1-\lambda_1)l_{\alpha_1+1}),...,\\&\qquad(\lambda_q l_{\alpha_q},(1-\lambda_q)l_{\alpha_q+1}))\\&=\pi^{-1}\left(\sum_{j=1}^{q}\omega_j(\pi(\lambda_{(j)}l_{(j)},(1-\lambda_{(j)})l_{(j)+1}))\right)\end{aligned}$$

where $\omega=(\omega_1,\omega_2,\ldots,\omega_q)^T$ be the weight vector of experts, with $\omega_j\geq 0$, $j=1,2,\ldots,q$, $\Sigma_{j=1}^{q}\omega_j=1$; $\eta=(\eta_1,\eta_2,\ldots,\eta_q)^T$ is the weighting vector of the PTHA operator, with $\eta_1\geq 0$, $j=1,2,\ldots,q$, $\Sigma_{j=1}^{q}\eta_j=1$.

Step 3. For the group collective decision matrix $\dot{R}^\sigma=(\dot{r}_i^{\sigma})_{m\times 1}$, calculate the overall aggregated values r^σ for each alternative A_σ ($\sigma=1,2,\ldots,n$) by the PTWA operator, where

$$\begin{aligned}r^{\sigma}&=\mathrm{PTWA}_{w}((\lambda_1 l_{\alpha_1},(1-\lambda_1)l_{\alpha_1+1}),...,\\&\qquad(\lambda_m l_{\alpha_m},(1-\lambda_m)l_{\alpha_m+1}))\\&=\pi^{-1}\left(\sum_{i=1}^{m}w_i(\pi(\lambda_i l_{\alpha_i},(1-\lambda_i)l_{\alpha_i+1}))\right)\end{aligned}$$

Step 4. Rank the alternatives or select the desired one(s) according to the values r^σ ($\sigma=1,2,\ldots,n$) by the comparison rules of proportional 2-tuples 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

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

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.

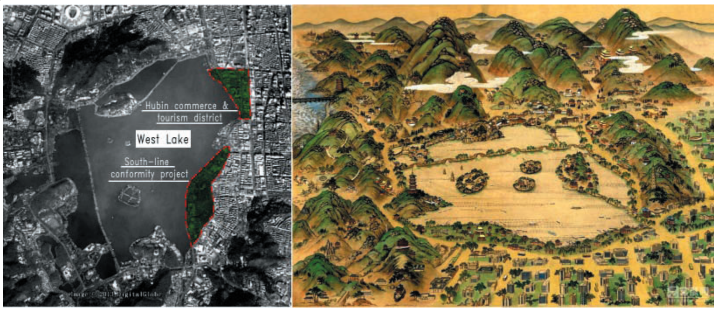

Fig.2 Landscape status of West Lake Waterfront and its master plan from Google Earth

Fig.3 Landscape design Plan of South-line conformity project (left)

& Master plan of Hubin commerce & tourism district (right)

Table 1. The group decision matrix R^1 for South-line conformity project using PTLVs

		E_1	E_2	E_3	E_4
$X_1(w_1=0.3)$	$X_{11}(w_{11}=0.5)$	$(0.3\ l_4,0.7l_5)$	$(0.3\ l_4,0.7\ l_5)$	$(0.3\ l_4,0.7\ l_5)$	$(0.3\ l_4,0.7\ l_5)$
	$X_{12}(w_{12}=0.5)$	$(0.2\ l_3,0.8\ l_4)$	$(0.3\ l_2,0.7\ l_3)$	$(0.9\ l_4,0.1\ l_5)$	$(0.3\ l_3,0.7\ l_4)$
$X_2(w_2=0.5)$	$X_{21}(w_{21}=0.2)$	$(0.7\ l_4,0.3\ l_5)$	$(0.5\ l_4,0.5\ l_5)$	$(0.2\ l_4,0.8\ l_5)$	$(0.2\ l_4,0.8\ l_5)$
	$X_{22}\ (w_{22}=0.1)$	$(0.3\ l_1,0.7\ l_2)$	$(0.9\ l_2,0.1\ l_3)$	$(0.8\ l_2,0.2\ l_3)$	$(0.1\ l_1,0.9\ l_2)$
	$X_{23}(w_{23}=0.2)$	$(0.9\ l_3,0.1\ l_4)$	$(0.8\ l_3,0.2\ l_4)$	$(0.8\ l_3,0.2\ l_4)$	$(0.7\ l_3,0.3\ l_4)$
	$X_{24}(w_{24}=0.1)$	$(0.9\ l_4,0.1\ l_5)$	$(0.7\ l_4,0.3\ l_5)$	$(0.8\ l_4,0.2\ l_5)$	$(0.7\ l_4,0.3\ l_5)$
	$X_{25}(w_{25}=0.1)$	$(0.9\ l_3,0.1\ l_4)$	$(0.7\ l_3,0.3\ l_4)$	$(0.7\ l_3,0.3\ l_4)$	$(0.8\ l_3,0.2\ l_4)$
	$X_{26}(w_{26}=0.1)$	$(0.8\ l_4,0.2\ l_5)$	$(0.9\ l_4,0.1\ l_5)$	$(0.8\ l_4,0.2\ l_5)$	$(0.9\ l_4,0.1\ l_5)$
	$X_{27}(w_{27}=0.2)$	$(0.2\ l_3,0.8\ l_4)$	$(0.2\ l_3,0.8\ l_4)$	$(0.3\ l_3,0.7\ l_4)$	$(0.3\ l_3,0.7\ l_4)$
$X_3(w_3=0.2)$	$X_{31}(w_{31}=0.5)$	$(0.5\ l_2,0.5\ l_3)$	$(0.2\ l_2,0.8\ l_3)$	$(0.6\ l_2,0.4\ l_3)$	$(0.6\ l_2,0.4\ l_3)$
	$X_{32}(w_{32}=0.5)$	$(0.1\ l_2,0.9\ l_3)$	$(0.3\ l_2,0.7\ l_3)$	$(0.5\ l_2,0.5\ l_3)$	$(0.2\ l_2,0.8\ l_3)$

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

		E_1	E_2	E_3	E_4
$X_1(w_1=0.3)$	$X_{11}(w_{11}=0.5)$	$(0.2\ l_4,0.8\ l_5)$	$(0.6\ l_4,0.4\ l_5)$	$(0.5\ l_4,0.5\ l_5)$	$(0.3\ l_4,0.7\ l_5)$
	$X_{12}(w_{12}=0.5)$	$(0.3\ l_3,0.7\ l_4)$	$(0.4\ l_2,0.6\ l_3)$	$(0.9\ l_3,0.1\ l_4)$	$(0.6\ l_3,0.4\ l_4)$
$X_2(w_2=0.5)$	$X_{21}(w_{21}=0.2)$	$(0.6\ l_4,0.4\ l_5)$	$(0.5\ l_4,0.5\ l_5)$	$(0.3\ l_4,0.7\ l_5)$	$(0.1\ l_4,0.9\ l_5)$
	$X_{22}(w_{22}=0.1)$	$(0.3\ l_2,0.7\ l_3)$	$(0.6\ l_2,0.4\ l_3)$	$(0.5\ l_2,0.5\ l_3)$	$(0.1\ l_1,0.9\ l_2)$
	$X_{23}(w_{23}=0.2)$	$(0.3\ l_3,0.7\ l_4)$	$(0.6\ l_3,0.4\ l_4)$	$(0.7\ l_3,0.3\ l_4)$	$(0.4\ l_3,0.6\ l_4)$
	$X_{24}(w_{24}=0.1)$	$(0.9\ l_4,0.1\ l_5)$	$(0.8\ l_4,0.2\ l_5)$	$(0.7\ l_4,0.3\ l_5)$	$(0.9\ l_4,0.1\ l_5)$
	$X_{25}(w_{25}=0.1)$	$(0.8\ l_3,0.2\ l_4)$	$(0.7\ l_3,0.3\ l_4)$	$(0.6\ l_3,0.4\ l_4)$	$(0.8\ l_3,0.2\ l_4)$
	$X_{26}(w_{26}=0.1)$	$(0.9\ l_4,0.1\ l_5)$	$(0.8\ l_4,0.2\ l_5)$	$(0.6\ l_4,0.4\ l_5)$	$(0.5\ l_4,0.5\ l_5)$
	$X_{27}(w_{27}=0.2)$	$(0.2\ l_3,0.8\ l_4)$	$(0.3\ l_3,0.7\ l_4)$	$(0.1\ l_3,0.9\ l_4)$	$(0.2\ l_3,0.8\ l_4)$
$X_3(w_3=0.2)$	$X_{31}(w_{31}=0.5)$	$(0.5\ l_2,0.5\ l_3)$	$(0.3\ l_2,0.7\ l_3)$	$(0.6\ l_2,0.4\ l_3)$	$(0.4\ l_2,0.6\ l_3)$
	$X_{32}(w_{32}=0.5)$	$(0.2\ l_2,0.8\ l_3)$	$(0.2\ l_2,0.8\ l_3)$	$(0.4\ l_2,0.6\ l_3)$	$(0.3\ l_2,0.7\ l_3)$

Table 3. The integrated decision matrix $\overline{R}^1$ using PTLVs

	E_1	E_2	E_3	E_4
$X_1(w_1=0.3)$	$(0.75\ l_4,\ 0.25\ l_5)$	$(0.3\ l_3,0.7\ l_4)$	$(0.6\ l_4,0.4\ l_5)$	$(0.8\ l_4,0.2\ l_5)$
$X_2(w_2=0.5)$	$(0.45\ l_3,0.55\ l_4)$	$(0.32\ l_3,0.68\ l_4)$	$(0.27\ l_3,0.73\ l_4)$	$(0.29\ l_3,0.71\ l_4)$
$X_3(w_3=0.2)$	$(0.3\ l_2,0.7\ l_3)$	$(0.25\ l_2,0.75\ l_3)$	$(0.55\ l_2,0.45\ l_3)$	$(0.4\ l_2,0.6\ l_3)$

Table 4. The integrated decision matrix $\overline{R}^2$ using PTLVs

	E_1	E_2	E_3	E_4
$X_1(w_1=0.3)$	$(0.75\ l_4,\ 0.25\ l_5)$	$(0.5\ l_3,\ 0.5\ l_4)$	$(0.2\ l_3,\ 0.8\ l_4)$	$(0.95\ l_4,\ 0.05\ l_5)$
$X_2(w_2=0.5)$	$(0.21\ l_3,\ 0.79\ l_4)$	$(0.27\ l_3,\ 0.73\ l_4)$	$(0.16\ l_3,\ 0.84\ l_4)$	$(0.17\ l_3,\ 0.83\ l_4)$
$X_3(w_3=0.2)$	$(0.35\ l_2\ ,0.65\ l_3)$	$(0.25\ l_2,0.75\ l_3)$	$(0.5\ l_2,0.5\ l_3)$	$(0.35\ l_2,0.65\ l_3)$

Table 5. The functions degree using PTLVs

	South-line conformity project	Hubin commerce & tourism district
X_1	$(0.408\ l_4,0.592\ l_3)$	$(0.718\ l_4,0.282\ l_3)$
X_2	$(0.0652\ l_3,0.9348\ l_4)$	$(0.8872\ l_4,0.1128\ l_3)$
X_3	$(0.204\ l_2,0.796\ l_3)$	$(0.194\ l_2,0.806\ l_3)$
Overall aggregated value	$(0.0918\ l_3,0.9042\ l_4)$	$(0.0978\ l_3,0.9022\ l_4)$

Table 6. The group decision matrix R^1 for South-line conformity project using NVs

		E_1	E_2	E_3	E_4
$X_1(w_1=0.3)$	$X_{11}(w_{11}=0.5)$	5	4	4	5
	$X_{12}(w_{12}=0.5)$	4	3	3	3
$X_2(w_2=0.5)$	$X_{21}(w_{21}=0.2)$	4	5	5	5
	X_{22} $(w_{22}=0.1)$	3	2	3	2
	$X_{23}(w_{23}=0.2)$	4	3	3	4
	$X_{24}(w_{24}=0.1)$	4	4	4	4
	$X_{25}(w_{25}=0.1)$	3	3	3	4
	$X_{26}(w_{26}=0.1)$	4	4	4	3
	$X_{27}(w_{27}=0.2)$	4	4	4	4
$X_3(w_3=0.2)$	$X_{31}(w_{31}=0.5)$	3	3	2	3
	$X_{32}(w_{32}=0.5)$	3	3	3	3

Table 7. The group decision matrix R^2 for Hubin commerce & tourism district using NVs

		E_1	E_2	E_3	E_4
$X_1(w_1=0.3)$	$X_{11}(w_{11}=0.5)$	5	5	4	4
	$X_{12}(w_{12}=0.5)$	4	3	4	4
$X_2(w_2=0.5)$	$X_{21}(w_{21}=0.2)$	2	5	5	5
	X_{22} $(w_{22}=0.1)$	2	2	2	2
	$X_{23}(w_{23}=0.2)$	3	3	3	3
	$X_{24}(w_{24}=0.1)$	4	4	4	4
	$X_{25}(w_{25}=0.1)$	3	3	3	4
	$X_{26}(w_{26}=0.1)$	4	4	4	3
	$X_{27}(w_{27}=0.2)$	4	4	3	4
$X_3(w_3=0.2)$	$X_{31}(w_{31}=0.5)$	3	3	2	2
	$X_{32}(w_{32}=0.5)$	3	3	3	2

Table 8. The integrated decision matrix $\overline{R}^1$ using NVs

	E_1	E_2	E_3	E_4
$X_1(w_1=0.3)$	4.5	3.5	3.5	4
$X_2(w_2=0.5)$	3.8	3.7	3.8	3.9
$X_3(w_3=0.2)$	3	3	2.5	3

Table 9. The integrated decision matrix $\overline{R}^2$ using NVs

	E_1	E_2	E_3	E_4
$X_1(w_1=0.3)$	4.5	4	4	4
$X_2(w_2=0.5)$	3.1	3.7	3.5	3.7
$X_3(w_3=0.2)$	3	3	2.5	2

Table 10. The functions degree using NVs

	South-line conformity project	Hubin commerce & tourism district
X_1	3.9	4.15
X_2	3.8	3.46
X_3	2.85	2.65
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[44] method, linguistic quantifier [45,46], etc.

Step 1. For each decision matrix R^1, R^2, calculate the integrated matrix $\overline{R}^1$, $\overline{R}^2$ for each sub-criteria X_i by PTWA operator. For instance, the integrated value $\overline{r}_{11}^1$ of the criteria X_1 for the South-line conformity project is:

$$\bar{r}_{11}^{1} = \pi^{-1}(0.5\times\pi((0.3l_4, 0.7l_5)) + 0.5\times\pi((0.2l_3, 0.8l_4))$$
$$= \pi^{-1}(4.25) = (0.75l_4, 0.25l_5)$$

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 $\dot{R}^{\sigma} = (\dot{r}_i^{\sigma})_{3\times1}$ for each criteria X_i (i=1,2,3) by the PTHA operator (let η=(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 also 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 (X3) 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*, 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 $\bar{R}^1$, $\bar{R}^2$ for each sub-criteria X_i by WA operator. For instance, the integrated value $\bar{r}_{11}^{1}$ of the criteria X_1 for the South-line conformity project is:

$$\bar{r}_{11}^{1} = 0.5\times5 + 0.5\times4 = 4.5$$

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 $\dot{R}^{\sigma} = (\dot{r}_i^{\sigma})_{3\times1}$ 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.

References

1. S. Oakley, The role of urban governance in re-constructing place, economic function and social relations in urban waterfront regeneration: the case of port adelaide, South Australia, *Space and Polity* **11** (2007) 279-295.
2. B. Hoyle, Global and local change on the port-city waterfront, *Geographical Review* **90** (2010) 395-417.
3. G. Norcliffe, K. Bassett, T. Hoare, The emergence of postmodernism on the urban waterfront: Geographical perspectives on changing relationships, *Journal of Transort Gegraphy* **4** (1996) 123-134.
4. S. Bunce, G. Desfor, Introduction to "Political ecologies of urban waterfront transormations", *Political Ecologies of Urban Waterfront Transformations* **24** (2007) 251-258.
5. R. Sairinen, S. Kumpulainen, Assessing social impacts in urban waterfront regeneration, *Environment Impact Assessment Review* **26** (2006) 120-135.
6. C.G. Wu, Z.X. Zhou, P.C. Wang, M.J. Teng, The concept and measurement of landscape connectivity and its application, *Acta Ecologica Sinica* **30** (2010) 1904-1910.
7. X.X. Cao, S.Y. Ding, Landscape pattern dynamics of water body in Kaifeng city in the 21th century, *Journal of Geographical Sciences* **15** (2005) 106-114.
8. T.X. Yue, Q.H. Ye, Q.S. Liu, On models for landscapte connectivity: A case study of the new-born wetland of the Yellow River delta, *Journal of Geographical Sciences* **12** (2002) 186-195.
9. K.S. Huang, Connecivity and linkage: urban design strategies of waterfront city, *City Planning Review* **30** (2006) 77-80 (in Chinese).
10. M. Rachel, "Connectivity" in urban rivers: Conflict and convergence between ecology and design, *Technology in Science* **28** (2006) 477-488.
11. T. Da, Analyses on three-dimensional connectivity of eco-social function-context of urban waterfront redevelopment, *Journal of Nanjing Forestry University* **37** (2013) 129-134 (in Chinese).
12. O. Cakir, M.S. Canbolat, A web-based decision support system for multi-criteria inventory classification using fuzzy AHP methodology, *Expert Systems with Applications* **35** (2008) 1367-1378.
13. Y.M. Wang, K.S. Chin, G.K.K. Poon, B.J. Yang, Risk evaluation in failure mode and effectes analysis using fuzzy weighted geometric mean, *Expert Systems with Applications* **36** (2009) 1195-1207.
14. Z.F. Zhang, X.N. Chu, Fuzzy group decision-making for multi-format and multi-granularity linguistic judgments in quality function deployment, *Expert Systems with Applications* **36** (2009) 9150-9158.
15. M. Saremi, S.F. Mousavi, A. Sanayei, TQM consultant selection in SMEs with TOPSIS under fuzzy environment, *Expert Systems with Applications* **36** (2009) 2742-2749.
16. C.C. Sun, G.T.R. Lin, Using fuzzy TOPSIS method for evaluating the competitive advantages of shopping websites, *Expert Systems with Applications* **36** (2009) 11764-11771.
17. M.M. Feng, The esthetic evaluation of urban plants landscape based on the model of AHP-fuzzy comprehensive evaluation, *Journal of HangZhou Teachers Colleages (Natural Sciences Edition)* **6** (2007) 373-378.
18. Y.J. Xu, Q.L. Da, Standard and mean deviation methods for linguistic group decision making and their applications, *Expert Systems with Applications* **37** (2010) 5905-5912.
19. Y.J. Xu, H.M. Wang, Approaches based on 2-tuple linguistic power aggregation operators for multiple attribute group decision making under linguistic environment, *Applied Soft Computing* **11** (2011) 3988-3997.
20. Y.C. Dong, Y.F. Xu, H.Y. Li, M. Dai, A comparative study of the numerical scales and the prioritization methods in AHP, *European Journal of Operational Research* **186** (2008) 229-242.
21. F. Herrera, L. Martíze, A 2-tuple fuzzy linguistic representation model for computing with words, *IEEE Transactions on Fuzzy Systems* **8** (2000) 746-752.
22. F. Herrera, L. Martíze, A model based on linguistic 2-tuples for dealing with multigranular hierarchical linguistic contexts in multi-expert decision-making, *IEEE Transactions on Systems Man and Cybernetics Part B-Cybernetics* **31** (2001) 227-234.
23. Z.S. Xu, A method based on linguistic aggregation operators for group decision making with linguistic preference relations, *Information Sciences* **166** (2004) 19-30.
24. Z.S. Xu, An approach based on the uncertain LOWG and induced uncertain LOWG operators to group decision making with uncertain multiplicative linguistic preference relations, *Decision Support Systems* **41** (2006) 488-499.
25. Z.S. Xu, Induced uncertain linguistic OWA operators applied to group decision making, *Information Fusion* **7** (2006) 231-238.
26. Y.C. Dong, Y.F. Xu, S. Yu, Linguistic multiperson decision making based on the use of multiple preference relations, *Fuzzy Sets and Systems* **160** (2009) 603-623.
27. Y.C. Dong, Y.F. Xu, H.Y. Li, B. Feng, The OWA-based consensus operator under linguistic representation models

using position indexes, *European Journal of Operational Research* **203** (2010) 455-463.
28. J.M. Merigo, A.M. Gil-Lafuente, Induced 2-tuple linguistic generalized aggregation operators and their application in decision-making, *Information Sciences* **236** (2013) 1-16.
29. Y.J. Xu, Q.L. Da, X.W. Liu, Some properties of linguistic preference relation and its ranking in group decision making, *Journal of Systems Engineering and Electronics* **21** (2010) 244-249.
30. Y.J. Xu, H.M. Wang, Power Geometric Operators for Group Decision Making under Multiplicative Linguistic Preference Relations, *International Journal of Uncertainty Fuzziness and Knowledge-Based Systems* **20** (2012) 139-159.
31. L. Martíze, F. Herrera, An overview on the 2-tuple linguistic model for computing with words in decision making: Extensions, applications and challenges, *Information Sciences* **207** (2012) 1-18.
32. F. Herrera, L. Martíze, The 2-tuple linguistic computational model. Advantages of its linguistic description, accuracy and consistency., *International Journal of Uncertainty Fuzziness and Knowledge-Based Systems* **9** (2001) 33-48.
33. E. Herrera-Viedma, L. Martíze, F. Mata, F. Chiclana, A consensus support system model for group decision-making problems with multigranular linguistic preference relations, *IEEE Transactions on Fuzzy Systems* **13** (2005) 644-658.
34. J.H. Wang, J.Y. Hao, A new version of 2-tuple fuzzy linguistic representation model for computing with words, *IEEE Transactions on Fuzzy Systems* **14** (2006) 435-445.
35. J.H. Wang, J.Y. Hao, Fuzzy linguistic PERT, *IEEE Transactions on Fuzzy Systems* **15** (2007) 133-144.
36. R.R. Yager, On ordered weighted averaging aggregation operators in multicriteria decision making, *IEEE Transactions on Systems Man and Cybernetics* **18** (1988) 183-190.
37. R.J. Naiman, R.E. Bilby, River ecology and management: lessons from the Pacific coastal eco-region, Springer, New York, 1998.
38. P. Sun, Z.F. Wang, The natural landscape of the river and waterfront design in urban areas, *City Planning Review* **24** (2000) 19-22 (in Chinese).
39. J.X. Zhang, Z.G. Li, Social and cultural significance of open space: evolution and new requirements of European cities *Urban Planning Overseas* **19** (2004) 24-27 (in Chinese).
40. Y.G. Zhou, X.W. Shen, Research on the development orientations of urban waterfront based on space-time dimension *Urban Problems* (2011) 30-35 (in Chinese).
41. L.A. Zadeh, The concept of a linguistic variable and its applications to approximate reasoning, *Information Sciences* **8,9** (1975) 199-249,301-357, 143-180.
42. Dialoge between nature and culture: comprehensive improvement of protection record for West Lake Hang zhou, China Architecture & Building Press (in Chinese), Hangzhou Landscape Architechure Design Institute Co.Ltd. 2009.
43. SWA, Hangzhou Hubin, http://www.swagroup.com/project/hangzhou-hubin.html.
44. T.L. Saaty, The Analytic Hierarchy Process, McGraw-Hill, New York, 1980.
45. Z.S. Xu, An overview of methods for determining OWA weights, *International Journal of Intelligent Systems* **20** (2005) 843-865.
46. R.R. Yager, On ordered weighted averaging aggregation operators in multicriteria decision making, *IEEE Transactions on Systems Man and Cybernetics* **18** (1988) 183-190.