The Study on the Time and Space Utility Value of Indoor Spaces to Individual

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Abstract

Based on the utility theory, this paper studies the relation between individual and space. By comparing individual subjective preference to each attribute of space, the weight of space's each attribute and the membership degrees in different periods can be obtained. Using fuzzy mathematics, this paper gets the calculation model of utility value under the influence of time, through which the utility value can be confirmed. Thus, this paper quantifies individual's subjective comments on pace.

Keywords

Utility value; preference compare; subjective comment.

1. Introduction

Indoor space is the carrier of individual daily activities. Any forms and kinds of indoor activities of individual are in indoor spaces. The study of distribution of individual in indoor spaces is an important theory basis for the rescue of individual in places where sudden accidents may happen, and the study of the distribution research starts from the relation of individual and indoor spaces. Indoor space has many classifications and is large in number. The relation between individual and indoor spaces can be regarded as the individual's subjective choice of indoor spaces, and the utility value can be used to study individual's subjective consciousness.

Originating from economic research, utility theory describes individual's compare and selection of commodities through subjective preferential comments on commodities' each attribute. Utility theory has been applied in many fields. For example, individual's selection of vehicle is based on individual's subjective preferential comments on each attribute of vehicle [1-10]. Therefore, the connotation of utility value lies in individual's attitude towards the choice of events.

2. The Attribute of Individual and Space

Individual and indoor space both have many attributes. The classifications of individual attribute include gender, age, job and so on, while the space attribute studied in this paper is different from the quantitative attributes of traditional sense, such as space area, space volume and so on. The space attribute in this paper refers to the evaluation standard formulated according to individual's daily activities in the space, including comfort level of job, and comfort level of rest.

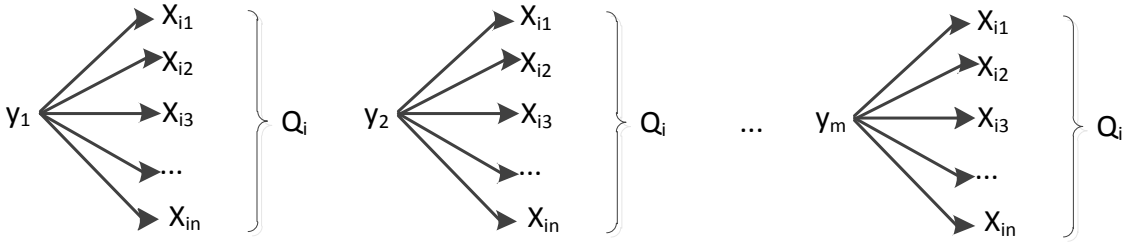
If the space is set as Q, individual as q, space's attribute as x_n, and individual's attribute as y_m, Q and q are functions with multiple attributes: $Q = Q\{x_1, x_2, x_3, \ldots, x_n\}$ and $q = q\{y_1, y_2, y_3, \ldots, y_m\}$.

When individual may be in some space, some factors in this spatial attribute set $\{x_1, x_2, x_3, \ldots, x_n\}$ match some factors in individual attribute set $\{y_1, y_2, y_3, \ldots, y_m\}$. This matching relation indicates individual's subjective willingness to go to this space.

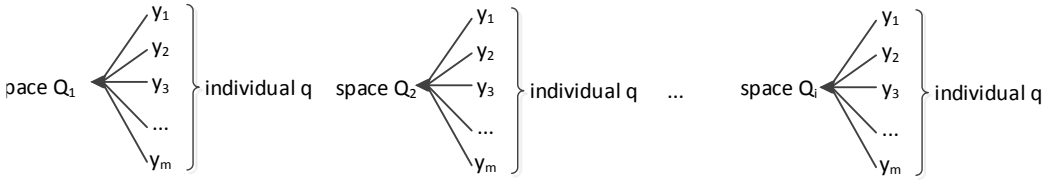
If i kinds of space is set, the calculation model $Q_i = Q_i\{x_{i1}, x_{i2}, x_{i3}, \ldots, x_{in}\}$ can be got. Whether individual q of one of the factors in attribute $\{y_1, y_2, y_3, \ldots, y_m\}$ wants to arrive at space Q_i or not are q's subjective consciousness, which can be described as q's preferential comment on each attribute $\{x_{i1}, x_{i2}, x_{i3}, \ldots, x_{in}\}$ of Q, reflecting q's final preferential comment on Q_i. As is shown in figure 1(a), figure 1 (b), and instances are shown in figure 2 (a), figure 2 (b).

In figure 2, individual who belongs to some attributes (student, female, above 20 years old) chooses dormitory and classroom with some attributes (comfort level of job, comfort level of rest, comfort level of leisure). Based on ordinal utility theory, this paper compares different individual's preference to the two spaces' different attributes. Thus, individual's preferential utility comment on dormitory and classroom can be got.

attributes of Q_i : $x_{i1}, x_{i2}, x_{i3} \ldots\ldots x_{in}$		*attributes* of $q: y_1, y_2, y_3 \ldots\ldots y_m$	
space Q_i	x_{i1}	y_1	individual q
	x_{i2}	y_2	
	x_{i3}	y_3	
	.....	.....	
	x_{in}	y_m	

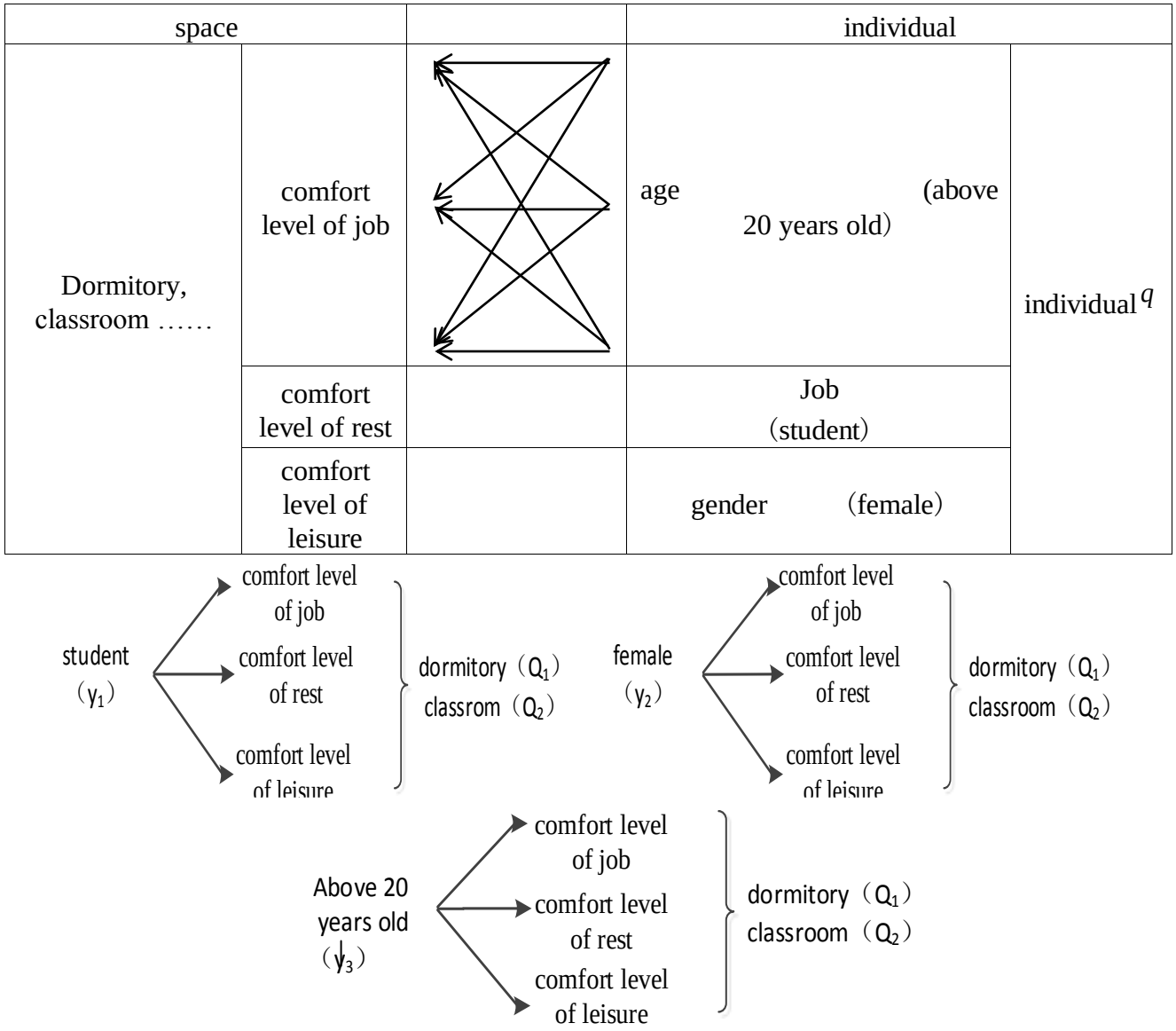


(a) Preferential comment of individual q with some attributes on each attribute of space Q_i

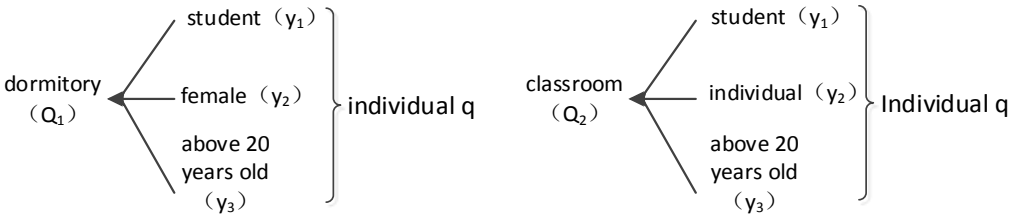


(b) Preferential comment of individual q with some attributes on space Q_i

Figure1 Individual's preferential comment on different spaces



(a) Preferential comment of individual who is student, female or above 20 years old on each attribute of dormitory and classroom



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b) Preferential comment of individual who is student, female or above 20 years old on dormitory and classroom

Figure 2 Process of preferential comment of individual q on dormitory and classroom

Therefore, individual's choice of space is shown by subjective preferential comment. When individual q_j's preferential comment on space Q_i is good, namely, utility evaluation is sound, showing that individual q_j wants to arrive at space Q_i.

Using relevant mathematical methods, this paper tries to quantify the subjective consciousness, namely, to calculate the utility value of indoor space to individual.

3. The Calculation Method of Spatial Utility Value

Utility comment reflects individual's subjective consciousness and shows individual tendency degree. To calculate utility value is to transform the qualitative evaluation into quantitative evaluation. The assignment of utility evaluation belongs to cardinal utility theory. Utility value reflects utility comment. If utility evaluation gets better, and the utility value gets larger.

Using relevant method of fuzzy mathematics, this paper gets utility value U of space to individual by comparing individual's preference to each attribute of space. Figure 3 shows the steps of getting utility value of space to individual. Individual with some attributes (age, gender, and job) is the prerequisite in discussing individual's utility comment on space, for individual with different attributes has different utility comment on space. Therefore, in this study, the first thing is to ensure individual attribute y_m. Foe example, individual job attributes, such as student, teacher and so on, are the research objects. Individual with job attribute is set as q_j, the space to be made utility comment is set as Q_i.

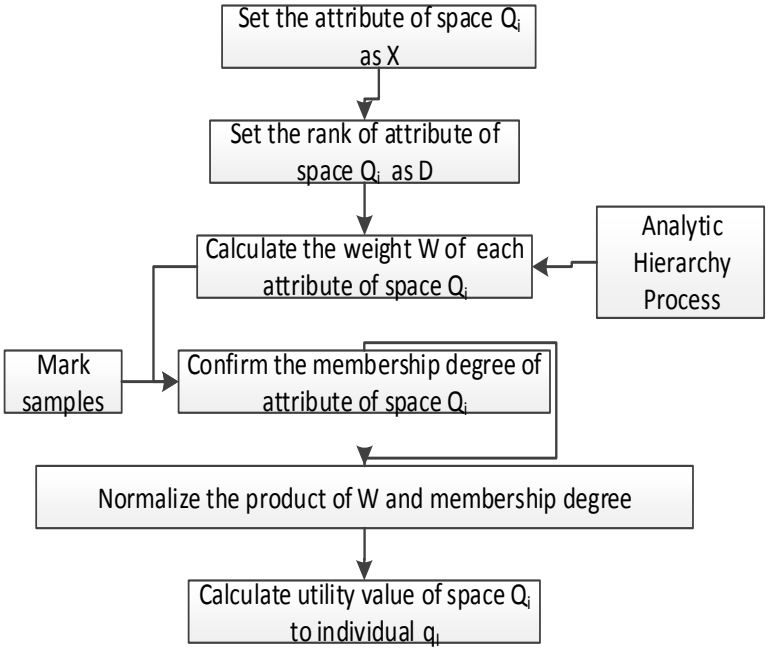

Figure 3 Steps to calculate utility value of space Qi to individual q_j

(1) Setting space Q_i 's attribute as X

Spatial attribute can be confirmed according to individual's evaluation standard on space in daily life. This paper regards comfort level as space's using standard, which is one of the reasons for individual to be in some space. The comfort level of space is higher, the individual is more willing to be in this space.

For space Q_i, comfort level of rest, comfort level of job and so on are its evaluation standard in terms of individual's daily activities. n kinds of evaluation standards are n kinds of attributes of space. Space Q_i 's attribute is set as X, then the assemblage is $X \in \{x_{i1}, x_{i2}, x_{i3}, \ldots, x_{in}\}$.

(2) Setting space Q_i 's each attribute rank as D

Space's each attribute is not equally important. Rank is set as D, then the rank's assemblage is $D \in \{e_1, e_2, e_3, \ldots, e_m\}$

(3) Calculating weight W of space's each attribute

Weight W describes the importance degree of each attribute of space Q_i to individual q_j, and q_j's preferential degree to each attribute of Q_i, which is the result of the two degrees comparison. The step should be completed through the method of expert scoring. The research object is individual q_j with job attribute. However, there are many kinds of jobs. Expert should compare each attribute from the perspective of individual with its own job, which is hard to guarantee the accuracy of evaluation result. However, individual samples from each kind of job compare the each attribute of space and get an average, which is much more objective than the former.

Analytic Hierarchy Process (AHP) is used to calculate weight, and the steps are as follows

Firstly, compare each attribute of space Q_i, and then grade. The scoring criteria are as follows:

If individual q_j's preferential degree of longitudinal attribute, compared to preferential degree of the lateral attribute, is absolute bigger, the number is 9; very bigger, the number is 7; relative bigger, the number is 5; a little bigger, the number is 3; the same big, the number is 1.

If individual q_j's preferential degree of lateral attribute, compared to preferential degree of the longitudinal attribute, is absolute bigger, the number is 1/9; very bigger, the number is 1/7; relative bigger, the number is 1/5; a little bigger, the number is 1/3; the same big, the number is 1.

Table 1. Grading chart of preferential degree of individual q_j to each attribute of space Q_i

attribute of Q_i / attribute of Q_i	$\boldsymbol{i}_1$	$\boldsymbol{i}_2$	…	$\boldsymbol{i}_n$
$\boldsymbol{i}_1$	1	B_{12}	…	B_{1n}
$\boldsymbol{i}_2$	B_{21}	1	…	B_{2n}
…	…	…	1	…
$\boldsymbol{i}_n$	B_{n1}	B_{n2}	…	1

Individual q_j compares each attribute of space Q_i, and the evaluation score is B, then there is assemblage $\{B_{12}, B_{13}, B_{14} \ldots B_{1n}\}, \{B_{21,}, B_{23}, B_{24} \ldots B_{2n}\}, \{B_{n1}, B_{n2}, B_{n3} \ldots B_{n(n-1)}\}$. As is listed in Table 1

The evaluation score is constructed as following judgment matrix:

$$W = \begin{bmatrix} 1 & B_{12} & B_{13} & \ldots & B_{1n} \\ B_{21} & 1 & B_{23} & \ldots & B_{2n} \\ B_{31} & B_{32} & 1 & \ldots & B_{3n} \\ \ldots & \ldots & \ldots & 1 & \ldots \\ B_{n1} & B_{n2} & B_{n3} & \ldots & 1 \end{bmatrix}$$

This is a reciprocal matrix, on the basis of which the corresponding eigenvector of the largest eigenvalue can be calculated. The nominalization of the eigenvector is as the weight $W = \{w_{1,} w_{2,} w_3 \ldots w_n\}$.

In calculating, the way to judge whether there is consistency index CI in the judgment matrix is to compare the size of CI and RI (the average random consistency index). $CI / RI < 0.1$, the judgment matrix passes consistency checks, while $CI / RI > 0.1$, the judgment matrix doesn't pass consistency checks, which needs to be modified. The software yaahp can simulate this method.

(4) Setting membership degree R_p of each attribute of space Q_i [11-12]

The membership degree of spatial attribute is determined by the evaluation and grade, based on 10-point system, of individuals taken as samples. Each attribute's membership degree in space Q_i 's each rank $\{e_1, e_2, e_3 \ldots e_m\}$ can be got. Then the following matrix can be obtained. Finally, normalize the matrix's average. Each attribute's membership degree under each rank in the kindred space can be calculated.

$$R_p = \begin{array}{c} \\ x_1 \\ x_2 \\ x_3 \\ \cdots \\ x \end{array} \begin{array}{c} \begin{array}{ccccc} e_1 & e_2 & e_3 & & e_m \end{array} \\ \begin{bmatrix} R_{11} & R_{12} & R_{13} & \ldots & R_{1m} \\ R_{21} & R_{22} & R_{23} & \ldots & R_{2m} \\ R_{31} & R_{32} & R_{33} & \ldots & R_{3m} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ R_{n1} & R_{n2} & R_{n3} & \ldots & R_{nm} \end{bmatrix} \end{array}$$

In the process of grading, numbers $(R_{11}, R_{12}, R_{13}, \ldots, R_{1m})$ of each line in the above matrix are average scores marked by each kind of individual, since there is more than one individual to mark. For each attribute, there is following matrix:

$$R_{p1} = \begin{array}{c} \\ \text{sample } 1 \\ \text{sample } 2 \\ \text{sample } 3 \\ \cdots \\ \text{sample } N \end{array} \begin{array}{c} \begin{array}{ccccc} e_1 & e_2 & e_3 & & e_m \end{array} \\ \begin{bmatrix} R_{11}(1) & R_{12}(1) & R_{13}(1) & \ldots & R_{1m}(1) \\ R_{11}(2) & R_{12}(2) & R_{13}(2) & \ldots & R_{1m}(2) \\ R_{11}(3) & R_{12}(3) & R_{13}(3) & \ldots & R_{1m}(3) \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ R_{11}(N) & R_{12}(N) & R_{13}(N) & \ldots & R_{1m}(N) \end{bmatrix} \end{array}$$

(5)Establishing calculation model Z_p

Normalizing weight W and fuzzy product of R_p, namely:

$$Z_p = W \bullet R_p$$

(6)Calculating utility value U of space Q_i to individual q_j

Rank D needs to ensure an assessment value. Connotation lies in quantifying the differences among ranks. The range of value can be (0, 1), (1, 10) and so on. For the convenience of calculating, (0, 1) is chosen as the value range of grade assessment value. On the basis of number of ranks, assign each rank in $D \in \{e_1, e_2, e_3, \ldots, e_m\}$, and get row vector $(e_1, e_2, e_3 \ldots e_m)$. For example, if value range is (0, 1), the number of ranks is five, value is in Table 2:

Table 2. Ranking assignment

e_1	e_2	e_3	e_4	e_5
0.2	0.4	0.6	0.8	1.0

The calculation model of utility value U of space Q_i to individual q_j is:

$$U = Z_p \bullet D^T = \sum_{n=1}^{m} (Z_{pn} \bullet e_m)$$

In calculating U , time's influence on utility value is not considered, which needs further research.

4. The Calculation Method of Utility Value of Time

4.1 The principle of time's influence on utility value

In reality, the utility value of space Q_i to individual q_j is not fixed. Difference of time leads to the change of utility value. For example, individual is set as student, and space is set as dining hall. In a day, the utility value of dining hall to students is different. During the time to have meals, the utility value of dining hall to hungry students is large, while outside meal times, the utility value of dining hall to students without hunger is small.

An actual questionnaire is made to testify this principle, and the object is a university. The data of Table 3(a), 3(b), and 3(c) is the utility comments made by three kinds of individuals on five kinds of space on campus during a portion of time period on weekdays. Firstly, investigate multiple individual as samples, and then average the data to reduce the randomness of individual cognition and answer.

Table 3. Utility value of space to individual during a portion of time period on weekdays in a university

(a)

t∈(6:00-8:00)	q_1	q_2	q_3
Q_1	1	2	1
Q_2	4	4	4
Q_3	4	4	4
Q_4	1	1	3
Q_5	1	1	1

(b)

t∈(8:00-9:50)	q_1	q_2	q_3
Q_1	3	3	4
Q_2	4	4	1
Q_3	2	2	1
Q_4	1	1	4
Q_5	3	2	1

(c)

t∈(9:50-12:15)	q_1	q_2	q_3
Q_1	4	4	4
Q_2	2	2	1
Q_3	1	1	1
Q_4	2	1	5
Q_5	4	2	1

In this questionnaire, individual types, being three kinds of individual q_1, q_2, q_3 who reside in school, are undergraduate, postgraduate and teacher. Five individual samples are chosen from each kind of

individuals. Spatial types are five kinds of basic space Q_1, Q_2, Q_3, Q_4, Q_5 in school, namely, classroom (laboratory), dormitory (student dormitory and teacher dormitory), dining hall, office building and library. The division of time period is based on official schedule of this school. 1, 2,3,4,5 represent utility value of every kind of space to individual. The number is larger, the preferential degree of the individual to the space is higher, namely, utility evaluation is better.

What's more, the change of place leads to the change of the type of individual and space. The division of time and the utility value of space to individual each time period will change accordingly. For example, for a student in school and a out-of-school worker, they have different space for activity. As for the division of time, to investigate the former needs school's schedule, and to investigate the later needs to consider his family and job.

An actual questionnaire is made to survey a community to testify this principle. The data of Table 4(a), 4(b), and 4(c) are the utility values of five kinds of space to three kinds of individuals during a portion of time period on weekdays. As the same, investigate multiple individual samples at first, and then average the data.

This survey chooses three kinds of individuals and five kinds of space. Both five kinds of space and three kinds of individuals' daily activities are in the community.

In this questionnaire, individuals are q_1, q_2, q_3, representing student (in middle and primary school), worker, and retired person respectively. Five individual samples are chosen from each type of individual. The types of space are Q_1, Q_2, Q_3, Q_4, Q_5, representing home, work unit, store (including restaurant, supermarket), school (open), recreational areas (including teahouse) respectively. The division of time period is based on daily lifestyles and hobbies of the individuals.

Table 4. Utility value of space to individual during a portion of time on weekdays in a community

(a)

Time period	$q_1 \to Q_1$	$q_1 \to Q_2$	$q_1 \to Q_3$	$q_1 \to Q_4$	$q_1 \to Q_5$
$t \in (6:00-7:20)$	5	1	3	1	1
$t \in (8:00-11:40)$	1	1	1	5	1
$t \in (12:00-13:40)$	4	1	3	1	1

(b)

Time period	$q_1 \to Q_1$	$q_1 \to Q_2$	$q_1 \to Q_3$	$q_1 \to Q_4$	$q_1 \to Q_5$
$t \in (6:00-7:30)$	4	1	2	1	1
$t \in (9:00-11:50)$	1	5	1	1	1
$t \in (12:00-13:00)$	4	2	4	1	1

(c)

Time period	$q_1 \to Q_1$	$q_1 \to Q_2$	$q_1 \to Q_3$	$q_1 \to Q_4$	$q_1 \to Q_5$
$t \in (6:00-8:30)$	5	1	1	3	1
$t \in (9:00-10:00)$	3	1	4	1	2

Time period	$q_1 \to Q_1$	$q_1 \to Q_2$	$q_1 \to Q_3$	$q_1 \to Q_4$	$q_1 \to Q_5$
$t \in (10:00-11:30)$	4	1	2	1	3

In combination with Table 3, the conclusion can be got: with the change of individual, time and place, utility comment of individual on space or utility value of space to individual changes, which conforms to the explanation of property of utility value in utility theory. When area and individual types are confirmed, utility value is piecewise function of time.

$$\mathrm{U}=\begin{cases} U\left(T_{(1,2)}\right), T_{12}\in(t_1,t_2) \\ U\left(T_{(3,4)}\right), T_{34}\in(t_3,t_4) \\ \cdots \\ U\left(T_{(g,g+1)}\right), T_{(g,g+1)}\in(t_g,t_{g+1}) \end{cases}$$

4.2 The calculating method of utility value under the influence of time

To understand membership degree of space's each attribute helps to understand time's influence on utility value. For example, for an ordinary individual, comfort level of rest is much lower than comfort level of job during 9: 00—11:00. The former has a low membership degree for level 1(the highest level), and has a high membership degree for low level, while the latter is on the contrary. However, during 22: 00—23:00, the membership degree of comfort level of rest is higher than comfort level of job, so the former's membership degree for the highest level increases accordingly, and for the low level reduces. The latter is on the contrary.

Therefore, each attribute of space has different membership degree in different time period. In calculating, the evaluation of membership degree (the construction of membership matrix) is based on different time period.

When $T\in(t_1,t_2)$, membership matrix of spatial attribute is:

$$\begin{array}{c} \\ x_1 \\ x_2 \\ x_3 \\ \cdots \\ x \end{array}\begin{array}{c} \begin{array}{cccccc} e_1 & & e_2 & & e_3 & & e_m \end{array} \\ \begin{bmatrix} R_{11}\left(T_{(1,2)}\right) & R_{12}\left(T_{(1,2)}\right) & R_{13}\left(T_{(1,2)}\right) & \cdots & R_{1m}\left(T_{(1,2)}\right) \\ R_{21}\left(T_{(1,2)}\right) & R_{22}\left(T_{(1,2)}\right) & R_{23}\left(T_{(1,2)}\right) & \cdots & R_{2m}\left(T_{(1,2)}\right) \\ R_{31}\left(T_{(1,2)}\right) & R_{32}\left(T_{(1,2)}\right) & R_{33}\left(T_{(1,2)}\right) & \cdots & R_{3m}\left(T_{(1,2)}\right) \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ R_{n1}\left(T_{(1,2)}\right) & R_{n2}\left(T_{(1,2)}\right) & R_{n3}\left(T_{(1,2)}\right) & \cdots & R_{nm}\left(T_{(1,2)}\right) \end{bmatrix} \end{array}$$

$$R_p\left(T_{(1,2)}\right)=$$

When $T\in(t_g,t_{g+1})$, membership matrix of spatial attribute is:

$$\begin{array}{cccccc} e_1 & & e_2 & & e_3 & & e_m \end{array}$$

$$R_p\left(T_{(g,g+1)}\right)=\begin{matrix}x_1\\x_2\\x_3\\\cdots\\x\end{matrix}\begin{bmatrix}R_{11}\left(T_{(g,g+1)}\right) & R_{12}\left(T_{(g,g+1)}\right) & R_{13}\left(T_{(g,g+1)}\right) & \ldots & R_{1m}\left(T_{(g,g+1)}\right)\\ R_{21}\left(T_{(g,g+1)}\right) & R_{22}\left(T_{(g,g+1)}\right) & R_{23}\left(T_{(g,g+1)}\right) & \ldots & R_{2m}\left(T_{(g,g+1)}\right)\\ R_{31}\left(T_{(g,g+1)}\right) & R_{32}\left(T_{(g,g+1)}\right) & R_{33}\left(T_{(g,g+1)}\right) & \ldots & R_{3m}\left(T_{(g,g+1)}\right)\\ \ldots & \ldots & \ldots & \ldots & \ldots\\ R_{n1}\left(T_{(g,g+1)}\right) & R_{n2}\left(T_{(g,g+1)}\right) & R_{n3}\left(T_{(1,2)}\right) & \ldots & R_{nm}\left(T_{(g,g+1)}\right)\end{bmatrix}$$

In calculating utility value, the influence of time is reflected in space's each attribute membership degree R_p, namely, $R_p\left(T_{(g,g+1)}\right)$, therefore,

$$Z_p\left(T_{(g,g+1)}\right)=W\bullet R_p\left(T_{(g,g+1)}\right)$$

The calculation formula of utility value becomes:

$$U\left(T_{(g,g+1)}\right)=Z_p\left(T_{(g,g+1)}\right)\bullet E^T=\sum_{n=1}^{m}(Z_{pn}\left(T_{(g,g+1)}\right)\bullet e_m)$$

5. Conclusion

Based on the method of fuzzy mathematics, the utility value of space to individual is obtained. This paper also studies the influence of time on utility value, obtaining utility value's function of time.

Acknowledgements

Sichuan province science and technology innovation talent project (2016096)

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