FUZZY COMPREHENSIVE ASSESSMENT, FUZZY CLUSTERING ANALYSIS, AND ITS APPLICATION FOR URBAN TRAFFIC ENVIRONMENT QUALITY EVALUATION

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abstract: Traffic environment quality assessment method and application are researched associated with Anshan City's Comprehensive Transportation Planning Project, applying Multistage Fuzzy Comprehensive Assessment and Fuzzy Clustering Analysis in this paper. The major works are as following: set up an assessment system, determining assessment criteria, the formulae of subordination function, allocating weights, modeling and program design, and example analysis.

1. INTRODUCTION

How to give an objective and scientific assessment of urban traffic environment quality is an important question for the developing countries. China has just begun to do some work in this field, and most of which are limited in analyzing the existing state of traffic environment qualitatively. This thesis has associated with Anshan City's Comprehensive Transportation Planning Project, applying Multistage Fuzzy Comprehensive Assessment and Fuzzy Clustering Analysis, and with the using of computer, calculating out a series of quantitative results of Anshan city from 1988 to 1993.

2. ELEMENTS ANALYSIS AND ASSESSMENT INDEX SYSTEM

Traffic environment pollution includes primly two aspects, automobile tail gas and noise. As showing in many references, seventy percent to eighty percent of air pollution in Europe and America countries is from automobile tail gas. Vehicle noise is the major source of noise pollution in urban area.

According to the Air Environment Quality Standard of China (GB3095-82) and the Urban Area Environment Noise Standard of China (GB3096-82), two groups of assessment subsystems, eight assessment indexes are selected to be used in urban traffic environment quality evaluation. The factors of air pollution are CO, SO_2, NO_x, TSP, dust. Three noise factors are Leg, L_{10},L_{90}(see Fig.1).

3. MULTISTAGE FUZZY COMPREHENSIVE ASSESSMENT METHOD

The works using multistage fuzzy comprehensive assessment method to assessment urban traffic environment qualities include: set an assessment system (as above, see Fig.1), determining assessment criteria, the formulae of subordination function, allocating weights, etc.

Assessment Factor Set

$$U=\{U_1(\text{air pollution}),U_2(\text{noise pollution})\} \tag{1}$$

$$U_1=\{u_{11}(CO),u_{12}(SO_2),u_{13}(NO_x),u_{14}(\text{dust}),u_{15}(TSP)\} \tag{2}$$

$$U_2=\{u_{21}(L_{eq}),u_{22}(L_{10}),u_{23}(L_{90})\} \tag{3}$$

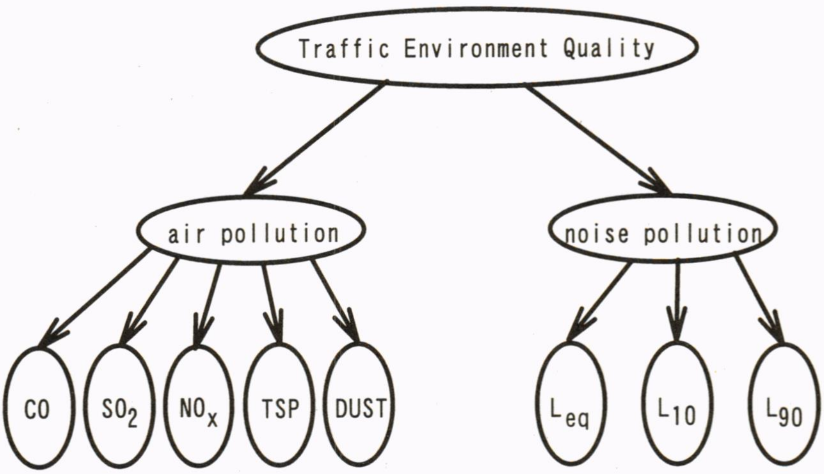

Fig 1. Urban Traffic Environment Assessment System

Assessment Classification and Its Criteria

According to the national environment standard and international experience, each index was classified five levels, such as: excellent, good, ordinary, poor, bad. The each level's assessment criterion of the indexes were determined by experts of environment engineering and traffic engineering.

$$V=\{V_1(\text{excellent}),V_2(\text{good}),V_3(\text{ordinary}),V_4(\text{poor}),V_5(\text{bad})\} \tag{4}$$

Level "excellent" indicates advanced environment quality in west, and is the first class environment quality standard in China. Level "good" indicates more advanced level in China, and is lower than the first class and higher than the third class environment quality standard in China. The situation lower than the third class standard is considered as "poor" or "bad". Each level's assessment criteria of each environment factor D_1 to D_5 are showed as table 1.

Tab.1 The Assessment Criterion of Traffic Environment Quality

Criterion Levels	CO	SO_2	NO_X	Dust	TSP	L_{eq}	L_{10}	L_{90}
D_1(Excellent)	3.00	0.02	0.05	5.00	0.15	50	55	45
D_2(Good)	3.50	0.10	0.07	8.00	0.20	55	60	50
D_3(Ordinary)	4.00	0.15	0.10	15.00	0.30	60	65	55
D_4(Poor)	4.50	0.20	0.13	20.00	0.40	65	70	60
D_5(Bad)	5.00	0.25	0.15	40.00	0.50	70	75	65

Note: the unit of CO,SO_2,$NO_X$and TSP is mg/m^3, the unit of dust is t/km^2,noise unit is dB(A).

The Formulae of Subordination Function

The value of subordination of each factor relative to five assessment levels can be described quantitatively by a set of formulae of subordination functions as following:

$$\mu_e(x) = \begin{cases} 1 & 0 \le x \le D_1 \\ \dfrac{D_2 - x}{D_2 - D_1} & D_1 < x < D_2 \\ 0 & 0 \ge D_2 \end{cases} \tag{5}$$

$$\mu_g(x) = \begin{cases} 0 & x \le D_1 \quad or \quad x \ge D_3 \\ \dfrac{x - D_1}{D_2 - D_1} & D_1 < x < D_2 \\ 1 & x = D_2 \\ \dfrac{D_3 - x}{D_3 - D_2} & D_2 < x < D_3 \end{cases} \tag{6}$$

$$\mu_o(x) = \begin{cases} 0 & 0 \le x \le D_2 \quad or \quad x \ge D_4 \\ \dfrac{x - D_2}{D_3 - D_2} & D_2 < x < D_3 \\ 1 & x = D_3 \\ \dfrac{D_4 - x}{D_4 - D_3} & D_3 \le x \le D_4 \end{cases} \tag{7}$$

$$\mu_p(x) = \begin{cases} 0 & 0 \le x \le D_3 \quad or \quad x \ge D_5 \\ \dfrac{x - D_3}{D_4 - D_3} & D_3 < x < D_4 \\ 1 & x = D_4 \\ \dfrac{D_5 - x}{D_5 - D_4} & D_4 \le x \le D_5 \end{cases} \tag{8}$$

$$\mu_b(x) = \begin{cases} 0 & 0 \le x \le D_4 \\ \dfrac{x - D_4}{D_5 - D_4} & D_4 < x < D_5 \\ 1 & x \ge D_5 \end{cases} \tag{9}$$

Weights Allocation and Fuzzy Assessment Model

The weight of assessment factors was determined as two levels. These Weights were also determined by experts of environment engineering and traffic engineering, while at the same time considering the references of similar cities.

$$\underset{\sim}{A} = \{\underset{\sim}{A}_1(0.4), \underset{\sim}{A}_2(0.6)\} \tag{10}$$
$$\underset{\sim}{A}_1 = \{\underset{\sim}{A}_{11}(0.3), \underset{\sim}{A}_{12}(0.15), \underset{\sim}{A}_{13}(0.1), \underset{\sim}{A}_{14}(0.3), \underset{\sim}{A}_{15}(0.15)\} \tag{11}$$
$$\underset{\sim}{A}_2 = \{\underset{\sim}{A}_{21}(0.25), \underset{\sim}{A}_{22}(0.35), \underset{\sim}{A}_{23}(0.40)\} \tag{12}$$

The first stage assessment matrices of single factor, $\underset{\sim}{R}_1, \underset{\sim}{R}_2$ are:

$$\underset{\sim}{R}_1 = \begin{bmatrix} r_{111} & r_{112} & r_{113} & r_{114} & r_{115} \\ r_{121} & r_{122} & r_{123} & r_{124} & r_{125} \\ & \cdots & & \cdots & \\ r_{151} & r_{152} & r_{153} & r_{154} & r_{155} \end{bmatrix}$$

$$\underset{\sim}{R}_2 = \begin{bmatrix} r_{211} & r_{212} & r_{213} & r_{214} & r_{215} \\ r_{221} & r_{222} & r_{223} & r_{224} & r_{225} \\ r_{231} & r_{232} & r_{233} & r_{234} & r_{235} \end{bmatrix}$$

$$r_{kij} = \mu_j(x) \qquad k = 1,2; i, j = 1,2,\cdots 5;$$
$$\{\mu_1, \mu_2, \mu_3, \mu_4, \mu_5\} = \{\mu_e, \mu_g, \mu_c, \mu_p, \mu_b\}$$

The first stage fuzzy comprehensive assessment indices, $\underset{\sim}{B}_1, \underset{\sim}{B}_2$ are:

$$\underset{\sim}{B}_1 = \underset{\sim}{A}_1 \underset{\sim}{R}_1 = (\underset{\sim}{B}_{11}\ \underset{\sim}{B}_{12}\ \underset{\sim}{B}_{13}\ \underset{\sim}{B}_{14}\ \underset{\sim}{B}_{15}) \tag{13}$$
$$\underset{\sim}{B}_2 = \underset{\sim}{A}_2 \underset{\sim}{R}_2 = (\underset{\sim}{B}_{21}\ \underset{\sim}{B}_{22}\ \underset{\sim}{B}_{23}\ \underset{\sim}{B}_{24}\ \underset{\sim}{B}_{25}) \tag{14}$$

There, two fuzzy algorithms are used, that is M(∨, ∧) and M(¡¤, ⊕). Thus, the second stage assessment matrices of single factor $\underset{\sim}{R}^*$ and fuzzy comprehensive assessment $\underset{\sim}{B}^*$ can be determined.

$$\underset{\sim}{B}^* = \underset{\sim}{A}\,\underset{\sim}{R}^* = (\underset{\sim}{A}_1, \underset{\sim}{A}_2)\begin{bmatrix} A_1 & R_1 \\ A_2 & R_2 \end{bmatrix} = (b_1,\ b_2,\ b_3,\ b_4,\ b_5) \tag{15}$$

Final, the fuzzy comprehensive assessment result can be made.

$$W = \underset{\sim}{B}^{*} \underset{\sim}{C}^{T} \tag{16}$$

CT is the standard matrix to adjust assessment results to numbers between 50-100.So we can make more direct judgment. We have developed a practicable software of urban traffic environment quality analysis applying multistage Fuzzy comprehensive method.

Case Study

The case study had been made combining with Urban Comprehensive Transportation Planning of Anshan City (1994-2010) in 1994. Anshan is the largest steel city located northeast China. Fourteen main roads were selected as the samples of the traffic environment quality assessment. The volume of three noise indexes and five air pollution indexes of these roads from 1988 to 1993 were collected based upon the environment survey data of the city. Based upon the data, and applying the dual stage comprehensive fuzzy assessment method, the evaluation values of each year's main lines were got(showed as table 2).Fig.2 represents the road net map of Anshan city.

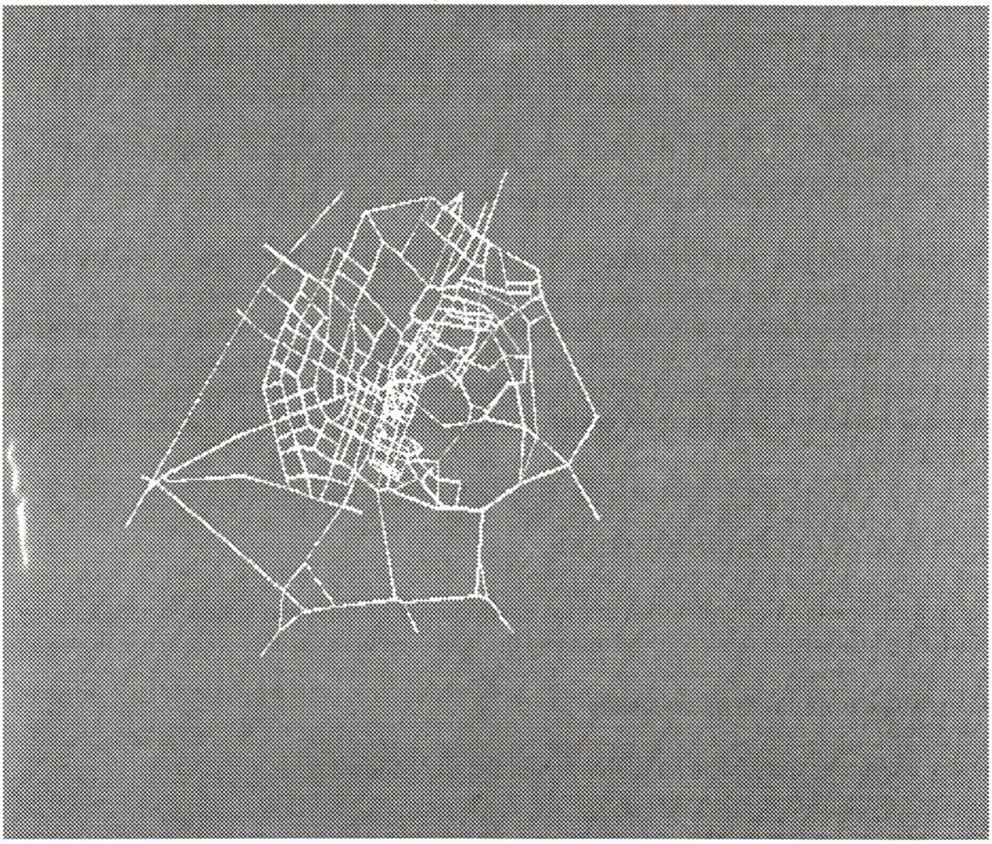

Fig 2. Road Net Map of Anshan City

Tab. 2 The Value of Road Traffic Environment Quality of Anshan City

Road Name	1988	1989	1990	1991	1992	1993
Jian Guo Road	57.71 (14)	57.75 (14)	56.83 (14)	53.33 (14)	53.02 (14)	53.22 (14)
Sheng Li Road	62.86 (8)	59.85 (6)	60.13 (7)	62.32 (7)	62.22 (6)	63.57 (4)
Zhong Hua Road	65.43 (5)	63.57 (2)	63.45 (2)	65.64 (2)	61.51 (4)	64.31 (2)
Yuan Lin Road	63.00 (7)	59.85 (7)	59.55 (10)	61.71 (8)	62.00 (7)	62.27 (7)
Shuang Shan Road	66.55 (1)	65.39 (1)	61.66 (4)	63.85 (3)	65.94 (2)	63.23 (6)
Qian Jin Road	59.20 (10)	58.07 (11)	57.62 (13)	57.71 (12)	55.56 (11)	54.09 (12)
Tian Dong Er Dao Road	60.04 (9)	58.50 (10)	58.48 (11)	58.57 (11)	55.56 (12)	54.09 (13)
Wu Yi Road	65.53 (4)	61.20 (4)	62.66 (3)	62.74 (5)	58.64 (8)	54.47 (10)
Jian Shen Road	65.93 (2)	59.85 (8)	61.27 (5)	63.27 (4)	63.05 (5)	63.95 (3)
Jian Fang Road	63.61 (6)	59.85 (9)	60.41 (6)	62.60 (6)	67.76 (1)	64.41 (1)
Min Shen Road	58.76 (13)	58.07 (12)	59.82 (9)	59.82 (10)	56.22 (9)	56.44 (8)
Ren min Road	59.15 (11)	58.07 (13)	60.02 (8)	60.10 (9)	56.08 (10)	55.81 (9)
Xing Sheng Road	65.57 (3)	60.33 (5)	63.85 (1)	66.04 (1)	65.77 (3)	63.36 (5)
Huan Gang Road	58.77 (12)	63.03 (3)	58.22 (12)	54.72 (13)	54.27 (13)	54.42 (11)

Note :The number in brackets indicates the position of that road among 14 main roads.

On historic analysis, as table 2 showed, traffic environment quality of fourteen main lines tends down. There were five roads being poor or bad traffic environment quality in 1988, otherwise up to seven roads in 1993. On horizontal analysis, the assessment results showed that the worst roads in 1993 were Jian Guo Road, Qian Jin Road, Tian Dong Er Dao Road, Wu Yi Road, Min Shen Road, Ren Min Road, and Huan Gang Road. These roads are located in dense residential area, business center, cultural or government area. So their impact is very serious.

4. FUZZY CLUSTERING METHOD

As a same case, Anshan's urban traffic environment quality was assessed using fuzzy clustering analysis method. The factors and the data used in case study were same as above.

Fuzzy Clustering Analysis Modeling

Fuzzy clustering analysis includes three main steps as following:

Step 1 Normalizing the sample data. Set

$$X_{ik} = \frac{X'_{ik} - \overline{X}'_k}{\sigma_k} \tag{17}$$

There ,

$$\overline{X}'_k = \frac{1}{n}\sum_{i=k}^{1} \overline{X}_k \tag{18}$$

$$\sigma_k = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X'_k - \overline{X}'_k)^2} \tag{19}$$

X'_k is the original value of *k* environment index of *i* road.

Step 2 Calculating the similar matrix using included angle cosine method.

$$r_{ij} = \frac{1}{m}\sum_{k=1}^{m}\exp\left(-\frac{3}{4}\bullet\frac{(X_i - X_{ij})^2}{\sigma_k^2}\right) \tag{20}$$

Step 3 Madding the equal matrix through fuzzy clustering.

$$\underset{\sim}{R}^{(2)} = \underset{\sim}{R} \circ \underset{\sim}{R} = (r_{ij}^{(2)})_{p\acute{\text{i}}\acute{A}p} \tag{21}$$

$$r_{ij}^{(2)} = \min\{1, \sum_{k=1}^{m} r_{ik}r_{jk}\} \tag{22}$$

$$\underset{\sim}{R}^{(4)} = \underset{\sim}{R}^{(2)} \circ \underset{\sim}{R}^{(2)} \tag{23}$$

$$\underset{\sim}{R}^{e} = \underset{\sim}{R}^{2l} = \underset{\sim}{R}^{2(l-1)} = t(\underset{\sim}{R}) \tag{24}$$

Thus, a clustering size $\lambda(0 \le \lambda \le 1)$ will be determined as the clustering criterion according to clustering requirement. According to the clustering criterion and the equal matrix $\underset{\sim}{R}^e=\{r_{ij}\}$, the clustering results can be determined.

Case Study

Based upon the fuzzy clustering analysis method as above, a computer software had been developed , and Anshan's traffic environment quality clustering of fourteen roads (using 1993' data) had been worked out. The clustering results are shown as tab. 3 to tab 5. Based upon the results showed as table 5, fourteen roads can be classified into three categories:

I: {3, 4, 6, 9, 13}

This category includes Zhong Hua Road, Yuan Ling Road, Shuang Shan Road, Jian Sheng Road, and Xing Shen Road. These roads have relative good environment quality because of their location far from industrial area and less traffic volume.

Tab. 3 The Environment Quality Similar Matrix of Anshan's Fourteen Roads

road	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.00	0.37	0.50	0.56	0.58	0.86	0.85	0.85	0.85	0.53	0.38	0.78	0.58	0.98
2	0.37	1.00	0.11	0.82	0.50	0.44	0.51	0.34	0.24	0.98	0.04	0.18	0.88	0.18
3	0.50	0.11	1.00	0.67	0.92	0.61	0.45	0.44	0.98	0.12	0.40	0.22	0.80	0.40
4	0.56	0.82	0.67	1.00	0.91	0.88	0.64	0.51	0.75	0.80	0.26	0.27	0.98	0.38
5	0.58	0.50	0.92	0.91	1.00	0.70	0.60	0.52	0.96	0.47	0.36	0.26	0.97	0.42
6	0.86	0.44	0.61	0.68	0.70	1.00	0.98	0.97	0.64	0.44	0.88	0.87	0.71	0.80
7	0.85	0.51	0.45	0.64	0.60	0.98	1.00	0.98	0.50	0.50	0.88	0.91	0.64	0.79
8	0.85	0.34	0.44	0.51	0.52	0.97	0.98	1.00	0.46	0.34	0.95	0.96	0.53	0.82
9	0.53	0.24	0.98	0.75	0.96	0.64	0.50	0.46	1.00	0.21	0.39	0.23	0.87	0.41
10	0.36	0.98	0.12	0.80	0.47	0.44	0.50	0.34	0.21	1.00	0.04	0.19	0.66	0.19
11	0.78	0.04	0.40	0.28	0.36	0.88	0.38	0.95	0.39	0.04	1.00	0.97	0.32	0.81
12	0.77	0.18	0.22	0.27	0.26	0.87	0.91	0.96	0.23	0.19	0.97	1.00	0.27	0.79
13	0.58	0.68	0.80	0.98	0.97	0.71	0.64	0.53	0.87	0.66	0.32	0.27	1.00	0.41
14	0.98	0.19	0.40	0.38	0.42	0.80	0.79	0.82	0.41	0.19	0.81	0.79	0.41	1.00

Tab. 4 The Environment Quality Equal Matrix of Anshan's Fourteen Roads

road	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.00	0.71	0.71	0.71	0.71	0.86	0.86	0.86	0.71	0.71	0.86	0.86	0.71	0.98
2	0.71	1.00	0.82	0.82	0.82	0.71	0.71	0.71	0.82	0.98	0.71	0.71	0.82	0.71
3	0.71	0.82	1.00	0.97	0.97	0.71	0.71	0.71	0.98	0.82	0.71	0.71	0.97	0.71
4	0.71	0.82	0.97	1.00	0.97	0.71	0.71	0.71	0.97	0.82	0.71	0.71	0.98	0.71
5	0.71	0.82	0.97	0.97	1.00	0.71	0.71	0.71	0.97	0.82	0.71	0.71	0.97	0.71
6	0.86	0.71	0.71	0.71	0.71	1.00	0.98	0.98	0.71	0.71	0.96	0.96	0.71	0.86
7	0.86	0.71	0.71	0.71	0.71	0.98	1.00	0.98	0.71	0.71	0.96	0.96	0.71	0.86
8	0.86	0.71	0.71	0.71	0.71	0.98	0.98	1.00	0.71	0.71	0.96	0.96	0.71	0.86
9	0.71	0.82	0.98	0.97	0.97	0.71	0.71	0.71	1.00	0.82	0.71	0.71	0.97	0.71
10	0.71	0.98	0.82	0.82	0.82	0.71	0.71	0.71	0.82	1.00	0.71	0.71	0.82	0.71
11	0.86	0.71	0.71	0.71	0.71	0.96	0.96	0.96	0.71	0.71	1.00	0.97	0.71	0.86
12	0.86	0.71	0.71	0.71	0.71	0.96	0.96	0.96	0.71	0.71	0.97	1.00	0.71	0.86
13	0.71	0.82	0.97	0.98	0.97	0.71	0.71	0.71	0.97	0.82	0.71	0.71	1.00	0.71
14	0.98	0.71	0.71	0.71	0.71	0.86	0.86	0.86	0.71	0.71	0.86	0.86	0.71	1.00

II: {2, 10}

This category includes Sheng Li Road and Jian Fang Road. These two roads are near by industrial area and transportation infrastructure, and have larger traffic volume, so their air and noise pollution are more serious.

III: {1, 6, 7, 8, 11, 12, 14}

This category includes Jian Guo Road, Jian Jin Road, Tian Dong Er Dao Road, Wu Yi Road, Min Shen Road,Ren Min Road, and Huan Gang Road. These roads are the worst roads in traffic pollution. The noise and air pollution values are overloaded seriously.

Tab. 5 The Environment Quality Clustering Matrix of Anshan's Fourteen Roads

road	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	0	0	0	0	1	1	1	0	0	1	1	0	1
2	0	1	0	0	0	0	0	0	0	1	0	0	0	0
3	0	0	1	1	1	0	0	0	1	0	0	0	1	0
4	0	0	1	1	1	0	0	0	1	0	0	0	1	0
5	0	0	1	1	1	0	0	0	1	0	0	0	1	0
6	1	0	0	0	0	1	1	1	0	0	1	1	0	1
7	1	0	0	0	0	1	1	1	0	0	1	1	0	1
8	1	0	0	0	0	1	1	1	0	0	1	1	0	1
9	0	0	1	1	1	0	0	0	1	0	0	0	1	0
10	0	1	0	0	0	0	0	0	0	1	0	0	0	0
11	1	0	0	0	0	1	1	1	0	0	1	1	0	1
12	1	0	0	0	0	1	1	1	1	0	1	1	0	1
13	0	0	1	1	1	0	0	0	1	0	0	0	1	0
14	1	0	0	0	0	1	1	1	0	0	1	1	0	1

5. CONCLUSIONS

It is an important new question that urban traffic environment evaluation in the fields of urban transportation planning and urban environment project planning for developing countries. In this thesis, the question is explored based upon multistage fuzzy comprehensive assessment method and fuzzy clustering analysis method. The index system, standard, and weight factors of traffic environment quality are proposed. The formulate of subordination function and the models of the assessment system are presented. Finally, through an application example at Anshan City, it is shown that the works done in this thesis is significant.

REFERENCES

Yager R R. Multiple Objective Decision-making Using Fuzzy Sets. Int J Man-Mach Stud. 1977, 9. 375-382.

Yager R R. Multicriteria Decisions with Soft Information (I)(II). Fuzzy Mathematics,1982, 2, 3.

Yeh R T. Fuzzy relations ,fuzzy graphs and their applications to clustering analysis in L A Zadeh sets. Fuzzy Sets and Their Applications to Cognitive and Decision processes, 1975, 125-149.