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Study and Implementation on the Grey Comprehensive Evaluation Support System of Ecocity*

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Abstract: According to basic connotation and design principles of ecocity, a comparatively integrated index system is constructed in the paper. And at the same time using hierarchy grey comprehensive evaluation method, a hierarchy grey comprehensive evaluation model of ecocity is established, then on the basis of the model, a comprehensive evaluation support system is developed, and the theoretical guidance supplied for construction of ecocity is provided.

Key words: ecocity, index system, evaluating level, hierarchy grey comprehensive evaluation, evaluation support system

City is the center of the economy, politics and people's spiritual activities, and also the main power of the social progress. Urbanization indicates the development level about economy and society in a country or an area. Whereas, in the course of urban development, some troublesome phenomenons occur in different degrees, such as strain of water supply, environmental pollution, traffic congestion and shortage of housing. These negative effects deteriorated the nature environment, broke the ecology balance and endangered the human's life and health, which induced the so-called name of "city diagnostic". So the conception of "ecocity" also emerges as the times require.

The ecocity is a harmonious inhabitation spot, which is constructed based on the ecology principle. In a fine-operated ecocity, material, energy and information are efficiently utilized, and society, economy and nature are well coordinated[1]. This framework reflects the requirement of building a modernized, efficient and standardized city, and presents the general direction of city construction in the 21st century. Now, countries worldwide are taking up to build the ecocities.

In fact, building an ecocity is a complex system project, which involves the areas of economy, society, and environment, and sometimes the particular situation. To make sure building ecocity smoothly, we should have a scientific evaluating index system, which can reflect the characteristics of the ecocity. Since building an ecocity is a process which is multi-target, multi-level, dynamic, information-imperfection and more artificial factors, the evaluation cannot be conducted easily. With the application of the grey theory, this paper forms a model with four levels to evaluate the ecocity, and then designs an integrated grey evaluation support system (IGESS). At last, the IGESS is illustrated with an applied example.

1 Construction of Ecocity Evaluation Index System

Urban ecosystem is a large system, which includes many factors, so it is impossible to cover all, we must choose some factors as evaluating indices. According to basic connotation and design principles of ecocity, on the basis of referring research productions in home and abroad[2-5], hiberarchy model of ecocity evaluation index system is constructed. Target layer is the comprehensive level of ecocity, which scales urban eco-development level, capability and harmony degree; rule layer is constituted by each rule which reflects the target layer, includes the categories of nature, economy and society; region layer is constituted by some subsystems of each rule layer; index layer is constituted by each index, which can reflect urban development comparatively whole. Tab.1 shows index system in detail.

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Tab.1 Ecocity evaluation index system, real value and expert grade of each index

Target layer	Rule layer	Region layer	Index layer	Real value	Expert 1	2	3	4	5
Ecocity U	Nature status U_1	Resource condition U_{11}	u_{111} Per capita cultivated land/hm^2	0.12	2	2.5	2.5	3	3
			u_{112} Per capita water resource volume/m^3	15?000	4	4	3.5	4	3.5
			u_{113} Per unit GDP energy consumption/(t·(10^3yuan)$^{-1}$)	0.04	3	3	3.5	2.5	3.5
			u_{114} Per unit GDP water consumption/(t·(10^3yuan)$^{-1}$)	1.8	2.5	3	2.5	2	3
			u_{115} Per capita energy consumption/tsc	1.8	3	2.5	3.5	3	3.5
			u_{116} Per capita water consumption/l	200.0	3.5	3	3	2.5	4
			u_{117} Per capita electricity consumption/(kW·h)	400.0	3.5	3	4	2.5	3
		Environment U_{12}	u_{121} Investment index of environment protection/%	3.5	2	1.5	2.5	2	2.5
			u_{122} Per capita urban public green areas/m^2	20.0	4	3.5	3	3	4
			u_{123} Green coverage ratio/%	40.0	3.5	3	2.5	3.5	3.5
			u_{124} Meeting ratio of environmental function district/%	80.0	3	2.5	2.5	3.5	3
			u_{125} Coverage ratio of nature reserve/%	12.0	2.5	3	3	2.5	3
	Economic status U_2	Total level U_{21}	u_{211} Per capita GDP/10^3 yuan	33.0	2	3	2.5	2	3
			u_{212} Employed coefficient/%	60.0	2.5	2.5	2	3	2.5
			u_{213} Proportion of three industry/%	48.0	2	2	2.5	2.5	3
			u_{214} Per capita grain yield/kg	600.0	3	2	1.5	1	3.5
			u_{215} Export-oriented economy/%	50.0	2	3	2	1.5	3
		Urban and rural economy U_{22}	u_{221} Engel coefficient of urban resident/%	28.0	1.5	2	2.5	2	2
			u_{222} Engel coefficient of peasant/%	40.0	2	3	2	2.5	3
		Ability of development U_{23}	u_{231} Land productivity/(10^6yuan·km^{-2})	260	3	3.5	2	2	3.5
			u_{232} Growth ratio of GDP/%	7.0	2.5	2	3	2.5	3
			u_{233} Variation coefficient of per capita GDP/%	30.0	2	3	2.5	2.5	2.5
	Social status U_3	Science and technology and education U_{31}	u_{311} Proportion of science and technology input in GDP/%	2.0	1.5	2	2	1	2.5
			u_{312} Proportion of science and technology personnel /%	8.1	2	3	2.5	2	3
			u_{313} Scientific and technical contribution ratio/%	78.0	2	2	3	2.5	3
			u_{314} Proportion of teacher/%	1.2	3.5	3	3.5	2.5	3.5
			u_{315} Enrollment rate of higher education/%	40.0	3	2.5	3	3	2.5
			u_{316} Per capita public book capacity/volume	4.0	3	4	2.5	3	3.5
			u_{317} Per capita education level/a	9.0	2.5	3	3	2.5	3
			u_{318} Proportion of culture and education and hygiene input in GDP/%	5.0	2	1.5	3	2.5	3
		Population and urban & rural construction U_{32}	u_{321} Population growth/‰	3.0	4	3.5	4	3.5	4
			u_{322} Population density/(person·km^{-2})	500	3.5	3	3.5	3	3.5
			u_{323} Average life expectation/a	78.0	4	4	4	3.5	4
			u_{324} Income ratio between urban and rural resident	0.80	2	2.5	3	1.5	3
			u_{325} Urbanization level/%	70.0	2.5	3	2	3	3
			u_{326} Per capita rural resident area/m^2	45.0	3	3.5	2	2	2.5
			u_{327} Per capita urban resident area/m^2	22.0	2.5	2	2	2	3
			u_{328} Per urban capita road area/m^2	20.0	2	2.5	3	3	3
		Social development U_{33}	u_{331} Comprehensive ratio of social insurance/%	96.0	4	3.5	4	3.5	3.5
			u_{332} Incidence ratio of Criminal cases/%	0.12	4	3.5	3.5	3	4
			u_{333} Urban unemployment rate/%	1.2	1.5	2	2	2.5	2
			u_{334} Proportion of fiscal payout in GDP/%	20.0	2.5	2	2	3	2.5
			u_{335} Per capita amount of sickbed/sickbed	0.011	3	3.5	2.5	2.5	3
			u_{336} Proportion of doctor/%	0.42	3	2.5	3.5	3.5	2.5
			u_{337} Proportion of telephone user/%	70.0	3	3.5	3	3	3

Note: tsc means ton standard coal.

2 Grey Comprehensive Evaluation Model of Ecocity

In the course of comprehensive evaluation about ecocity, since evaluating indices have the characters of excessive quantity, complex level, multi-correlation, dynamic state and imperfect information, in addition evaluation is founded on the knowledge level, cognitive ability, personal preference and experience of estimator, the evaluation cannot be conducted easily without windage of artificial factor. Whereas grey theory[6-8] is good at dealing poor information system, and if we lack datum and information, modeling, forecast and decision can also be done, so grey theory is applicaiton for evaluation of ecocity. Considering the circumstantialities of ecocity, we adopt hierarchy grey

comprehensive evaluation method. The process of evaluation is described as follows:

1) Confirm evaluating index set

According to above comprehensive index system, index set of target layer is denoted as $\boldsymbol{U} = \{\boldsymbol{U}_1, \boldsymbol{U}_2, \boldsymbol{U}_3\}$; index set of rule layer is denoted as $\boldsymbol{U}_i = \{\boldsymbol{U}_{i1}, \boldsymbol{U}_{i2}, \cdots, \boldsymbol{U}_{ik_i}\}$ $(i = 1,2,3)$; index set of region layer is denoted as $\boldsymbol{U}_{ij} = \{u_{ij1}, u_{ij2}, \cdots, u_{ijl_{ij}}\}$ $(i = 1,2,3; j = 1,2,\cdots,k_i)$. Where k_i is the amount of region in certain rule layer; l_{ij} is the amount of index in certain region layer.

2) Confirm grade level of index

When we evaluate an ecocity, since we lack uniform evaluating standards, it is unconventional for comprehensive compare and evaluation. Therefore, in this paper, all indices are divided into four levels as excellent, good, middle and bad, corresponding value is 4, 3, 2 and 1, respectively. When index level intervenes between two levels, corresponding grade is 3.5, 2.5 and 1.5. Level standards are confirmed by each expert.

3) Confirm weight of each evaluating index

Commonly, influencing degree of each index is different. Some indices are outbalancing, so their weights must be considered more; whereas weights of other indices can be considered less. Hence we must endow with corresponding weight based on importance degree of each index. Weight sets can be obtained by method of subjective endowing, objective endowing or combined endowing. Weight sets can be described as:

Weight set of target layer is denoted as $\boldsymbol{A} = \{\boldsymbol{A}_1, \boldsymbol{A}_2, \boldsymbol{A}_3\}$; weight set of rule layer is denoted as $\boldsymbol{A}_i = \{\boldsymbol{A}_{i1}, \boldsymbol{A}_{i2}, \cdots, \boldsymbol{A}_{ik_i}\}(i = 1,2,3)$; weight set of region layer is denoted as $\boldsymbol{A}_{ij} = \{a_{ij1}, a_{ij2}, \cdots, a_{ijl_{ij}}\}$ $(i = 1,2,3; j = 1,2,\cdots,k_i)$. Where every weight set must satisfy normalization and nonnegativity.

4) Expert grade

Suppose that serial number of an expert is $n(n = 1,2,\cdots,p)$, namely we have p experts. According to above evaluating level, organize experts grade each index based on real value of each index and personal professional experience, and fill in the table of evaluating expert (evaluating table is omitted).

5) Evaluating sample matrix

According to the evaluating result of experts, we can confirm the evaluating sample matrix of the evaluated object, $\boldsymbol{D} = (d_{ijmn})_{q\times p}$, where d_{ijmn} is the grade which n-th expert gives to the index $u_{ijm}, q = \sum_{i=1}^{3}\sum_{j=1}^{k_i} l_{ij}$.

6) Confirm the evaluating grey cluster

When we confirm the evaluating grey cluster, we must base on the real problem. After we analyzed grade level standards of above evaluating index, we decide to use four evaluating grey clusters. Serial number of grey cluster is e, $e = 1,2,3,4$, represents "excellent", "good", "middle" and "bad", respectively. Fig.1 shows their corresponding grey number and whitened weight function.

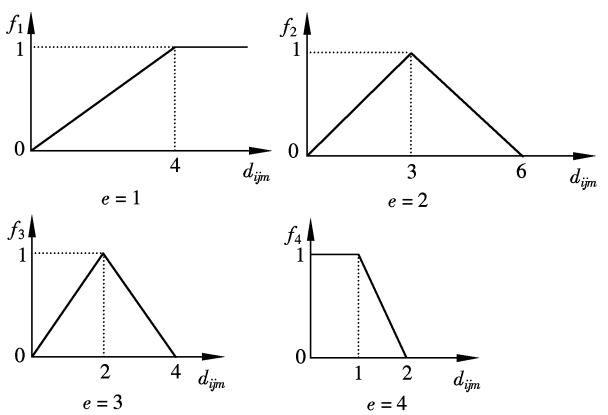

Fig.1 Relation figure of grey number and whitened weight function

7) Calculate the grey evaluating coefficient

To the evaluating index u_{ijm}, let x_{ijme} denote the grey evaluating coefficient that u_{ijm} belongs to evaluating grey cluster of No.e, and let x_{ijm} denote total grey evaluating number that u_{ijm} belongs to each evaluating grey cluster.

$$x_{ijme} = \sum_{n=1}^{p} f_e d_{ijmn}$$

$$x_{ijm} = \sum_{e=1}^{4} x_{ijme}$$

8) Calculate the grey evaluating weight vectors and matrices and determine each index what grey cluster is affiliated with

According to above grey evaluating coefficient, we can calculate the grey evaluating weight vector $\boldsymbol{r}_{ijm}$ and matrix $\boldsymbol{R}_{ij}$ of the region layer $\boldsymbol{U}_{ij}$.

$$\boldsymbol{R}_{ij} = \begin{bmatrix} r_{ij1} \\ r_{ij2} \\ \vdots \\ r_{ijl_{ij}} \end{bmatrix} = \begin{bmatrix} r_{ij11} & r_{ij12} & r_{ij13} & r_{ij14} \\ r_{ij21} & r_{ij22} & r_{ij23} & r_{ij24} \\ \vdots & \vdots & \vdots & \vdots \\ r_{ijl_{ij}1} & r_{ijl_{ij}2} & r_{ijl_{ij}3} & r_{ijl_{ij}4} \end{bmatrix}$$

where $r_{ijme} = x_{ijme}/x_{ijm}$.

Based on maximum principle, we can determine each index what grey cluster is affiliated with. Namely, if $r_{ijmq} = \max(r_{ijm1}, r_{ijm2}, r_{ijm3}, r_{ijm4})$, evalu-

ating index belongs to grey cluster of No. q.

9) Comprehensive evaluation of region layer

To the region layer $\boldsymbol{U}_{ij}$, we can evaluate it comprehensively by using the following equation:

$$\boldsymbol{B}_{ij} = \boldsymbol{A}_{ij}\boldsymbol{R}_{ij} = \{b_{ij1}, b_{ij2}, b_{ij3}, b_{ij4}\}$$

10) Comprehensive evaluation of rule layer

According to $\boldsymbol{B}_{ij}$, we can evaluate the rule layer $\boldsymbol{U}_i$ comprehensively by using the following equation:

$$\boldsymbol{B}_i = \boldsymbol{A}_i\boldsymbol{R}_i = \{\boldsymbol{A}_{i1}, \boldsymbol{A}_{i2}, \cdots, \boldsymbol{A}_{ik_i}\}\begin{Bmatrix}\boldsymbol{B}_{i1}\\ \boldsymbol{B}_{i2}\\ \vdots\\ \boldsymbol{B}_{ik_i}\end{Bmatrix} = \{b_{i1}, b_{i2}, b_{i3}, b_{i4}\}$$

11) Comprehensive evaluation of target layer

According to $\boldsymbol{B}_i$, we can evaluate the target layer $\boldsymbol{U}$ comprehensively by using the following equation:

$$\boldsymbol{B} = \boldsymbol{A}\boldsymbol{R} = \{\boldsymbol{A}_1, \boldsymbol{A}_2, \boldsymbol{A}_3\}\begin{Bmatrix}\boldsymbol{B}_1\\ \boldsymbol{B}_2\\ \boldsymbol{B}_3\end{Bmatrix} = \{b_1, b_2, b_3, b_4\}$$

12) Evaluating result

According to comprehensive evaluating vector $\boldsymbol{B}$, we can confirm the evaluated object what grey cluster is affiliated with based on maximum principle or comprehensive evaluating value $W = \boldsymbol{B}\boldsymbol{C}^{\mathrm{T}}$. Where $\boldsymbol{C}$ is the value vector of grey clusters, in this paper we set $\boldsymbol{C} = \{4,3,2,1\}$.

3 Grey Comprehensive Evaluation Support System of Ecocity

According to above model, using principle of software engineering and object-oriented method, grey comprehensive evaluation support system of ecocity is developed. Fig.2 shows the system framework and flow.

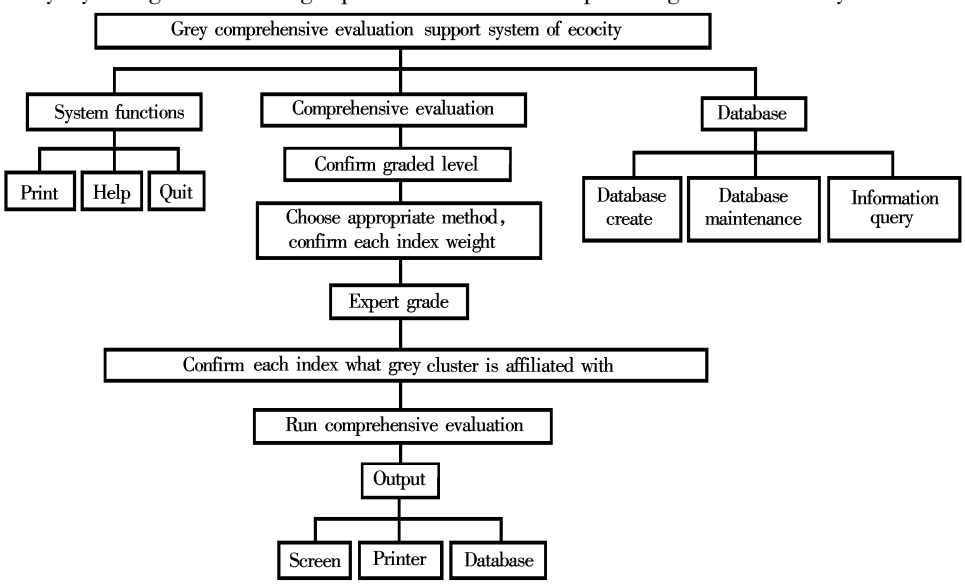

Fig.2 System framework and flow

4 Examples

Now, we will apply the proposed integrated grey evaluation model of ecocity and the support system to a real city for case study.

In the course of evaluation, firstly we must measure each index overall, and gain their real value. Then we choose five evaluating experts to grade each index. Tab.1 shows real value of each index and general grade table.

According to the above proposed evaluation model, grey evaluating weight vector and matrix of each evaluating index are calculated, and comprehensive evaluation to indices of each layer is done. Final comprehensive evaluating results are: (Because space is limit, course detail of calculation is complete by evaluation support system, the paper omittes this part.)

Excellent index: u_{112}, u_{122}, u_{321}, u_{323}, u_{331}, u_{332};

Good index: u_{111}, u_{113}, u_{114}, u_{115}, u_{116}, u_{117}, u_{123}, u_{124}, u_{125}, u_{211}, u_{212}, u_{213}, u_{214}, u_{215}, u_{222}, u_{231}, u_{232}, u_{233}, u_{312}, u_{313}, u_{314}, u_{315}, u_{316}, u_{317}, u_{318}, u_{322}, u_{324}, u_{325}, u_{326}, u_{328}, u_{334}, u_{335}, u_{336}, u_{337};

Middle index: u_{121}, u_{221}, u_{311}, u_{327}, u_{333};

Bad index: none.

$\boldsymbol{B}$ = {0.330?4, 0.389?2, 0.264?8, 0.015?6}, W = 3.034?5, namely comprehensive developing level of whole city is good.

5 Conclusions

The essential concept of building an ecocity points

out the future direction of the city development, which is an efficient way to keep the city growing in a stable track and developing towards an international city. We have to overcome all the research barriers to form a practical, perfect and integrated evaluation index system for the construction of the ecocity.

This paper proposes an evaluation index system of ecocity, and forms an integrated, multi-level, and grey evaluation model of ecocity. Based on that, this paper develops an evaluation support system for the ecocity evaluation problem. The model integrates the characteristics of the grey evaluation, and reflects the main aspects of the ecocity. Hence, this paper makes a contribution to both the literature and the practice in the area of the construction of ecocity.

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生态城市灰色综合评价支持系统研究与实现

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摘 要 本文根据生态城市的基本内涵和设计原则,构建了相对完整的生态城市指标体系.同时运用多层次灰色综合评价方法,建立了生态城市多层次灰色综合评价模型,并开发了综合评价支持系统,为生态城市的建设提供了理论指导.

关键词 生态城市, 指标体系, 评价等级, 多层次灰色综合评价, 评价支持系统

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