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Establishment of Intelligent Development Evaluation System for a City Based on Analytic Hierarchy Process

Yuhao Li
Department of Electrical Engineering, North China Electric Power University, Baoding, China
email:941582424@qq.com

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Abstract. In this paper, we model a metric for measuring the success of smart growth of a city and apply it to a mid-size cities. In the first step, we develop a metric A to measure the success of smart growth of a city using Analytic Hierarchy Process, including 5 facets: Intelligent development level, economy, resource, social harmony level as well as geography. After that, we select a mid-size cities: Plano, US and get change values about indicators from the present plans and standardize it to a scale of 0-1 according to international standard. Finally, we develop a growth plan for Plano, US. After implementing the plan, the comprehensive development of Plano, US will increase 5.6%.

Introduction

With Global Urbanization pushes on dramatically, ensuring all communities become a more economically prosperous, socially equitable, and environmentally sustainable place to live is a challenge and has become an intricate issue that should embrace all aspects of social. Despite improvements through technology, education and so on, some regions still face a severe situation.

Several cities in America have carried out some measures of smart growth and achieved certain results, such as neighborhoods which can walk *Northwest Landing* devised by *Calthorpe Associates,* mix land use in Legacy Town Centre. These cases verify the operability of smart growth directly. Aiming to help figure out smart growth, defining a metric to measure the success of the growth plan of a city plays a significant role. Many studies have developed a series of evaluation systems to deal with it. However, a huge majority of them proved to be unsuccessful because smart growth is newly proposed and implemented partly. It is not sure if an evaluation system is effective.

Under this background, we are required to select a mid-sized cities (with a population of between 100,000 and 500,000 persons) , and to model to measure the success of smart growth of a city judge with the goal of implementing smart growth theories into city design around the world. The problem is analyzed into three parts:

Define a metric to measure the success of smart growth of a city which meets the three E's of sustainability and/or the 10 principles of smart growth.

Research the current growth plan of the selected cities. Measure and discuss how the current growth plan of a city meets the smart growth principles. How successful are the current plans according to our metric. Develop a growth plan for this city.

Analysis on Determinant Factors

Numerous factors, ranging from economic size and structure, resource and environment quality to social harmony level, all define whether the smart growth of a city is successful or not. In order to solve the problem better, the drivers of water scarity are too numerous to address in this paper, we have identified several key causes of the problem. We treat the 10 principles of smart growth as the starting point to select these indicators. Meanwhile making selected indicators reflect all aspects of the society as far as possible. This way, these factors are divided into 4 categories, they are economy, resource and environment, social harmony level, the level of intelligent development. Each factor is determined by several metrics which can be easily detected.

The Measurement Model

Table 1 shows the measurement of the intelligent development level. We give a notation of I representing it. And I_1—I_7 represent its specific indicators. Thus we define the level of intelligent development level by Performance Evaluation Method, which is reachable and operable. Furthermore, positive I means the success of growth plan and negative I means the failure of growth plan. In addition, this indicator I is for each area and the varience among different areas show fair or unfair the development of a city is. An overview of other 4 variables and our justification for their selection is presented in table 2 below.

Table 1 The indicators pertaining to the level of intelligent development level (I)

Notation	Indicator	Description	Rules of evaluation
I_1	Main building	As a proxy of measurement of mix use of land, the more the functions are(such as schools and restaurants), the bigger degree of comprehensive utilization is.	Add 4 more for each feature with the upper limit 20.
I_2	Surrounding buildings	Reflecting the level of compact building design, the more the functions are, the bigger degree of comprehensive utilization is.	Add 4 more for each feature with the upper limit 20.
I_3	The functions of a community	Measuring whether the community is walkable or not. More functions means a community locates in walking distance.	Add one more for other features with the upper limit 5, except for living, offices, stores and restaurants.
I_4	Population	Demonstrating residents having housing opportunities. It is measured by population per Ha. According to the standard, 600 people/Ha is the best situation. And too large and too small number is not good.	10 for 600people/Ha; 9 for 500~700people/Ha; 6 for 300~500people/Ha and for 700~900people/Ha; 3 for <300 people/Ha and for 900~1200people/Ha; 0 for >1200 people/Ha.
I_5	Landmark Building	Taking GDP as the main indicator of the attraction of a community.	Add 15 for a landmark.
I_6	The area of green	Indicating open space, farmland, natural beauty, and critical environmental areas. According to the standard, the area of green35% is the best circumstance for living.	12 for >35%; 20 for >60%; The upper limit is 20.
I_7	Transportation choices		Add 2 more for each choice with the upper limit 10.
Sum	—	—	100

Table 2 shows the measurement of economy. We also give a notation of E representing it. And E_1, E_2 represent its specific indicators, R_1, R_2 represent specific indicators of resource, S_1—S_4 represent specific indicators of social harmony level, in addition, geography expressed in G. According to Delphi Method and the importance of every facet, we look up a literature value and determined weights of each factors[1].

What calls for special attention is that the evaluation of smart growth is different traditional comprehensive evaluation of urban development. The biggest difference between the two is “smart”. The key to our problem is how to measure “smart”. Given this, we using traditional weight of evaluation system as a foundation and attach more importance to “smart”. Alternatively, we give 0.5 for indicators on “smart growth” and scale down other 4 aspects to 0.5 in total. Specially, take 0.5 for I, 0.12 for E, 0.1 for R, 0.2 for S, 0.08 for G.

It should be noted that it is difficult to demonstrate the effect of geography. *Comfort index* might be the major concern. As discussed above, *Comfort index* characterizes the degree of comfort to the air environment of a person in a certain temperature and humidity. These two factors is mainly

decided by geographical features. Then we combine these two factors into one term which on behalf of geography. This allows us to examine the effect of geography.

Table 2 The indicators pertaining to economy

Order	Notation	Indicator	Weight	Justification
Economy Index	E_1	GDP per capita	0.06	Reflecting economic size from different views.
	E_2	Economic density	0.06	
Resource	R_1	Green area per capita	0.04	It Indicates the resource a city possess for smart growth.
	R_2	Greenhouse gas emissions, HFC, PFC and SF_6	0.03	It is a proxy of air quality in cities.
	R_3	Total natural resources rents	0.03	Take it as a proxy of urban environmental protection effects.
Social harmony level	S_1	Researchers in R&D	0.05	It is a measurement of intelligence in cities.
	S_2	Health expenditure, total	0.04	It responses to the health if urban residents.
	S_3	Government expenditure on education, total	0.04	It is the main factor of the education.
	S_4	Added road area	0.06	Use it as a basic measurement of urban transportation.
Geography	G	Comfort index	0.08	It is a comprehensive description of the impact of temperature and humidity on human.

Taking all these parameters into account and quantify we can step further to define a set of notations in designing a mathematical model. All these indicators are shown mathematically below.

Table 3 Mathematical Description of the indicators

Order	Notation	Indicator	Unit	Mathematical Description
Economy Index	E_1	GDP per capital	Current US$	$E_1 = \frac{Total\ GDP}{Population}$
	E_2	Economic density	Current US$ per hectare	$E_2 = \frac{Industrial\ output}{Area\ of\ urban\ built-up}$
Resource	R_1	Green area per capital	Square meters per person	—
	R_2	Greenhouse gas emissions, HFC, PFC and SF_6	Thousand metric tons of CO_2 equivalent	—
	R_3	Total natural resources rents	% of GDP	$R_3 = \frac{Investment\ in\ environment}{GDP}$
Social harmony level	S_1	Researchers in R&D	Per million people	—
	S_2	Health expenditure, total	Person	$H_2 = \frac{Number\ of\ doctors}{Per\ million\ population}$
	S_3	Government expenditure on education, total	% of GDP	$H_3 = \frac{Investment\ in\ education}{GDP}$
	S_4	Added road area	Km	—
Geography	G	Comfort index	In absolute terms	$G = T - (0.55 - 0.55f)(T - 58)$ Where: T is temperature; f is humidity

Indexes Normalization

Firstly, depending on GDP Index proposed by UNDP in HDI, the standardization of GDP per capita is defined as formulae 1:

$$E_1' = \begin{cases} 1 & E_1 \geq 9582.15\$ \\ \dfrac{\lg E_1 - 100}{(\lg 9582.15 - \lg 100)} * 100\%, & E_1 < 9582.15\$ \end{cases} \quad (1)$$

Where: 9582.15 refers to the international standard on GDP per capita. Secondly, as with other indicators, we standardize them by formulae 2:

$$P' = \begin{cases} 1 & when\ P\ exceeds\ the\ standard \\ \dfrac{P}{The\ standard\ value} & when\ P\ is\ less\ than\ the\ standard \end{cases} \quad (2)$$

Where: P represents those indicators mentioned above, *i.e.*E_1, E_2, R_1,R_2, S_1—S_4, G. *P'* is the standardized value.

Table 4 The standards of the parameters

Order	Notation	Unit	Standard
Economy Index	E_1	Current US$	9482.15
	E_2	Current US$ per hectare	213502
Resource	R_1	Square meters per person	13
	R_2	Thousand metric tons of CO_2 equivalent	7058023.272
	R_3	% of GDP	4.714
Social harmony level	S_1	Per million people	1282.147
	S_2	Person	10.031
	S_3	% of GDP	4.634
Geography	G	In absolute terms	65

Differ from *E,R,S,G*, *I* is measured through performance evaluation, the upper limit is 100. Divided by 100 we can standard I to the range of 0-1 and *I* is united with other indicators. As shown in formulae 3.

$$I' = \frac{\sum_{i=1}^{7} I_i}{100} \quad (3)$$

This way, the units of all these indicators are both 1 and dimensionless is realized. All data given as a percentage are shown on a 0 to 1 scale. Therefore it is possible to combine all these indicators into a comprehensive term and to compare.

A Comprehensive Evaluation System

Depending on AHP and Delphi method, a comprehensive metric *A* to measure the success of smart growth of a city can be determined as formulae 4.

$$\begin{aligned} A &= f(I, E, R, S, G) \\ &= 0.5I' + 0.12E' + 0.10R' + 0.20S' + 0.08G' \end{aligned} \quad (4)$$

The bigger *A* is, the development of a city is higher. Besides, the bigger ΔA means more successful the smart growth of a city is. Moreover, a positive ΔA means the success of smart growth of a city and vice verse.

Test Results

Applicability to Plano, US, North American Continent. *Growth Plan of Plano, US*. Tomorrow Plan in Plano reduces the chances of additional housing and limits housing to job centers, highways

corridors, besides, it creates a new policy that gives priority to job creation in the remaining open space[3].

Tomorrow Plan identified five regions as compact, complete centers around major catalysts (Legacy, Willow Bend, Cillin Creek Mall) or future railway stations. Furthermore, the type and number of dwellings will be managed zoningly by estate either development or redevelopment[3].

Save and enhance the existing area. 80% of the land area should be preserved and enhances in its present form or should be kept open[3].

Dividing the Region. According to main streets, Hainan County is divided into eight areas shown below:

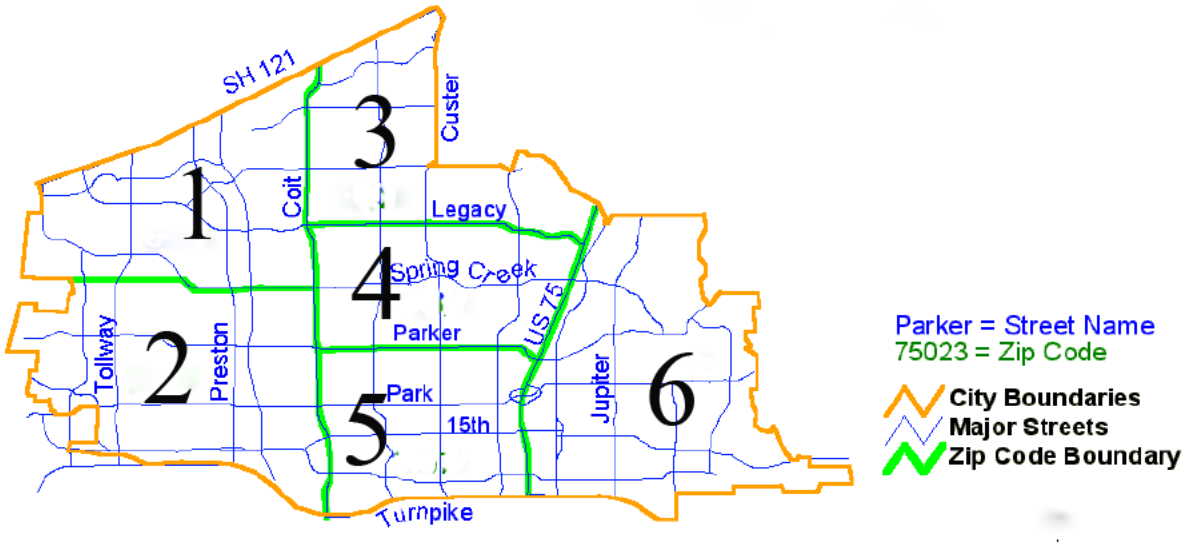

Fig.1 Zoning of Plano

Evaluation. According to the rule of evaluation of I described above, the scores of each area of Hainan County are shown as Table 5. After implementing growth plan, all these values are shown mathematically as Table 6 and Table 7.

Table 5 Scores of different areas of Plano before implementing plan

Area number	Main Building I1	Surrounding Buildings I2	The functions of a community I3	Population I4	Landmark building I5	The area of green I6	Transportation Choice I7	Score
1	4	4	0	9	15	16	2	50
2	4	8	0	9	15	14	2	52
3	8	8	0	9	15	14	4	58
4	8	8	5	9	15	12	6	63
5	4	8	0	6	0	14	4	36
6	4	4	0	6	0	16	2	32

Discussion. It can be easily get from ΔI = 0.083>0 that the growth plan of Plano meets the principles of smart growth. Because I change from 50 to 58, which illustrates the city will become more “smart”. ΔA for Plano is 0.2217>0, which reveals the success of the growth plan and represents the comprehensive development increases by 22.17%.

Calculating the variance of I of 8 areas, we get 148.7 before implementing the plans for it and 245.4 for after implementing the plans, the difference is -96.7 between them which means Plano will become more unfair .

Table 6 Scores of different areas of Plano after implementing plan

Area number	Main Building I1	Surrounding Buildings I2	The functions of a community I3	Population I4	Landmark building I5	The area of green I6	Transportation Choice I7	Scores
1	8	4	0	9	15	14	2	52
2	8	8	0	9	15	12	2	54
3	12	16	5	9	15	12	6	75
4	12	16	5	9	15	10	8	75
5	8	16	5	6	0	12	6	53
6	8	4	0	6	0	14	2	34

Table 7 Scores of each indicators on smart growth

Order	Notation	Indicator	Weight	Change after implementing growth plan
Smart (0.50)	I	The level of smart	0.50	+0.083
Economy Index	E1	GDP per capita	0.06	+0.12
	E2	Economic density	0.06	+1
Resource	R1	Green area per capita	0.04	+0.2
	R2	Greenhouse gas emissions, HFC, PFC and SF6	0.03	+0.3
	R3	Total natural resources rents	0.03	+1
Social harmony level	S1	Researchers in R&D	0.05	+1
	S2	Health expenditure, total	0.04	+0.1
	S3	Government expenditure on education, total	0.04	+0.3
	S4	Added road area	0.06	+0
Geography	G	Comfort index	0.08	+0
A	ΔA	Comprehensive metric	1	0.2217

A New Growth Plan for Plano, US

Justification. ***Geography***. Close to Dallas, an economically prosperous city, Plano owns a good environment for economic development and convenient transportation[5].

Expected Growth Rate. The expected GDP growth rate is 2%, and the expected population growth rate is 8.1%. The expected investment proportion for urban construction and education are 21%(of GDP) and 24% respectively figuring out by the method mentioned above[5].

Economic Opportunities. The new president has come to power and put forward to a series of policies which promote the development of the domestic manufacturing industry.

Growth Plan. Depending on these characteristics, we propose 5 specific plans for it. They are listed as follows:

• Develop area 1 to a trade center. Already has a logistics center, it is easy to be a trade center based on the economic advantage and to build a compact, multifunctional area. In addition, rebuild houses to apartments for more living.

• Develop cultural industry in area 4,5 and encourage people to start business in other areas. These measures are helpful for residents to enjoy a high-quality life.

• Promote the development of manufacturing to coordinate with trade of area 1.

Results and Evaluation. Apply this plan to Plano to forecast the growth and the result is shown below.

Table 8 New results of smart growth plan for Hainan County

Order	Notation	Indicator	Weight	Change after implementing growth plan
Smart	I	The level of smart	0.50	+0.033
Economy Index	E_1	GDP per capita	0.06	+0.2
	E_2	Economic density	0.06	+0.3
Resource	R_1	Green area per capita	0.04	-0.05
	R_2	Greenhouse gas emissions, HFC, PFC and SF_6	0.03	0
	R_3	Total natural resources rents	0.03	-0.15
Social harmony level	S_1	Researchers in R&D	0.05	+0.1
	S_2	Health expenditure, total	0.04	+0.05
	S_3	Government expenditure on education, total	0.04	+0.1
	S_4	Added road area	0.06	+0.2
Geography	G	Comfort index	0.08	0
A	ΔA	Comprehensive metric	1	0.056

The comprehensive metric A for Plano is 0.056>0, Indicating that our model does have its value. The varience of I is 148.7 before plan and 234.8 for after. The latter is more than the former and shows Plano will become more unfair after plan.

Conclusion

In order to analyze the degree of urban intelligence development, we divide the whole city into multiple areas, and in accordance with the principle of intelligent growth to develop an evaluation system for each region to assess the degree of intelligent development. Finally, we combined the traditional urban evaluation system with regional intelligence development degree evaluation index to be a new intelligent development evaluation system. We select a mid-size cities and get change values about indicators Then the success of smart growth can be evaluated by change of A. The results are: ΔI= 0.0833 for Plano shows it meets the principles. ΔA=0.2217 for Plano, illustrating the success of the plan for it and the rate of development is 22.17% after plan. Finally, we develop a growth plan based on its geography, expected growth rates, and economic opportunities, taking principles of smart growth as constraints. After implementing the plan, the comprehensive development will increase 5.6% and show the success of the plans.

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