For office use only	Team Control Number	For office use only
T1 ________________	**56224**	F1 ________________
T2 ________________		F2 ________________
T3 ________________	Problem Chosen	F3 ________________
T4 ________________	**E**	F4 ________________

2017

MCM/ICM

Summary Sheet

(Your team's summary should be included as the first page of your electronic submission.)

Type a summary of your results on this page. Do not include the name of your school, advisor, or team members on this page.

In this paper, we create a 4-level Evaluation Indicator System to measure the success of smart growth of a city. It takes the three E's of sustainability and the ten principles of smart growth into consideration. There are 37 indicator items in the 4th level and 15 indicator classes in the 3rd level, we use Grey Clustering to find the relationship between the indicators in 3rd and 4th level to make a scalable system for possible new indicators. Then we use Analytic Hierarchy Process to set up our evaluation system, including data processing, judgement matrix construction, weight calculation and consistence check. To check the correctness of this system, we use it to study the development of a specific city influenced by smart growth in 20 years and do a sensitivity analysis before we do the case study. After that, to improve the model, we think out four optimizations, including over-standard with weight, tendency consideration, cost performance consideration in suggestion and measures for unexpected incidents. Then we analyze the strengths and weaknesses of our system, the sensitivity, stability and accuracy of it have been improved.

In case study section, we choose Pittsburgh (US) and Sanya (China) for research since they are at different stages of smart growth and both governments have published detailed statistical data. For task 1, we describe the metric we have built and use it to analyze the overall situation of both cities. For task 2, we selected two current growth plans for each city from their official websites and use our metric to abstract a few indicators from published plans to evaluate whether these indicators can be improved. For task 3, our metric can reflect the shortcomings of a city in smart growth, so we can develop a suitable growth plan for each city and evaluate those indicators to see the trends of their changes in a few decades. For task 4, we calculate the weight of those initiatives in our plan and rank them between two cities, and then compare and analyze why they have such priorities. For task 5, since we already know in sensitivity analysis that our metric is acute enough to reflect the changes whose impact factor are high, so we conclude that the effect of such great population growth is worse on Pittsburgh rather than Sanya.

CONTENTS

1 Introduction

How can a city achieve sustainable development has been widely discussed around the world. As developing countries speed up their pace of urbanization, a series of problems appear, including water contamination, health problem, loss of farmland and so on. As for developed countries, sustainable development also cannot be ignored when densely populated towns and cities are short of water and the shrinking farmland cannot meet all the food needs, the transport system accounts for huge emissions but is expensive and inadequate. To solve these problems and improve smart growth, one best solution is to establish an efficient Evaluation Indicator System which can reflect the city's comprehensive ability of achieving smart growth and tell us about the shortcomings as well.

2 Assumptions and Definitions

2.1 Assumptions

Our model makes the following assumptions:

- During our research, the general development situation of the city remains stable.
- The data we find about these cities from the internet is authentic and the result we get by analyzing initial data is close to the real one.
- The people in different cities will have similar options about smart growth theory.
- The scores from emergency we give is reasonable.
- The evaluation about the effect of development plans is accurate and there won't be any emergencies happen during the process.

2.2 Descriptions and Definitions

We use **Analytic Hierarchy Process** to set up our Evaluation Indicator System which is a 4-level structure. The 1st level is called Target Layer, including one main indicator named Comprehensive ability of achieving Smart Growth (CSG). The 2nd level contains three indicator categories which can represent the Three E's of sustainability. The 3rd level consists of 15 indicator classes. Most of them are selected from the 10 principles of Smart Growth, rest of them are added by ourselves to strengthen the system's evaluation ability. The most significant is 4th level containing detailed indicator items. Here is the definition and abbreviation of all these indicators:

Table 1: Definition of Indicators

1st Level Target Layer			
Comprehensive ability of achieving smart growth			
2nd Level Indicator Category		**2nd Level Indicator Category**	
Social Development	***SD***	Economic Prosperity	***EP***
Environmental Sustainability	***ES***		
3rd Level Indicator Class Name		**3rd Level Indicator Class Name**	
Compact building design & Walkable	***CW***	Good Ecological Environment	***GEE***

neighborhoods			
Mix land use & Housing opportunity	***MH***	Build green communities. A good sense of place	***BA***
Transportation	***TP***	Make predictable, fair, effective development Decisions	***MD***
Community Energy Conservation	***CEC***	Community Planning and Construction	***CPC***
Community Efficient management Mechanism	***CEM***	Encourage Collaboration in development Decision	***ECD***
Harmonious Interpersonal Relationships	***HIR***	Concerned about Vulnerable Groups	***CVG***
Economic Development	***ED***	Economic Growth Rate	***EGR***
Economic Structure	***ES***		
4th Level Indicator Item Name		**4th Level Indicator Item Name**	
Urban population density	***UPD***	Government Policies	***GP***
Road Area per Capita	***RAC***	Open Space	***OS***
Compactness of Urban Construction	***CUC***	GDP per Capita	***GPC***
Medical Insurance Rate	***MIR***	GDP Growth Rate	***GGR***
Proportion of Residents who travel by multiple Transportations	***PRT***	Proportion of the Second and Tertiary industry	***PST***
Education Investment per Capita	***EIC***	Total Investment	***TI***
Average Education Period	***AEP***	Engel Coefficient	***EC***
Proportion of College Students	***PCS***	Social Labor Productivity	***SLP***
Point of Different styles of Houses	***PDH***	Total Retail Sales of social consumer goods per capita	***TRS***
Gini Coefficient	***GC***	Green Area per Capita	***GAC***
Crime Rate	***CR***	Percentage of Waste Recycling	***PWR***
Point of Mixed use of different Houses	***PMH***	Greenhouse Gas Emissions	***GGE***
Point of Different Income people	***PDI***	Harassment Indicators	***HI***
Proportion of Energy-efficient Buildings	***PEB***	Residents' Satisfaction	***RS***
Proportion of Residents with a Sense of place	***PRS***	A Reasonable Management Mechanism	***RMM***
Neighborhood Familiarity	***NF***	Number of times that Residents Participated in community building	***NRP***
Geographic Location	***GL***	Degree of Road Patency	***DRP***
Coverage of urban Public Services	***CPS***	Proportion of the Elderly who feel Happy	***PEH***
Number of cultural and sports Venues per Capita	***NVC***		

3 Models for Smart Growth Evaluation

3.1 Grey Clustering Evaluation

We use Grey Clustering Evaluation to find the relationship between 3rd level and 4th level. Grey Clustering Evaluation is used to merge the similar factors, making the complex relationship simple. If we have n cities and each city have m indicators, we can get the following sequence:

$$Y_i = \big(x_i(1), x_i(2) \dots, x_i(n)\big) \ \ 1 \le i \le m,\ \ 1 \le n \le 5$$

m is the number of indicator items in the 4th level and we have chosen 5 cities in different stages of development to give scores to the indicators in 4th level, which can make the Indicator Correlation Matrix more objective and accurate. The five cities we chose are New York(US), Guiyang(China), Hanoi(Laos), Kinshasa(Congo) and Santa Cruz(Bolivia). We think such choices should not be limited to the size of city, because the size of a city doesn't influence the relationship between two indicators

3.1.1 Calculate Absolute Correlation Degree

For each $i \le j,\ i,_{,} j = 1,2,3 \dots m$, we calculated the **Absolute Correlation Degree** ε_{ij} to get **Indicator Correlation Matrix** as follows:

$$A = \begin{bmatrix} \varepsilon_{11} & \varepsilon_{12} & \cdots & \varepsilon_{1m} \\ & \varepsilon_{22} & \cdots & \varepsilon_{2m} \\ & & \ddots & \\ & & & \varepsilon_{mm} \end{bmatrix} \varepsilon_{ii} = 1; i = 1,2 \dots m$$

To get ε_{ij}, first initialize all the indicators since the differences between them are large. The method is to invite an expert to give each indicator a score that can represent the degree of whether it is good. Then we use the result to find indicator classes and relationship between 3rd level and 4th level. The initialization evaluation is:

$$x_0 = \left\{ x_0(k) = \frac{X_0(k)}{X_0(1)}, k = 1, 2, \dots, n \right\}$$

$$x_i = \left\{ x_i(k) = \frac{X_i(k)}{X_i(1)}, k = 1, 2, \dots, n \right\} \ \ i = 1,2, \dots, N$$

x_0 is the referenced sequence and x_i is the sequence to be compared. For these two sequences, when $k = t$, the **Correlation Coefficient** is done:

$$\xi_i(t) = \frac{\min\limits_i \min\limits_k |x_0(k) - x_i(k)| + P \max\limits_i \max\limits_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(t)| + P \max\limits_i \max\limits_k |x_0(k) - x_i(k)|}$$

For the whole sequence the **Correlation Coefficient** r_i is:

$$r_i = \frac{1}{n} \sum_{t=1}^{n} \xi_i(t)$$

The r_i is what we need.

3.1.2 Evaluation Indicator System

After calculating the ε_{ij}, the **Indicator Correlation Matrix** A is done. It is a 37×37 matrix and too large to draw here. Here is a part of it:

$$\begin{array}{cc} & \begin{matrix} i_1 & i_2 & \cdots & \cdots & i_{37} \end{matrix} \\ \begin{matrix} i_1 \\ i_2 \\ \vdots \\ \vdots \\ i_{37} \end{matrix} & \begin{bmatrix} 1 & 0.32 & \cdots & \cdots & 0.59 \\ & 1 & \cdots & \cdots & 0.74 \\ & & \ddots & \cdots & \vdots \\ & & & \ddots & \vdots \\ & & & & 1 \end{bmatrix} \end{array}$$

Indicator Correlation Matrix

$$i_m \in \{set\ \ of\ \ 4th\ \ level\ \ indicator\ \ items\}\ \ 1 \le m \le 37$$

We choose a threshold r as a separator to classify the 4th level indicator items into classes. If r is close to 1, it means it should be put in one class. Since the value of r will affect the result, we try different values and compare them with the data we have searched from the database of the local Bureau of Statistics of the city to check the rationality. Finally, the hierarchy of this Evaluation Indicator System is:

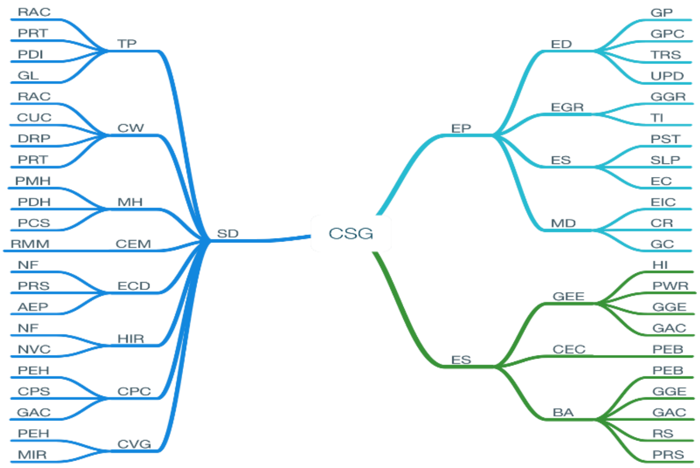

Figure 1: The Hierarchy of Evaluation Indicator System

3.1.3 Discussion

Sometimes you need to adjust these indicator classes based on your own experience and real situation. We can find that the indicator items in one class can represent something similar. We also take the principles of smart growth into account when classification. During it, we find that the principles of smart growth mainly focus on the Social Development, the other two aspects in three E's are important as well. So, we add some indicator classes to make the model system more impeccable.

3.2 Analytic Hierarchy Process

3.2.1 Outline of Our Approach

The method we use to set up our system is Analytic Hierarchy Process. Since the judgment of a city cannot be absolutely clear because some indicator items are difficult to measure, the AHP is helpful to make the problem simple. As is described in Definition, we create a 4-level evaluation system.

3.2.2 Data Processing

First, we must standardize the data because the units of data from statistical form are usually not the same, we cannot evaluate directly based on them. The nondimensionalization of data can provide us with the result that can be calculated and compared directly. The formula is:

$$Z_x = \frac{x - \bar{x}}{SD}$$

Z_x means the data after nondimensionalization, x is the initial data, $\bar{x}$ is the average value of x and SD is the variance. Since the calculation above may have negative number ($x < \bar{x}$) which is not convenient for us to understand and compare, so we use another formula to process:

$$T_x = 50 \pm 10 \times Z_x$$

If the indicator x is positive related indicator, use '+'; if it is negative, use '-'. We now get T_x in the range of 0 to 100 and it can reflect whether this indicator is positive for the city.

3.2.3 Construct Judgment Matrix

First, we need an export about the importance of different factors in one layer (one group in our case). It is suggested that Pairwise Comparison Judgment is needed because this method can reduce deviation and is easy to accept.

So, if we want to compare n factors $X = \{x_1, x_2, x_3, \dots, x_n\}$ to see how much they affect the factor Z, we should build the Comparative Matrix. Every time we pick X_i and X_j, we use a_{ij} to represent the ratio of influence degree to Z between X_i and X_j. The whole result is in matrix A=$(a_{ij})_{n*n}$. We call A the Paired Comparison Judgment Matrix between Z and X. It's obvious that $a_{ij} = \frac{1}{a_{ji}}$. Then we use Saaty's function to get a_{ij} which uses number 1-9 and its reciprocals as scale according to the following form:

Table 2: Scales of importance between a_i and a_j

Scales	Meanings
1	The former has the same importance as the latter.
3	The former is slightly more important.
5	The former is more important.

7	The former is much more important.
9	The former is quite important.
2, 4, 6, 8	Indicate the scale between the above scales.

From point of psychology, if we make too many levels, the people will have difficulty in making decisions. Some tests have been done to prove the superiority of the above 9 scales. Another thing to notice is that it's necessary to do pairwise comparison judgement for $\frac{n(n-1)}{2}$ times. Because if we compare all factors with a standard one, every single error will cause wrong order and mistakes to happen frequently. The pairwise comparison judgment is a good method to avoid this problem.

Then we can use this method to get our **Judgement Matrix**. We find layer *i* and layer *i-1*, get factors *B* $\{B_1, B_2, ..., B_n\}$ in layer *i* which belongs to factor A_k in layer *i-1*. Then we do pairwise comparison for *B* to get the degree of how much the factor affects A_k. The result is:

$$\begin{pmatrix} b_{11} & b_{12} & \cdots & b_{1i} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2i} & \cdots & b_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ b_{i1} & b_{i2} & \cdots & b_{ii} & \cdots & b_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ b_{n1} & b_{n2} & \cdots & b_{ni} & \cdots & b_{nn} \end{pmatrix}$$

b_{ij} means the ratio of influence degree between B_i and B_j.

3.2.4 Weight Calculation

In different cities or communities, the residents and the surroundings are different, so the factor in 3rd layer will affect the feelings of people as well as our evaluation system. Since the weights of different factors will directly affect the result, it's important to give a good weight allocation. Now we have the judgment matrix *B*, we calculate its largest eigenvalue and maximal eigenvector:

$$BW = \lambda_{max} W$$

λ_{max} is the largest eigenvalue and *W* is the maximal eigenvector. After the normalization of *W*, it represents the weights of all the factors that belong to A_k.

3.2.5 Consistency Check

When people judge many cases, they can hardly keep consistent, so we should check the result and ensure it's strong enough. We first calculate its coincidence indicator CI:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

λ_{max} is the largest eigenvalue and *n* is the matrix dimension. Second, check the standard coincidence indicator according to Saaty's theory:

Table 3: Values of RI for each n (n<=9)

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Finally, we calculate the consistency ratio CR:

$$CR = \frac{CI}{RI}$$

When CR<0.1, the judgment matrix can be considered acceptable. Otherwise, we should adjust the matrix.

3.2.6 Calculate the final point

The last step is to use layer *i* to get the score of layer *i-1*. For an element A_k in layer *i-1*, in our model it will contain some elements in layer *i*, and let the score of group members in A_k be $B\{p_1, p_2, \dots, p_m\}$ (*m* is the number of members in A_k). Besides, we have the weights of them $W\{w_1, w_2, \dots, w_m\}$, so A_k can be calculated by:

$$P_A = \sum_{i=1}^{m} p_i * w_i$$

After we get all the scores in layer *i-1*, we can turn to *i-2* and so on. Finally, we can reach the target level and get its final score which is the judgment of the success of smart growth of a city. Moreover, we use some typical city data to check our model to determine the boundary between different levels of development of cities. The higher score a city achieves, the better evaluation result our model provides.

3.3 Correctness Analysis

To analyze whether the model can correctly reflect the success of a city's smart growth. Before we do the Case Study Section, we select a typical urban case which has undergone a development process from non-smart-growth to smart-growth to see whether the evaluation result is reasonable. The city we chose was Zhangjiagang (China) which was a poor town before 1996 and now is one of the most livable city awarded by the UN. Great changes have taken place because of the smart growth theory.

The judgement matrix and the evaluation form which contains the 4^{th} level indicators' score based on the data of Zhangjiagang were written into appendix. Based on it, we have calculated the weights of 4^{th} level indicator items and then we got the 15 indicator classes score by:

$$3^{rd}\ \textit{Level Indicator Class Score} = \sum_{i=1}^{n} \omega_i x_i \quad 1 \le n \le m$$

m represents the number of indicator items in the 4^{th} level in one 3^{rd} indicator class. ω_i is the weight calculated from the judgement matrix and x_i is the score from evaluation form. The result is in appendix:

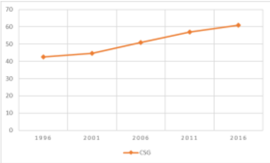

Figure 3.1

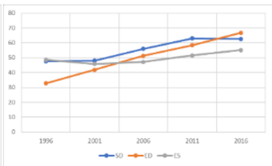

Figure 3.2

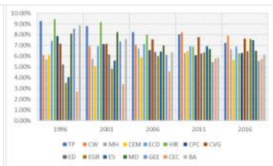

Figure 3.3

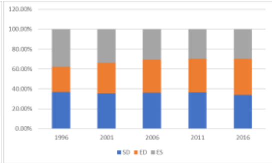

Figure 3.4

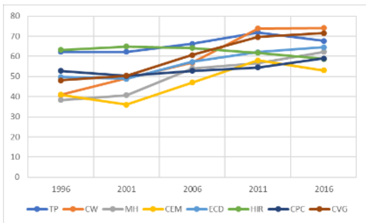

Figure 3.5

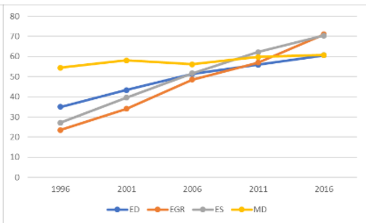

Figure 3.6

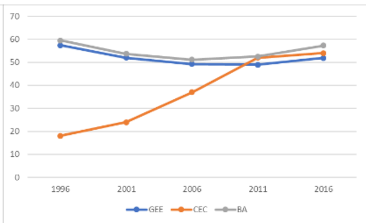

Figure 3.7

Figure 3.1 is for Target Level, Figure 3.2 to 3.4 are for 2nd Level Indicator Categories and Figure 3.5 to 3.7 are for 3rd Level Indicator Classes. Obviously, Figure 3.1 points out that the degree of smart growth of Zhangjiagang has been more and more successful. Figure 3.2 describes the general trend of the three E's between 1996 and 2016 while Figure 3.4 describes the proportion of each part. Figure 3.5 to 3.7, represent the details of the trends of the development of society(SD), the trends of the development of economy(ED) and the trends of ecological construction(ES) respectively.

Compared with the government reports over the years, we find that our metric can accurately reflect most trends of indicators, especially in these following aspects:

- In Figure 3.3, with the rapid social development, traffic has become more convenient so that the proportion of transportation has declined while the CPC has raised due to the higher requirement from citizens.
- From Figure 3.5, we can see the trends of all indicators based on economy are enjoying rapid growth, which is corresponding to the economic report it has published on official websites.
- In Figure 3.6, we find a line in orange representing Community Energy Conservation has raised quickly between 1996~2016 since the government has announced Green Construction Plan among society in 2000.
- we find in Figure 3.7, the indicator named GEE in grey has experienced first decline and then gradual rise, which is corresponding to the real situation because early development was at the expense of the environment and after the economy became mature people tend to be aware of the importance of environmental construction.

3.4 Sensitivity Analysis

3.4.1 Denoising

In our model, we decide to take CSG, SD, ED and ES as sensitivity analysis indicators. First, we remove three 4th level indicator items, including NF, PDH and CUC in SD or

PST, GGR and CR in ED or PEB, GGE, RS in ES to see the changes conveyed by the charts:

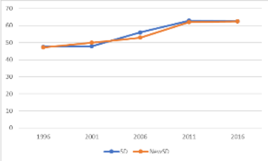

Figure 3.8: SD

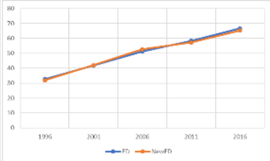

Figure 3.9: ED

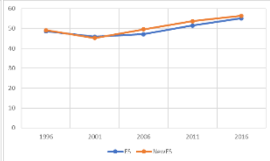

Figure 3.10: ES

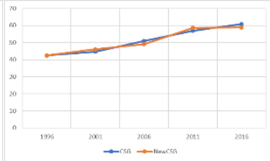

Figure 3.11: CSG

From the result, we can see the two lines are basically the same. There are just a few small fluctuations. So, we think that the absence of individual indicators does not affect the overall evaluation, which shows that our model has a good stability and good resistance to risk.

3.4.2 Variations in the Indicators

Next, we choose two indicator items that ensure the former one has a high impact factor in the judgement matrix while the latter one is low. When it comes to PCS and PDH, Zhangjiagang has established the first university called ShaZhou Professional Institute of Technology in 1991, so we increase the score of PCS and with the development of society, different styles of houses appear, so increasing the score of PDH is also reasonable. Then we do the same operation on ED and ES.

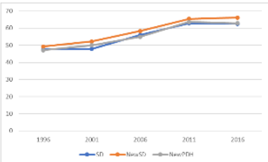

Figure 3.12: SD

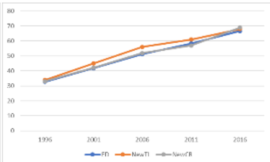

Figure 3.13: ED

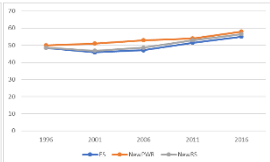

Figure 3.14: ES

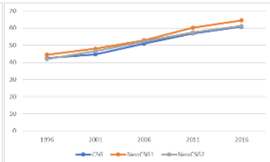

Figure 3.15: CSG

We can find that if we increase the score of one indicator with a high impact factor, then no matter for Indicator Classes or CSG, the result will be obviously improved just like the orange lines in the above charts. However, if we increase the score of one indicator with low impact factor, then the result is almost unchanged or very small. So, based on the statements above, our model:

- When a small number of evaluation indicators are lost, the evaluation result is still correct, the model has a good stability
- Can respond acutely to a change of indicator item with a high impact factor and ignore the impact caused by low impact factors.

3.5 Model Optimization

3.5.1 Weight Calculation Optimization

There exists a rule that if one factor is extraordinary extrude, people will pay more attention to that aspect, then the weight of that factor should be greater and the extrude factor will become a bottleneck during the city development. We choose a method of over-standard with weight to do the optimization after we get the original weight form based on the comparison between measured data and standard data. The standard data, in this case, can be the government standard or local standard. Since the smart growth concept is new and we cannot find such standard, we replace it with our own preset value. In short, the more our measured data exceed the standard, the heavier the weight will be. The calculation goes as:

$$r_i = \frac{1}{2}(m_i + \frac{\frac{m_i}{s_i}}{\sum_{i=1}^{n}\frac{m_i}{s_i}})$$

m_i is the measured weight, s_i is the standard weight and r_i is the optimized weight.

3.5.2 Tendency Consideration in Evaluation

When giving scores, we will search for the historical data of the city, then calculate the tendency of the score. Finally, increase the score which reflect the trend of development into the final score. The method can be used in any layer according to actual requirement and calculated by the following formula:

$$SF = \frac{1}{2}(\frac{\sum_{i=1}^{n}(a_{i+1} - a_i)}{n} + S)$$

a_i is data of year *i*, *n* is number of years, *S* is current score given by the model and *SF* is final score after calculation.

3.5.3 Cost Performance Consideration in Suggestion

The suggestion we used to give mainly depend on the weights of different factors, however, the most useful way to improve the life may not be the high investment on the factor which weighs most. So, we add some functions into **Advice System**. Originally, we can only provide the information based on weights. By comparison, we now take the value of score and rangeability into account. We provide people with more information, including the factor whose score is low (which means its potential is large and its cost performance is good) and whose score fluctuates a lot. This can help the administrators make better development decisions.

3.5.4 Optimization for Unexpected Incidents

Until now, the metric we have built is expected to be able to work for a relatively long period since the statistics of a city are collected annually under normal circumstances. However, the situation of a place may change a lot because of some incidents including financial crisis, policy changes or natural disasters. Thus, a method that can make a timely amendment to the Evaluation System. Our solution is as follows:

$$E_c = E_{c0} + \varepsilon_c$$
$$E_q = E_{q0} + \varepsilon_q$$
$$E_n = E_{n0} + \varepsilon_n$$

E_{c0}, E_{q0}, E_{n0} are the original values of three E's, E_c, E_q, E_n are the adjusted values of three E's and ε_c, ε_c, ε_c are the amendments caused by unexpected incidents. The values of ε show how an incident affects the city and ε will be positive if there are positive effects. Otherwise, ε will be negative.

3.5.5 Comments on Optimization

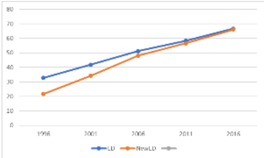

Figure 3.16

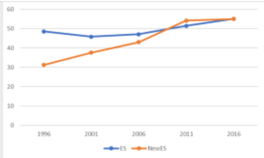

Figure 3.17

Figure 3.18

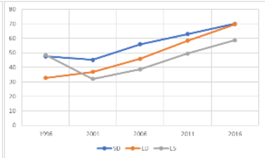

Figure 3.19

After we apply weight calculation optimization to the model, we can see:

- Under new assessment, in Figure 3.16, the starting point of the line is lower than before because the early economic development is not efficient and environmentally friendly, which is not equal to the standards so we increase the weight of it and the score is getting lower. It is the same when it comes to ES.
- Based on the Optimization 2, in Figure 3.17, because nowadays the government and society have been aware of the importance of the green development, so it is reasonable to predict the trend of future development is bright, then we increase its weight and score.
- Based on the Optimization 3, our model can provide you with the suggestion that you should invest on the most promising indicators which can make the score of CSG grow quickly rather than focusing on the indicators that are already excellent.
- In Figure 3.19, considering the enormous impact of emergencies on social development, our model needs to be able to reflect it. In 1998, Zhangjiagang has experienced a flood disaster, which has caused a great harm to ecological construction.

3.6 Strengths and Weaknesses

3.6.1 Strengths

- When we build the model, we don't classify those categories subjectively but use Grey Clustering Evaluation to make the initial data be used in a more suitable way.
- The model is not only based on research but also has the mechanism to evaluate the city dynamically.
- Our model can help the city administrators make better decisions by data processing and can tell the best or fastest way to improve the smart growth of the city. It can also compare the performance between past and now, which is more accurate and convictive.
- The model can divide the complex problem into simple parts and standardize the data of different types by giving grade. It can help us solve the problem which is huge and difficult to solve by single method without using many complex mathematical methods.

3.6.2 Weaknesses

- Our model requires indicators of high quality. The data in 4th layer should be accurate but it's hard to achieve.

- The model needs to be updated frequently because the data it uses should be realtime. Thus, the cost of maintaining the model may be heavy.
- The suggestions the model can give are limited to the categories that we have. The model itself cannot give some creative ways for us to choose from. Instead, it can only help us find the bottleneck and the problem.

4 Case Study: Pittsburgh and Sanya

4.1 Rationale

In this section, we decide to choose city Pittsburgh in US and city Sanya in China to study since these two cities are at different stages of development. The former one is a high developed city which nowadays focuses more on social construction based on Smart Growth Theory and the latter one is a developing city which focuses more on tourism construction and has been experiencing long-time rapid economic growth. Another reason is that both are under different political systems and located in different continents but put Smart Growth on a significant position in government plans.

4.2 Task 1 Define a Metric

We have built the metric before, the indicators we choose are based on statistical data and reasonable experience, which can be seen in appendix. The process of the whole model is shown before. And these are two histograms based on the 2nd level and 3rd level of both cities:

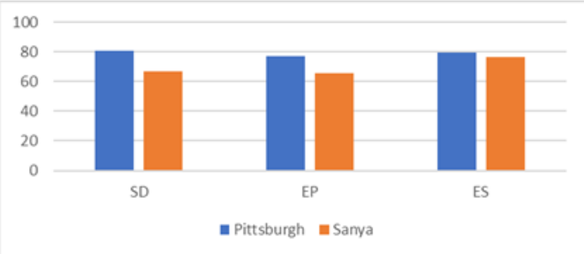

Figure 4.1

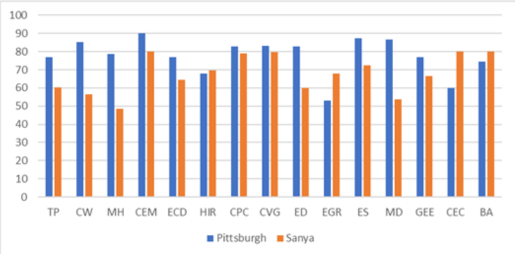

Figure 4.2

4.3 Task 2 Use the Metric to Research the Growth Plan

4.3.1 A Study of Pittsburgh

For Pittsburgh, we select two current policies:

- The city's administrator will optimize the city layout, it will build more communal facilities like libraries and pedestrian streets but keep the tradition of the city. The government also emphasizes the importance of mix land use.
- The city will exploit North Shore, an area from West End Bridge to Fort Wayne Railroad Bridge, they will build some recreational facilities like stadiums to make the place attractive. The city will try to make the development more environmentally friendly, so they will build underground parking lots.

The effect on indicators is clear to identify, the first one will benefit UPD, GP, CUC, GPC, PCS, PDH, PMH, PEB, PRS, NVC. And the bad part is that the improvement is not obvious. The second policy will benefit NVC, GP, GPC, NVC, TI, AEP, EIC. However, it will affect GAC, GGE and UPD negatively. From the data below, we can infer that the smart growth theory is more popular around the US than China and the US government have taken actions to practice the theory.

Table 4: Changes caused by policies for Pittsburgh

Indicator	Change	Indicator	Change
CUC	+1	GP	+2
OS	-5	GGR	+0.5
PMH	+3	GAC	-3
TI	+3	GGE	-2
PRS	+3	PST	+2

After calculation, our metric gives the evaluation of current plan for Pittsburgh:

Table 5: Evaluation of growth plan for Pittsburgh

Pittsburgh			
CW	0.4	ECD	0.93
MH	0.75	BA	-0.83
CPC	-0.75	SD	0.22
ED	1	EP	1.088
EGR	1.75	ES	-0.627
ES	1.46	CSG	0.225
GEE	-0.87		

The result is corresponding to what we expected, the bad effect remains a low level and the whole situation is good because the American policies make the smart growth theory in practice. The pity is that positive improvements are also not significant, possibly because the city is already developed.

4.3.2 A study of Sanya

For Sanya, we pick two policies from the 2016 government work report for analysis:

- The government decides to invest a lot on the project that aims to make Sanya a prosperous city in tourism industry. It will help some companies build resorts and help upgrade existing scenic spots.
- Sanya will accelerate the build of roads around communities, it will also try to make the roads clean and unblocked, hoping the convenience of traffic can promote the local economic growth.

Those places the government chooses to build new resorts are mostly located on suburb which can promote rural economic growth and the mix land use. And through building a more perfect infrastructure system, it can not only make trips faster but also provide more choices of transportation.

By using our metric, the first policy has an influence on GP, CUC, GPC, GGR, TI, GAC, PWR, PRS and NVC. Since the development of tourism will make economy and population density better. So, indicators like GC, GGR, CUC will grow positively. However, it will damage the environment if the constructions don't take care, resulting in decreases of indicators such as GAC and PWR. Similarly, we infer that the second policy will benefit the indicators like RAC, GC, TI, DRP, PRT. Maybe the only negative part is that the construction will affect people's daily life, so the scores of indicators like GGE and HI will be a little lower. Table below shows how indicators may change.

Table 6: Changes caused by policies for Sanya

Indicator	Change	Indicator	Change
CUC	+2	GGR	+2
DRP	+3	GDP	+1
PRT	+2	TI	+5
OS	-8	PST	+2
GAC	-5	GGE	-6
PWR	-3	RS	+2

After calculation, our metric gives the evaluation of current plan for Sanya:

Table 7: The Evaluation of current plan for Sanya

Sanya			
TP	0.3	BA	-2.33
CW	1.8	SD	0.085
CPC	-1.25	EP	1.692
EGR	3.5	ES	-2.18
ES	1.46	CSG	-0.09
GEE	-4.06		

Apparently, the current policies will make the economic better while do harm to the ecological construction and the effect on society is not apparent.

4.4 Task 3 Develop and Evaluate a Growth Plan

4.4.1 Develop a Growth Plan

Figure 4.

Figure 4.6

For **Pittsburgh**, we have:

- **Social Aspect:** After the analysis of the current conditions of Pittsburgh, we find that the city is good in most aspects, but there exists a that the living space of the city center is small. Since the smart growth theory emphasizes that compact buildings are important. So, we advise that Pittsburgh build more different kinds of residence.
- **Economic Aspect:** Pittsburgh used to be a city that produced much steel and now has become a city with advanced technology and science. We think it can invest more in the development of science and technology, with the help of two famous universities, we believe that Pittsburgh can make more achievements and then improve economic growth.
- **Ecological Aspect:** Pittsburgh cares much about ecological protection during its development, so the natural environment there is good. However, the green area inside the communities is not enough, so we think Pittsburgh can design a new structure for each community especially the city center, then it can increase the proportion of green area.

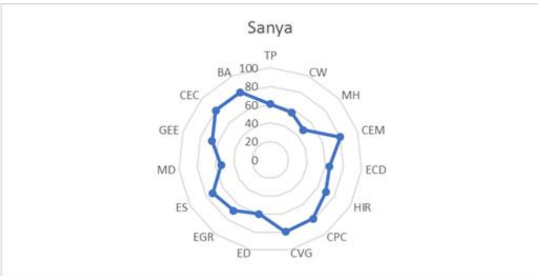

Figure 4.5

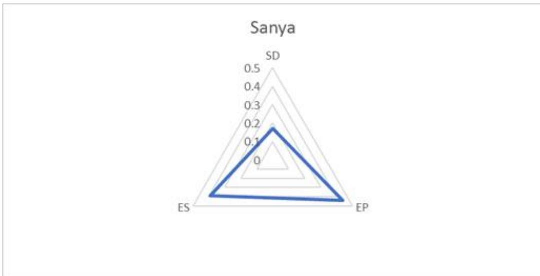

Figure 4.6

For **Sanya** we have:

- **Social Aspect:** Based on the 5th principle of Smart Growth, we know that Sanya is on the progress of building a developed tourism city. We think that Sanya can build some communities around the scenic spots or the holiday resorts. These communities will have their own features, people there will have a strong sense of place.
- **Economic Aspect:** The aim of the city is to put more effort into the construction of tourism, so the tertiary industry should be improved. But Sanya's tertiary industry is not predominate and the ratio of secondary industry in Sanya is still too high. So, we suggest that Sanya upgrade the industrial structure, making full use of its strengths and close outdated production facilities.
- **Ecological Aspect:** Sanya is a coastal city, so the protection of water resource is important. So, we come out with a method which asks the government to build more sewage treatment plants and Sanya should publish a regulation which asks the factories to do sewage treatment.

4.4.2 Evaluate the Growth Plan

We evaluate the development of both cities after few decades based on these policies. We have listed the indicators that might change because of the policy below, the tag **Change** indicates the degree of the indicator which has increased or decreased over the years

Table 8: Changes caused by future plans for Pittsburgh

Social Aspect		Economic Aspect		Ecological Aspect	
Indicator	Change	Indicator	Change	Indicator	Change
CUC	+5	GP	+1	PWR	+2
PDH	+2	GPC	+2	GGE	+1
TI	+3	GGR	+1	RS	+2
OS	-4	TI	+2	PEH	+1
		PST	+1	GGR	-3
		PWR	-1	TI	-2

Table 9: Changes caused by future plans for Sanya

Social Aspect		Economic Aspect		Ecological Aspect	
Indicator	Change	Indicator	Change	Indicator	Change
UPD	+8	GP	+6	PWR	+7
CUC	+14	GPC	+4	GGE	+5
PDH	+6	GGR	+5	HI	+4
TI	+13	TI	+8	RS	+6
PRS	+10	PST	+8	PEH	+2
OS	-15	GGE	+12	OS	+7
GAC	-11	GAC	-13	GGR	-10
HI	-8	PWR	-12	TI	-9

After using our metric, the result is as follows:

Table 10: Evaluation Result for Pittsburgh

Pittsburgh					
Social Aspect		Economic Aspect		Ecological Aspect	
CW	2	ED	0.84	GEE	0.87
MH	1	EGR	1.5	BA	0.51
EGR	1.5	ES	0.73	EGR	-2.5
MD	-1.33	GEE	-0.29	CPC	0.5
				CVG	0.67
SD	0.39	SD	0	SD	0.117
EP	0.096	EP	0.8	EP	-0.625
ES	0	ES	-0.096	ES	0.49
CSG	0.219	CSG	0.224	CSG	0.026

Table 11: Evaluation Result for Sanya

Sanya					
Social Aspect		Economic Aspect		Ecological Aspect	
ED	1.36	ED	3.68	GEE	4.04

CW	5.6	EGR	6.5	BA	1.87
MH	3	ES	5.84	CPC	1
EGR	-5	BA	-2.25	CVG	1.34
BA	-1.93	GEE	-3.77	EGR	-9.5
CPC	-2.75	CPC	-3.25		
GEE	-1.12				
SD	0.885	SD	-0.33	SD	0.23
EP	-1.728	EP	4.5	EP	-3.8
ES	-1.245	ES	-2.07	ES	4.975
CSG	-1.1	CSG	1.12	CSG	0.31

From the evaluation result for city Pittsburgh and Sanya, we can find that

- For city Pittsburgh, the increment of social and economic aspect is similar to each other and higher than that of ecological aspect, which indicates that our growth plan has brought Pittsburgh a balanced development. And we know that Pittsburgh has pleasant environment and because of its mature development model, it will not bring pollution, so our plan didn't affect city's environment much.
- For city Sanya, the increment of CSD on economic and ecological aspect are positive, which indicates that our plan has a positive impact on economic and ecological development. But it has negative effect on social aspect. And we think such result reflects our smart growth plan is successful because though it has bad impact on social aspect, tourism is the pillar industry of Sanya, which means the protection of its environment is of great importance and highly developed tourism brings Sanya huge economic benefits. The reason about negative effects on social aspect is that the population flows in city Sanya is frequent and the nature of the tourism industry decided the small number of resident population. So, though our plan focus much on social aspect, it didn't achieve satisfactory results.

4.5 Task 4 Rank and Compare

We abstract the indicators from the plan and calculate the weights of those indicators to represent the potential of these individual initiatives. A higher weight means a greater potential of the initiative. We can see from the result of calculation that for city Sanya and Pittsburgh, the order of three individual initiatives after ranking is:

Table 12: The result of ranking between two cities

Pittsburgh		Sanya	
Rank	Initiatives	Rank	Initiatives
1	Economic Aspect	1	Economic Aspect
2	Social Aspect	2	Ecological Aspect
3	Ecological Aspect	3	Social Aspect

By comparison, we can see that Pittsburgh is a highly-developed city while Sanya is a emerging city with a high development speed. As we know, economy is always the most important factor when it comes to development, so economic aspect rank first in both cities. Since the former has a mature development model and has already experienced the stage of relying on sacrificing environment to develop economy, so the method of protecting environment almost does not work and the potential of it is the lowest while the latter is just aware of the importance of environmental protection and take actions to improve this work, so the potential of it rank second when considering Sanya. When talking about social aspect, it is acceptable because Pittsburgh has paid more attention to mix land use and compact communities built nowadays, so it ranks second. However, to give priority to the development of their tourism industry, hoping to rapidly improve its economic efficiency, Sanya focus too much on the social construction of tourist resorts and attractions, ignoring the built of ordinary communities, so the potential of it rank last.

4.6 Task 5 Support the Population Growth

- **Pittsburgh:** Compared with Sanya, though Pittsburgh is well developed, it still has some problems. The fast growth of population makes people care more about the economy. But the impetus of economic development of Pittsburgh comes from progress of science and technology and may meet some new problems under the population growth. We have no idea whether the development of science or technology can help fill the gap between population and positions. As we know, the policies of the US will be care about factors like the environment and traditions, so the effect may not be prominent. Because Pittsburgh is already a developed city, there does not exist a lot of space to expand. The main idea of our social plan is to maximize mix land use and try to build compact city. The 50% increase in population will make the green land per person decrease sharply. Thus, our plan has been changed to pay more attention on policies that can renovate the existing infrastructure, which can help provide more positions. During the process of the plan, Pittsburgh can make a better society structure.

- **Sanya:** If the population of Sanya increases by additional 50%, the total population of Sanya will be large since the population base of Sanya is already high. The situation of city at that time will be: the number of communities is large and these communities are scattered throughout the city. Then we can see that our social development plan will do a good job. Because these scattered communities will gradually make each of themselves a small center of its surroundings, which is a kind of smart growth. And each community will become a new special city and the compactness of these ‘cities’ also meet the requirements of smart growth. Based on the economic and environment plans and the update of industrial structure, the people in Sanya will prefer to choose tertiary industry rather than secondary industry. After that, the industry can be more advanced and the environment will be better than before. So, the three initiatives of Sanya can support the new situation.

5 Future Work of Our Model

- The data in 4^{th} layer need to be designed according to the development of society, adding more indicators will help. And we will make the standard for evaluation depend less on subjective judgment.

- The research method should be made standard, the judgment matrix can be convictive.
- We can build a database for all the cities that use this evaluation model, then the process of data analysis can be more accurate, also the report provided by the model will be more abundant since the current data has more reference.
- We can make the weight calculation part better, the smart growth theory can provide more principles about economy and environment to let the weight count more rational.

6 Conclusion

This paper mainly talks about a metric that measures the success of applying smart growth policy of a city. First, indicators that can reflect the degree of a city's development is basically needed. We can get the relationship among these indicators and make categories for them by applying Grey Clustering Evaluation to the original data. We use Analytic Hierarchy Process to build our model which includes data processing, constructing judgment matrices, weights calculation, consistency check and the final answer. Then comes the correctness analysis and sensitivity analysis which can describes the strengths and weaknesses of the model. Also, four different optimizations have been made to mitigate problems in our metric. The evaluation of the optimized model shows that it can generate more accurate answers. In case study, we choose two typical cities in different continents to test our model. We pick some policies of the cities and do some analysis to judge the success of smart growth. Next, the redesigned plan for two cities can be given according to smart growth theory and our metric can be used to analyze and rank the individual initiatives and their potentials. Then we compare the initiatives and their ranking between the two cities. Finally, we discuss the situation when the population grows by 50% and if our plan can support it.

7 References

[1] "This is Smart Growth." International City/County Management Association and U.S. Environmental Protection Agency, 2006.

[2] Smart Growth: A Sustainable Approach, 2016.
http://www.smartgrowthuk.org/

[3] Duany, Andres, Jeff Speck and Mike Lydon. The Smart Growth Manual. McGraw-Hill. 2010.

[4] Li Ming, "Based on the principle of SmartGrowth evaluation index system of harmonious community construction and research". 2007

[5] Xiang-jun Pu, "Environmental capacity of urban sustainable development index and model research". Engineering Journal of Wuhan University. 2001

[6] Edward K Mul1er. Downtown Pittsburgh :Renaissance and Renewal[M], Kevin J. Patrick, Joseph L. Scarpaci, Jr., A Geographic Perspective of Pittsburgh and the Alleghenies: From Precambrian to PostIndustrial, 1727; revised and pub1ished in A Geographic/ Perspective of Pittsburgh and the A11eghenies, same editors, (Pittsburgh: University of Pittsburgh Press, 2006.

[7] Alberts Robert C. The Shaping of the Point: Pittsburgh's Renaissance Park[M]. Pittsburgh: University of Pittsburgh Press, 1980.

[8] Stewman Shelby, Joel A Tarr. Four Decades of Pub1ic − Private Partnerships in Pittsburgh[M], Pub1ic − Private Partnerships in American Cities, ed. R. Scott Fos1er and Renee A. Berger. Lexington, MA: D. C. Heath and Company, 1982.
[9] Muller Edward K, Morton Co1eman, David Houston. Skybus: Pittsburgh's Failed Industry Targeting Strategy of the 1960s. Center for Industry Studies, University of Pittsburgh, 2002.
[10] Jing Li, "Resource-exhausted cities sustainable development evaluation index system model". 2005.
[11] North Shore Master P1an, Revised Apri1 2009.
[12] Lan Wang and Hao Gu, "Process and planning in the transformation of central city of Pittsburgh" from http://www.govinfo.so/news_info.php?id=26525
[13] "The theory of smart growth" from http://wenku.baidu.com/link
[14] "Gray absolute correlation degree and its calculation method" from http://wenku.baidu.com/link
[15] "The advantages and disadvantages of analytic hierarchy process (ahp)" from http://www.doc88.com/p-23345272676.html
[16] Data of Pittsburgh from https://datausa.io/profile/geo/pittsburgh-pa/#intro and http://www.census.gov/quickfacts/table/PST045215/4261000
[17] Data of Sanya from https://www.bls.gov/regions/mid-atlantic/data/xg-tables/ro3fx9529.htm
[18] "The report of government work of Sanya" from http://www.systats.gov.cn/
[19] Guizhi Huang, "The mathematical model and index system, industrial and mining city sustainable development"-1004- 4051(2004) 02- 0075- 04
[20] EPA, "Smart Growth: A Guide to Developing and Implementing Greenhouse Gas Reductions Programs." 2011. http://www.sustainablecitiesinstitute.org/Documents/SCI/Report_Guide/Guide_E PA_SmartGrowthGHGReduction_2011.pdf

8 Appendix

Statement: most of the data are retrieved from: the government official websites and the Bureau of Statistics websites of Pittsburgh, Sanya and Zhangjiagang. Some are from National Bureau of Statistics. The rest that we cannot find are created based on experience and official report.

Table1: Evaluation Form For Zhangjiagang

4^{th} indicator items	Scores after standardization				
	1996	**2001**	**2006**	**2011**	**2016**
UPD	32	47	68	82	71
RAC	46	54	51	77	60
CUC	50	58	57	68	75
MIR	32	47	62	87	95
PRT	29	41	71	89	90
EIC	25	56	77	74	77
AEP	45	47	52	54	62
PCS	17	18	29	31	38
PDH	30	37	52	57	60
GC	56	52	49	50	47
CR	74	78	69	81	80
PMH	26	37	64	71	83
PDI	67	52	48	41	46
PEB	18	24	37	52	54
PRS	45	53	59	62	68
NF	84	80	76	71	62
GL	76	74	78	75	73
CPS	25	38	49	56	68
NVC	21	34	40	43	52
GP	35	46	52	50	57
OS	58	60	47	42	46
GPC	26	38	52	68	77
GGR	17	26	40	52	67
PST	26	40	51	62	70
TI	30	42	57	62	75
EC	29	35	48	60	72
SLP	31	40	56	64	71
TRS	21	36	54	61	66
GAC	74	59	42	40	48
PWR	24	36	50	54	52
GGE	65	50	47	42	45
HI	72	71	64	68	70
RS	78	74	76	75	77

RMM	41	36	47	58	53
NRP	47	42	53	60	62
DRP	29	34	48	67	70
PEH	56	52	60	61	60

According to the Statistical Yearbook published by the government of Zhangjiagang, a score is given for each indicator and it is used to check the correctness of our model. The data comes from:
http://www.zjg.gov.cn/Home/wsbgs/057027/057027001/057027001011/

Table2: Judgement Matrices For Zhangjiagang:

TP	**RAC**	**PRT**	**PDI**	**GL**
RAC	1	1	1/5	1/3
PRT	1	1	1/5	1
PDI	5	5	1	2
GL	3	1	1/2	1

CW	**RAC**	**CUC**	**DRP**	**PRT**
RAC	1	1/2	1	1
CUC	2	1	2	2
DRP	1	1/2	1	1
PRT	1	1/2	1	1

MH	**PMH**	**PDH**	**PDI**
PMH	1	1/2	1
PDH	2	1	2
PCS	1	1/2	1

CEM	**RMM**
RMM	1

HIR	**NF**	**NVC**
NF	1	2
NVC	1/2	1

CPC	**PEH**	**CPS**	**GAC**
PEH	1	2	2
CPS	1/2	1	1
GAC	1/2	1	1

CVG	**PEH**	**MIR**
PEH	1	2
MIR	1/2	1

ED	GP	GC	GGR	TI
GP	1	3	3	3
GPC	1/3	1	1	1
TRS	1/3	1	1	1
UPD	1/3	1	1	1

EGR	GGR	TI
GGR	1	1
TI	1	1

ES	PST	SLP	EC
PST	1	8	4
SLP	1/8	1	4
EC	1/4	1/4	1

MD	GP	CR	GC
EIC	1	1	1
CR	1	1	1
GC	1	1	1

GEE	HI	PWR	GGE	GAC
HI	1	1/2	1/2	1/2
PWR	2	1	1	1
GGE	2	1	1	1
GAC	2	1	1	1

ECD	NF	PRS	NRP
NF	1	1/4	1/8
PRS	4	1	1/2
AEP	8	2	1

CEC	PEB
PEB	1

BA	PEB	GGE	GAC	RS	PRS
PEB	1	1	1/2	1	1
GGE	1	1	1/2	1	1
GAC	2	2	1	2	2
RS	1	1	1/2	1	1
PRS	1	1	1/2	1	1

SD	TP	CW	MH	CEM	ECD	HIR	CPC	CVG

TP	1	1	1/2	1/2	1	1	1	1
CW	1	1	1/2	1/2	1	1	1	1
MH	2	2	1	1	2	2	2	2
CEM	2	2	1	1	2	2	2	2
ECD	1	1	1/2	1/2	1	1	1	1
HIR	1	1	1/2	1/2	1	1	1	1
CPC	1	1	1/2	1/2	1	1	1	1
CVG	1	1	1/2	1/2	1	1	1	1

EP	**ED**	**EGR**	**ES**	**MD**
ED	1	1/2	1	1
EGR	2	1	2	2
ES	1	1/2	1	1
MD	1	1/2	1	1

ES	**GEE**	**CEC**	**BA**
GEE	1	1	1/2
CEC	1	1	1/2
BA	2	2	1

CSG	**SD**	**EP**	**ES**
SD	1	1	1
EP	1	1	1
ES	1	1	1

Table 3: Weight Calculation For Zhangjiagang:

TP	**Weight**	**CW**	**Weight**	**MH**	**Weight**	**CEM**	**Weight**
RAC	0.11	**RAC**	0.20	**PMH**	0.25	**RMM**	1.00
PRT	0.15	**CUC**	0.40	**PDH**	0.50		
PDI	0.50	**DRP**	0.20	**PCS**	0.25		
GL	0.24	**PRT**	0.20				
HIR	**Weight**	**CPC**	**Weight**	**CVG**	**Weight**	**ED**	**Weight**
NF	0.67	**PEH**	0.50	**PEH**	0.67	**GP**	0.5
NVC	0.33	**CPS**	0.25	**MIR**	0.33	**GPC**	0.17
		GAC	0.25			**TRS**	0.17
						UPD	0.17
EGR	**Weight**	**ES**	**Weight**	**MD**	**Weight**	**GEE**	**Weight**
GGR	0.50	**PST**	0.73	**GP**	0.33	**HI**	0.14
TI	0.50	**SLP**	0.18	**CR**	0.33	**PWR**	0.29
		EC	0.09	**GC**	0.33	**GGE**	0.29
						GAC	0.29

ECD	Weight	**CEC**	**Weight**	**BA**	**Weight**		
NF	0.08	**PEB**	1.00	**PEB**	0.17		
PRS	0.31			**GGE**	0.17		
AEP	0.62			**GAC**	0.33		
				RS	0.17		
				PRS	0.17		
SD	**Weight**	**EP**	**Weight**	**ES**	**Weight**	**CSG**	**Weight**
TP	0.10	**ED**	0.20	**GEE**	0.25	**SD**	0.33
CW	0.10	**EGR**	0.40	**CEC**	0.25	**EP**	0.33
MH	0.20	**ES**	0.20	**BA**	0.50	**ES**	0.33
CEM	0.20	**MD**	0.20				
ECD	0.10						
HIR	0.10						
CPC	0.10						
CVG	0.10						

Table 4: Scores for Zhangjiagang

3rd Indicator Class Name	**Score**					**Standardization**				
	1996	**2001**	**2006**	**2011**	**2016**	**1996**	**2001**	**2006**	**2011**	**2016**
3rd Level Indicator Classes										
TP	62.28	62.27	66.25	71.92	67.70	9.28%	8.81%	8.24%	8.02%	7.23%
CW	40.80	49.00	56.80	73.80	74.00	6.08%	6.93%	7.07%	8.23%	7.90%
MH	38.25	40.75	54.00	56.50	62.25	5.70%	5.76%	6.72%	6.30%	6.65%
CEM	41.00	36.00	47.00	58.00	53.00	6.11%	5.09%	5.85%	6.47%	5.66%
ECD	49.81	48.87	57.23	62.1	64.48	7.42%	6.91%	7.12%	6.93%	6.88%
HIR	63.21	64.82	64.12	61.76	58.70	9.42%	9.17%	7.98%	6.89%	6.27%
CPC	52.75	50.25	52.75	54.50	59.00	7.86%	7.11%	6.56%	6.08%	6.30%
CVG	48.08	50.35	60.66	69.58	71.55	7.16%	7.12%	7.55%	7.76%	7.64%
ED	35.01	43.40	51.33	55.94	60.63	5.22%	6.14%	6.39%	6.24%	6.47%
EGR	23.50	34.00	48.50	57.00	71.00	3.50%	4.81%	6.03%	6.36%	7.58%
ES	27.17	39.55	51.63	62.18	70.36	4.05%	5.59%	6.42%	6.94%	7.51%
MD	54.45	58.08	56.10	59.73	60.72	8.11%	8.22%	6.98%	6.66%	6.48%
GEE	57.35	51.99	49.27	48.96	51.85	8.55%	7.35%	6.13%	5.46%	5.54%
CEC	18.00	24.00	37.00	52.00	54.00	2.68%	3.39%	4.60%	5.80%	5.77%
BA	59.44	53.64	51.09	52.47	57.32	8.86%	7.59%	6.36%	5.85%	6.12%
2nd Level Indicator Categories										
SD	47.54	47.91	55.98	62.91	62.59	36.90%	35.35%	36.27%	36.41%	33.93%
ED	32.73	41.81	51.25	58.37	66.74	25.41%	30.85%	33.21%	33.79%	36.18%
ES	48.56	45.82	47.11	51.48	55.12	37.69%	33.81%	30.52%	29.80%	29.88%
1st Level Final Point										
CSG	42.51	44.73	50.93	57.01	60.87					

Table 5: Data of two cities and data sources

	Pittsburgh, Pennsylvania, USA (2015)		Sanya, Hainan, China (2015)	
	Data	**Sources**	**Data**	**Sources**
Urban population density	**2,140 /km^2**	https://datausa.io/profile/geo/pittsburgh-pa/#intro	**360 /km^2**	http://www.systats.gov.cn/
Road Area per Capita	/	/	**9m^2**	http://www.systats.gov.cn/
Medical Insurance Rate	**90%**	https://datausa.io/profile/geo/pittsburgh-pa/#intro	**99%**	http://www.systats.gov.cn/
Education Investment per Capita	**$2,684**	http://learning.sohu.com/20130306/n367913844.shtml	**$103.5**	http://www.stats.hainan.gov.cn/
Average Education Period	**13.4 years**	https://zhidao.baidu.com/question/937761993987100492.html	**10.7 years**	http://www.stats.hainan.gov.cn/
Proportion of College Students	**38.30%**	http://www.census.gov/quickfacts/table/PST045215/4261000	**7.80%**	http://www.systats.gov.cn/
Gini Coefficient	**0.472**	https://datausa.io/profile/geo/pittsburgh-pa/#intro	**0.381**	http://www.systats.gov.cn/
Crime Rate	**0.42%**	https://datausa.io/profile/geo/pittsburgh-pa/#crime	**4.10%**	http://www.systats.gov.cn/
GDP per Capita	**$430,037**	https://datausa.io/profile/geo/pittsburgh-pa/#intro	**$8,502**	http://www.systats.gov.cn/
GDP Growth Rate	**3.10%**	https://datausa.io/profile/geo/pittsburgh-pa/#intro	**8.10%**	http://www.systats.gov.cn/
Proportion of the Second and Tertiary industry	**96.56%**	https://www.bls.gov/regions/mid-atlantic/data/xg-tables/ro3fx9529.htm	**86.30%**	http://www.systats.gov.cn/

Table6: Evaluation Form

4^{th} level indicators	Scores after standardization

	Pittsburgh, Pennsylvania, USA (2015)	Sanya, Hainan, China (2015)
UPD	77	59
RAC	41	86
CUC	90	40
MIR	90	99
PRT	80	80
EIC	78	30
AEP	67	53
PCS	98	42
PDH	70	50
GC	94	76
CR	44	83
PMH	50	50
PDI	80	20
PEB	60	50
PRS	70	90
NF	70	70
GL	60	80
CPS	90	80
NVC	60	80
GP	80	70
OS	80	90
GC	86	37
GGR	31	81
PST	97	86
TI	70	80
EC	35	97
SLP	74	10
TRS	90	50
GAC	82	96
PWR	80	50
GGE	50	70
HI	70	80
RS	80	70
RMM	90	80
NRP	80	50
DRP	80	60
PEH	80	70

Judgement matrices (Pittsburgh):

Matrices of the 3rd level indicators of Pittsburgh are the same as that of previous cities we observed since all the 4th level indicators must follow a global standard. Matrices of other indicators are as follows:

Table7: Judgement Matrices For Pittsburgh

SD	TP	CW	MH	CEM	ECD	HIR	CPC	CVG
TP	1	1	1/2	1/2	1	1	1	1
CW	1	1	1/2	1/2	1	1	1	1
MH	2	2	1	1	1	2	2	2
CEM	2	2	1	1	1	2	2	2
ECD	1	1	1	1	1	1	1	1
HIR	1	1	1/2	1/2	1	1	1	1
CPC	1	1	1/2	1/2	1	1	1	1
CVG	1	1	1/2	1/2	1	1	1	1

EP	ED	EGR	ES	MD
ED	1	2	1	1
EGR	1/2	1	1	2
ES	1	1	1	1
MD	1	1/2	1	1

ES	GEE	CEC	BA
GEE	1	1	1
CEC	1	1	1/2
BA	1	2	1

CSG	SD	EP	ES
SD	1	1	1
EP	1	1	1
ES	1	1	1

Table8: Weight Calculation For Pittsburgh

TP	Weight	CW	Weight	MH	Weight	CEM	Weight
RAC	0.11	RAC	0.20	PMH	0.25	RMM	1.00
PRT	0.15	CUC	0.40	PDH	0.50		
PDI	0.50	DRP	0.20	PCS	0.25		
GL	0.24	PRT	0.20				
HIR	**Weight**	**CPC**	**Weight**	**CVG**	**Weight**	**ED**	**Weight**
NF	0.67	PEH	0.50	PEH	0.67	GP	0.5
NVC	0.33	CPS	0.25	MIR	0.33	GPC	0.17
		GAC	0.25			TRS	0.17
						UPD	0.17

EGR	Weight	ES	Weight	MD	Weight	GEE	Weight
GGR	0.50	PST	0.73	EIC	0.33	HI	0.14
TI	0.50	SLP	0.18	CR	0.33	PWR	0.29
		EC	0.09	GC	0.33	GGE	0.29
						GAC	0.29
ECD	Weight	**CEC**	**Weight**	**BA**	**Weight**		
NF	0.08	**PEB**	1.00	**PEB**	0.17		
PRS	0.31			**GGE**	0.17		
NRP	0.62			**GAC**	0.33		
				RS	0.17		
				PRS	0.17		
SD	**Weight**	**EP**	**Weight**	**ES**	**Weight**	**CSG**	**Weight**
TP	0.10	**ED**	0.30	**GEE**	0.33	**SD**	0.33
CW	0.10	**EGR**	0.25	**CEC**	0.26	**EP**	0.33
MH	0.19	**ES**	0.24	**BA**	0.41	**ES**	0.33
CEM	0.19	**MD**	0.21				
ECD	0.12						
HIR	0.10						
CPC	0.10						
CVG	0.10						

Judgement matrices (Sanya):

Matrices of the 3rd level indicators of Pittsburgh are the same as that of previous cities we observed since all the 4th level indicators must follow a global standard. Matrices of other indicators are as follows:

Table9: Judgement Matrices For Sanya

SD	TP	CW	MH	CEM	ECD	HIR	CPC	CVG
TP	1	1	1/2	1/2	1	1	1	1
CW	1	1	1/2	1/2	1	1	1	1
MH	2	2	1	1	2	2	2	2
CEM	2	2	1	1	2	2	2	2
ECD	1	1	1/2	1/2	1	1	1	1
HIR	1	1	1/2	1/2	1	1	1	1
CPC	1	1	1/2	1/2	1	1	1	1
CVG	1	1	1/2	1/2	1	1	1	1

EP	ED	EGR	ES	MD

ED	1	1/2	1	1
EGR	2	1	2	2
ES	1	1/2	1	1
MD	1	1/2	1	1

ES	**GEE**	**CEC**	**BA**
GEE	1	1	1/2
CEC	1	1	1/2
BA	2	2	1

CSG	**SD**	**EP**	**ES**
SD	1	1	1
EP	1	1	1
ES	1	1	1

Table10: Judgement Matrices For Sanya

TP	**Weight**	**CW**	**Weight**	**MH**	**Weight**	**CEM**	**Weight**
RAC	0.11	**RAC**	0.20	**PMH**	0.25	**RMM**	1.00
PRT	0.15	**CUC**	0.40	**PDH**	0.50		
PDI	0.50	**DRP**	0.20	**PCS**	0.25		
GL	0.24	**PRT**	0.20				
HIR	**Weight**	**CPC**	**Weight**	**CVG**	**Weight**	**ED**	**Weight**
NF	0.67	**PEH**	0.50	**PEH**	0.67	**GP**	0.5
NVC	0.33	**CPS**	0.25	**MIR**	0.33	**GPC**	0.17
		GAC	0.25			**TRS**	0.17
						UPD	0.17
EGR	**Weight**	**ES**	**Weight**	**MD**	**Weight**	**GEE**	**Weight**
GGR	0.50	**PST**	0.73	**EIC**	0.33	**HI**	0.14
TI	0.50	**SLP**	0.18	**CR**	0.33	**PWR**	0.29
		EC	0.09	**GC**	0.33	**GGE**	0.29
						GAC	0.29
ECD	Weight	**CEC**	**Weight**	**BA**	**Weight**		
NF	0.08	**PEB**	1.00	**PEB**	0.17		
PRS	0.31			**GGE**	0.17		
NRP	0.62			**GAC**	0.33		
				RS	0.17		
				PRS	0.17		
SD	**Weight**	**EP**	**Weight**	**ES**	**Weight**	**CSG**	**Weight**
TP	0.10	**ED**	0.20	**GEE**	0.25	**SD**	0.33

CW	0.10	**EGR**	0.40	**CEC**	0.25	**EP**	0.33
MH	0.20	**ES**	0.20	**BA**	0.50	**ES**	0.33
CEM	0.20	**MD**	0.20				
ECD	0.10						
HIR	0.10						
CPC	0.10						
CVG	0.10						