Analysis of the Suitable and Low-Cost Sites for Industrial Land Using Multi Criteria Evaluation: A Case of Panzhihua, China

Jing Jiang

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School of Architecture and the Built Environment
Royal Institute of Technology (KTH)
100 44 Stockholm, Sweden

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Abstract

With the rapid industrial development, the Geographic Information System (GIS) and Multi Criteria Evaluation (MCE) have been widely used to analysis the land utilization. In this project, the area of Panzhihua was chosen to conduct the industrial suitability and economic land analysis. GIS analysis was performed to investigate the suitability and cost of land using various data such as DEM and various landuse information. The most important spatial analysis techniques used in this project are Multi Criteria Evaluation and a dual equation. Costs associated with terrain conditions (slope), green land, build up area, factories, streets, country road, highway, railway and water body were derived from virtual costs that are used to identify the relative costs of all criteria. The suitability- cost ratio was performed incorporating with the land suitability map and land cost map to identify the suitable-low cost industrial siting.

Key Words: MCE, GIS, land suitability, industry , suitability- cost ratio
Acknowledgement

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Thanks for my mother, father and boyfriend. They encouraged me when I met difficulties in my work.

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<td>------------------------------------</td>
<td></td>
</tr>
<tr>
<td>AHP</td>
<td>Analytical Hierarchy Process</td>
<td></td>
</tr>
<tr>
<td>CGIS</td>
<td>Canadian Geographic Information Systems</td>
<td></td>
</tr>
<tr>
<td>DEM</td>
<td>Digital Elevation Model</td>
<td></td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
<td></td>
</tr>
<tr>
<td>MCE</td>
<td>Multi Criteria Evaluation</td>
<td></td>
</tr>
<tr>
<td>NBSC</td>
<td>National Bureau of Statistics of China</td>
<td></td>
</tr>
<tr>
<td>TIN</td>
<td>Triangulated Irregular Network</td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 1 INTRODUCTION

1.1 History of industrial land development in China and project

In the past decades, the development of industry has been very rapid in China. The gross output value of the industry is just 9189.4 billion in the year of 1995, and has grown to 22231.593 billion in the year of 2004 (NBSC, 2005). A rapid growing industry posts many problems, like land resources and energy waste, ecology and environment pollution. In the year 2004, the ratio of the area of industrial land use in the cities of China is more than twenty percent; meanwhile, the world average level is less than ten percent. The main restriction to the development of industry nowadays is the shortage of energy and nature resources. In the recent time, the rapid industrial development typically depends on the low density of land use, high consumption of energy and natural resources. These increased industries make a large amount of waste and reduces resources. To make a suitable and efficient land utilization and continuable development of industry is a major problem in China.

In order to fully understand the problem, we have to review the industrial land policy changes in the last sixty years. In this period, the development of industrial land policy can be divided into two parts.

The first period is from 1950s to 1990s, when the lands for the industry were provided by government for free. This is known as “Allocation”. The allocation industrial land has many restrictions, for example, the term, purpose and location of land use are all limited. Government did not pay sufficient attention to the industrial land use planning. Many constructions depended on the decisions of government officer or in the place which had sufficient natural resources. This practice of factory site selection has caused many problems.

First problem is the water pollution and waste of energy. Many sites were in the upstream of rivers. The sewage was usually discharged into the rivers directly. It led to the pollution of water. Another problem was wastage of resources. Some sites did not have enough infrastructures to supply the resources required. So the factories had to build up water supply, drainage, power supply, heating or other energy supplies to meet the production needs.

Another problem is the waste of land. As the allocated land was free to use and government usually encouraged the industry development. The investors usually applied for large lands to build up plants. The government usually did not restrict the size of factories. As a result, large areas of lands including farmlands, woodlands and other kinds of lands had been expropriated and transferred to industrial land.

The second period is from 1990s till now. In the end of the 1990s, the government promulgated a new policy of land use, which stipulates that the industrial lands are provided for a cost. The government states a price for the land with different utilizations, including business, residential and industrial land use. The government charges the owner for different utilities. So the owners or directors have to consider the cost of
land. They no longer build up large plant as before. Meanwhile, the government began to pay more attention to the environment impact of the industrial production. The plant constructions should be based on approved plan. On the other hand, if the industrial production caused the environment pollution, it would be published.

With the consideration above, the government and factory owners began to pay more attention to the position of factories. How to find the suitable and low cost land became a practical and important problem. This thesis will discuss the issue and try to give a solution based on GIS (geographic information system) and MCE (Multi criteria evaluation).

1.2 Background of GIS and MCE development

1.2.1 Definition and development of GIS

GIS (Paul Longley, 2005) is defined as a system for creating, handling, storing, analyzing and managing data and associated attributes which are spatially referenced to the earth. GIS is a computer system which combines the spatial and attributes data of earth and which allow people to create, edit, analysis, store, display and print the geographic information. GIS was evolved based on the computer system and spatial analysis needs. In the 1960s, the U.S. Census Bureau adopted the large-scale of digital mapping. In 1964, the CGIS (Canadian Geographic Information Systems) was developed by Roger Tomlinson in Ottawa, Ontario, which was used to store, analyze, and manipulate data collection for the Canada Land Inventory. CGIS has the basis functions of the GIS, like supporting the coordinate system, overlying, measuring and digitizing the geodata. It stored the attribute and spatial information in separate files. All these functions are necessary in subsequent GIS softwares. In 1966, the SYMAP and GRID definition was proposed in the Laboratory of Computer Graphics and Spatial Analysis in the Harvard Graduate School of Design. After 1970s, various GIS softwares appeared, like AutoCAD, ARCINFO, MapInfo, etc.

1.2.2 Definition and development of MCE

In the recent years, the spatial analysis of GIS has had a significant development. The spatial analysis includes the geovisualization, geographic knowledge discovery and spatial decision support systems. MCE is a method for decision support. It is defined (Malcewski 1999) as the evaluation of a set of alternatives based on multiple criteria where the criteria are quantifiable indicators of the extent to which decision objectives are realized. In real life (Mohamed Rami, 2000), due to the complex situations and tasks increase, people always can not select the “best” alternative. So the MCE can be used to help people to make the proper decisions. In the beginning, the MCE is concerned with how to evaluate a result from several criteria. To the Boolean criteria, the union and intersection of conditions were used. On the other hand, the linear combination was used to the continuous factors. In the linear combination (Shirley Ballaney, 2003), factors are sined weights advanced and summated to yield a suitability map.

MCE is widely used as a spatial analysis tool in energy evaluation and environmental fields. It integrated the social, political, environmental and economic factories with the decision makers’ preferences. Naim H. Afgan (2006) used the MCE to present an evaluation of the potential natural gas utilization in energy sector. Dimitrina Boteva (2004) uses MCE to determine the conservation significance of vegetation communities and habitats for a case study of a proposed NATURA 2000 site on the northwest coast of Crete, Greece.
MCE was attached importance as a tool for the land use and planning. Alejandro Ceballos-Silva (2002) used MCE and land use mapping to delineate the suitable area for crops in central Mexico. Ron Store (2001) integrated MCE and expert knowledge in a GIS based habitat suitability modeling. Laura Schneider (2001) modeled land-use change in the Ipswich watershed. Hemayet Hossain combined MCE and empirical data with experts’ judgments to the strategic regional planning of South Gippsland Shire in Victoria. Tal Svoray (2005) incorporated habitat heterogeneity model with MCE for the urban land-use allocation in a Mediterranean ecotone.

Meanwhile, some experts did not only concern about the environmental effect on the results, but also took account of the economic factor in MCE analysis. R.KerryTurner, Jeroen C.J.M. van den Bergh, et.al. (2000) combined economic valuation, integrated modeling, stakeholder analysis in MCE to provide a sustainable wetland management and policy.

In this thesis, the MCE and GIS will be used to build a model to discuss and try to solve the problem of how to find a suitable and low cost industrial site.

1.3 Research Objective

The aim of the thesis is to combine MCE and different GIS tools to analysis and solve the problem of finding the most suitable and low cost industrial site. The result will be shown and discussed in the result section.

The main objectives are:
♦ Using the coordinate transfer and multi-original data standardization to build up the geo-database of Pan Zhihua for MCE analysis.
♦ Establishing decision rules, selecting criteria and creating criteria maps.
♦ Gain the most suitable and low cost map using MCE and ARCMAP spatial analysis tools

1.4 The organization of the thesis

♦ Chapter 1 gives the background of the study.
♦ Chapter 2 introduced the study area.
♦ Chapter 3 is the methodology of the project. It contains the MCE structure, GIS model. The theories and experiment operations are presented in this part.
♦ Chapter 4 shows the result and gives the discussion of the result.
♦ Chapter 5 shows the conclusion of the project.
CHAPTER 2 STUDY AREA

2.1 study area --- Panzhihua

The study area of this thesis is the Panzhihua municipality (Public information net of Panzhihua, 2007). It consists of three districts- the East district, the West district and the Rehen district and two towns- the Miyi town and the Yanbian town. The geographic extent is specified as 26°5′6″N to 27°20′46″N, 101°8′9″E to 102°14′46″E (Figure 2-1).

![Figure 2-1 the study area](image)

Land siting is strictly associated with the natural resource, population and economic factors of the place.

2.2 Geographic Location of Panzhihua

Panzhihua City is a municipality of Sichuan Province of China. It has good conditions of both shipping and road transport condition. Panzhihua is at the junction of Sichuan and Yunnan in southwest of China (Figure 2-2). It is on the confluence of Jinsha River and Yalong River. The northeast is adjacent to the Huili, Dechang and Yanyuan towns of Liangshan Yi Autonomous Prefecture in Sichuan Province. The southwest is adjacent to the Ninglang, Huaping, Yongren towns of Yunnan Province. The Cheng-Kun Railway and the number 108 National Highway cross the Panzhihua area. It is 749 kilometers south of Chengdu, 351 kilometers north of Kunming. It is an important port on the way from Sichuan to the south of China and the Southeast Asia. It is an important traffic hub and trade goods distribution on the "Southern Silk Road".
2.3 Nature resources

The terrain of Panzhihua inclines from the northwest to the southeast. The highest site is at Chuandongzi, and the lowest point is Shizhuang. The gap of between the highest and lowest elevation is huge and it is more than 3000 meters. The terrain is very sharp. This is a weak condition for industrial siting.

Panzhihua has sufficient water resource. There are ninety-five rivers flowing through Panzhihua. The main two rivers are Jinsha River and Yalong River; both of them belonging to Changjiang River.

Panzhihua has very rich mineral resources. Till now, there are 76 discovered minerals, of which 39 are proven, and 45 are exploited. Because of the extremely rich mineral resource, the Panzhihua Iron and Steel (Group) Co, the largest steel-making centre of the southwest in China and the largest titanium and vanadium-producing centre of China was established in 1965. In the database, there is a data layer named factories. It has a number of mineral resources processing plants.
CHAPTER 3 METHODOLOGY

In order to find out the suitable and low-cost industrial sites, we should consider some questions: What factors should be considered? How would the criteria be evaluated? Which factors should be more important than others? How could we be able to determine the most preferred suitable and low-cost sites considering the complex spatial interactions? The MCE and GIS-based model will be used to answer the questions above.

3.1 MCE procedure

There are three general hierarchies in MCE approach: decision, objectives and criterion. The decision is a choice between objectives. An objective (J.Ronald Eastman, 1995) is a perspective that serves to guide the structuring of decision rules. A criterion (J.Ronald Eastman, 1995) is the basis that can be measured and evaluated. Criteria can be of two kinds: factors and constrains. The figure 3-1 shows the MCE structure that will be used to identify the suitable and low-cost industrial sites.

![MCE Structure Diagram](image)

From the figure 3-1, we can see the MCE model of the project. The MCE procedure will be described as below:

1. **Defining the decision/overall objective desired.** The decision/overall objective of the project is to identify the suitable and low-cost industrial sites.
2. **Defining the sub-objectives.** There are two objectives under decision-identifying suitable industrial sites and identifying land cost.
3. **Identifying the criteria.** In order to approach the objectives, the criterias have to be made.
Normally, the criteria of industrial construction are defined by the land planning officers and engineering experts and the land costs are regulated by the land management governments in China. Referring to the opinions of experts and government officers, the criteria are considered as below.

- **Slope**
The slope degree should not be more than 70 degrees. It is better to build the factories on the flat places.

- **Land use**
  i. It is not allowed to build up factories on water body. But the areas around the rivers and lakes have high suitability.
  ii. The places near the factories are more suitable than build up areas.

- **Traffic condition**
The places near the streets, country roads, high ways and railways have high suitability.

- **Nature**
  Avoid to building up factories on nature reservation areas, for example, the Green land.

- **Land cost**
  Land costs are regulated by the land management governments.

4. **Classifying the criteria to constraints and factors.**
According to the criteria, the dataset are divided into constrains and factors.

<table>
<thead>
<tr>
<th>Type</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constrains</td>
<td>Green land</td>
</tr>
<tr>
<td></td>
<td>Water body</td>
</tr>
<tr>
<td></td>
<td>Slope equal or more than 70 degrees</td>
</tr>
<tr>
<td>Factors</td>
<td>Factories</td>
</tr>
<tr>
<td></td>
<td>Build up areas</td>
</tr>
<tr>
<td></td>
<td>Streets</td>
</tr>
<tr>
<td></td>
<td>Country roads</td>
</tr>
<tr>
<td></td>
<td>High ways</td>
</tr>
<tr>
<td></td>
<td>Rail ways</td>
</tr>
<tr>
<td></td>
<td>Slope less than 70 degrees</td>
</tr>
<tr>
<td></td>
<td>Land cost</td>
</tr>
</tbody>
</table>

5. **The continuing procedure for objective of identifying the suitable industrial sites**

- **Creating factor maps and standardization**
The factors are buffered with multi-distance, and then the buffer areas are reclassified to standard the factor maps based on the multi-distance.

- **Sign weight to the factors**
The weights of the factors show the suitability of factors to meet the objective. The expert decisions and AHP (Analytical Hierarchy Process) are used to weight the factors.

- **Combine the factors using the weight linear combination**
The simple additive weight method, known as the weighted linear combination, was used in to combine the criterias (Malczewski, 1999). With a weight linear combination, factors are combined by applying a weight.
to each followed by a summation of results to yield a factor map: \( S = \sum w_i x_i \). \( \sum w_i = 1 \) Where S is suitability, \( w_i \) is the weight of factor and \( x_i \) is the criterion score of factor i (J.Ronald Eastman, 1995).

- **Combine the suitability map**
The Boolean constrains was applied with the simple additive weight method to yield the suitability map: \( S = \sum (w_i x_i) H_{cj} \), where \( c_j \) is the criterion score of constraint j, \( H \) is the product (J.Ronald Eastman, 1995).

6. **Standardize the land cost map for objective of identifying the land cost**
The paper map was digitized to gain the land cost vector map. The vector map was changed to raster, and then reclassified to get the standardized land cost map.

7. **Combine the two objectives to yield the decision/overall objective of the project**
The suitability- cost ratio of land utilization was used to analysis the relationship between land suitability and land cost (Liu Guili, 2000). Suitability- cost ratio = \( E / C \), where E is land suitability, C is land cost.

3.2 Dataset

The original types of dataset are raster and vector. The spatial format of vector data can be divided in three kinds: Polyline, Polygon and Point. The working resolution 90 m\(^2\) was chosen based on the spatial resolution of DEM.

The dataset attributes used in this project are shown in the table 3-2:

<table>
<thead>
<tr>
<th>Data layer</th>
<th>Description</th>
<th>Type</th>
<th>Vector Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEM</td>
<td>The scale of DEM is 1:250000. DEM represents the elevation at a 3 arc-second resolution (around 90 meters). The DEM was generated from a TIN model.</td>
<td>raster</td>
<td>---</td>
</tr>
<tr>
<td>Region</td>
<td>The region area of Panzhihua.</td>
<td>vector</td>
<td>polygon</td>
</tr>
<tr>
<td>Street</td>
<td>The roads go through the urban area of Panzhihua.</td>
<td>vector</td>
<td>polyline</td>
</tr>
<tr>
<td>Country road</td>
<td>The roads connect the entire region of Panzhihua.</td>
<td>vector</td>
<td>polyline</td>
</tr>
<tr>
<td>High way</td>
<td>The high ways go through Panzhihua.</td>
<td>vector</td>
<td>polyline</td>
</tr>
<tr>
<td>Rail way</td>
<td>The rail ways go through Panzhihua.</td>
<td>vector</td>
<td>polyline</td>
</tr>
<tr>
<td>Factories</td>
<td>Major factories in Panzhihua, including manufactories, energy supply industries, etc.</td>
<td>vector</td>
<td>point</td>
</tr>
<tr>
<td>Build up area</td>
<td>The build up areas and associated infrastructure in study area.</td>
<td>vector</td>
<td>polygon</td>
</tr>
<tr>
<td>Water</td>
<td>The rivers and lakes found in the study area.</td>
<td>vector</td>
<td>polygon</td>
</tr>
<tr>
<td>Green land</td>
<td>The public green land in the urban area.</td>
<td>vector</td>
<td>polygon</td>
</tr>
</tbody>
</table>
3.3 GIS Model

A GIS-based model was developed with the MCE structure. The GIS Model utilizes various spatial data layers and uses GIS processes such as reclassification, buffering, raster calculation and 3D analysis tools to create data layers that represent the impacts on each criterion. The simple additive weight method will be used to combine land suitability factors. The classification will be used to the land cost map. Then, a Boolean constrains equation will be used to both land suitability and land cost map to get the result map. The results of the MCE are used to determine the suitable-cost areas. The work flow of the GIS model is showed in the Figure 3-2.

3.4 Coordinate system transfer

The original data were produced by the software of MapInfo. MapInfo has three hundred self-defined coordinate systems. Because the data will be analyzed by the ArcGIS spatial analysis tools, the coordinate
systems of data should be translated to the ones which can be conducted in ArcGIS. The ARCMAP *feature project* tool was used to transfer the coordinate system. All the original data were transferred (Figure 3-3). The unit is meter. The project coordinate system is World-Cube. The geographic coordinate system is GCS_WGS_1984 (Figure 3-4).

![Figure 3-3 Original data, data are in the coordinate systems in MapInfo.](image1)

![Figure 3-4 Data with the coordinate systems in ARCGIS](image2)

### 3.5 Mask of the study area

When we do the spatial analysis in ARCGIS, usually the extent will be expanded to the full area of the four directions, top, bottom, left and right of the extent. But in the project, I just need the data which belong to the area of Panzhihua. So, a mask was made to reduce the analysis to the study area (Figure 3-5).
3.6 Identify Constrains and Factors

3.6.1 Identifying Constrains and Standardization of Constrains

3.6.1.1 Identifying Constrains

In order to identify the constraints for the analysis, we had to determine which variables are identified as constraints when selecting the suitable and low-cost land area. The areas of constrains were combined in order to restrict the analysis only to areas of interest. The constraint map was associated with the factors for analysis in order to utilize only that data which was found in the available study area. We decided that the following variables would be considered as constrains: water, green land and slope more than 70 degrees. The reasons are as specified below:

Water: Factories can not be built on rivers or lakes.

Green land: Factories are forbidden to be built on the public green land in the urban areas.

Slope more than 70 degrees: When the slope of land is more than 70 degrees, it is not suitable to construct plants.

3.6.1.2 Standardization of Constrains

First, the data of constrains were transferred from vector data to raster data with the resolution of 90 meters by using the vector to raster transfer tool of ArcGIS. Then the areas of constrains were reclassified into Boolean map. One stands as available areas and zero stands for forbidden areas.
3.6.1.2.1 Water

The process of water criteria standardization is: water vector (Figure 3-6) --- water raster --- reclassification (Figure 3-7) --- extraction the reclassified layer by mask (Figure 3-8).

Figure 3-6 transfer the vector to raster

Figure 3-7 reclassification of the water layer

Figure 3-8 extraction of the reclassified layer by mask
From the figure 3-9 we see that all the water bodies are included as constraints. The rest of the area is available for future analysis.

### 3.6.1.2.2 Green land

The process of green land criteria standardization is the same as water. So it will not be described in details. The result map is shown in the below picture.

From the figure 3-10 we can see that the area of green land is not big nor distributes widely. It is mainly distributed in the middle part of study area.
3.6.1.2.3 Slope more than 70 degrees

When the slope of land is more than 70 degrees, it is assumed as not suitable for construction. So, the areas where the slope is more than 70 degrees are defined as constrains. The spatial analysis of the slope constrains is: combination of DEM data, extraction of DEM by mask, transfer DEM to TIN and transfer TIN to slope, reclassify the slope.

3.6.1.2.3.1 Combination of DEM data

The area of Panzhihua is covered by four mosaics of original DEM data. The four raster data was combined with the raster data manage tool of Mosaic to New Raster (Figure 3-11).

![Figure 3-11 the combined dataset of DEM](image)

3.6.1.2.3.1.2 Extraction of DEM by mask

The extraction of DEM defines the study area of DEM for further analysis (Figure 3-12).

![Figure 3-12 the extraction of DEM by mask](image)
3.6.1.2.3.3 DEM to TIN

The extraction of DEM dataset was put into the tool of *raster to TIN* in 3D analysis tools of ARCGIS to generate TIN. It is shown in the (Figure 3-13).

From the figure 3-13 we can find out that the elevation of the North-west part of study area is high and the South-east part of study area is low. The lowest elevation is in the water and valley areas.

3.6.1.2.3.1.5 TIN to slope

The TIN was put into the tool of *TIN slope* in 3D analysis tools of ARCGIS to get the slope layers. It is shown (Figure 3-14).
From the Figure 3-14 we can find out that in the north part of the study area the terrain is sharp and the south part of study area the slope is small. The South-east part of edge also has a sharp slope.

3.6.1.2.3.1.6 Reclassification of slope

The slope data was reclassified to the value one and zero. One stands of the areas where the slope is less than 70 degrees and zero stand for the areas where the slope is equal and more than 70 degrees.

![Reclassification of slope](image)

Figure 3-15 Reclassification of slope

From the figure3-15, we can not see the areas whose slope is equal and more than 70 degrees clearly; this is because that there are just five pixels.

3.6.2 Identifying Variables of Factors and Standardize the Factor maps

3.6.2.1 Identifying the variables of factors

The buffer areas of factors are defined as the variables of factors. These variables show the impact changes of factors to the adjacent places. The score of variables described the suitable degree of the variables. The scores are one, three, five, seven, and nine. One means less suitable, three means little suitable, five means middle suitable, seven means much suitable, and nine means most suitable. Meanwhile, the score of zero does not stand for the suitability of variables. It just means that the area is no data.

The process of GIS model on factors is that: every factor deals with the multiple ring buffer tool to get the variables. Then the variable maps were changed to raster format and the raster factor maps were reclassified to be standardized. The flow chart of GIS model is shown in the Figure 3-16.
3.6.2.1.1 Factories

The factor of factories including major factories in Panzhihua, for example the manufactories, energy supply industries, etc (Figure 3-17).
The centralization effect is an important factor to the construction of plants. The close and centralized factories have more effect on each other than the distant and dispersed ones. So if the new sites of plants are adjacent to the old factories, they have more suitability. I have identified five major variables under the factory factor to describe the suitability changes of the new sites. The tool of multiple ring buffer is used to produce the variables. There are five circles/variables and their scores are shown in the Table 3-3:

<table>
<thead>
<tr>
<th>Buffer Distance (Unit: meters)</th>
<th>Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 200</td>
<td>9</td>
</tr>
<tr>
<td>200 - 400</td>
<td>7</td>
</tr>
<tr>
<td>400 - 600</td>
<td>5</td>
</tr>
<tr>
<td>600 - 800</td>
<td>3</td>
</tr>
<tr>
<td>800 - 1000</td>
<td>1</td>
</tr>
<tr>
<td>Nodata area</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 3-18 Part of standardization map for Factories

3.6.2.1.2 Build up area

The factor of the build up areas is the city center of Panzhihua. It includes residential areas, governments, schools, museum, hospitals and other types of build up areas and associated infrastructure in study area (Figure 3-19).

Figure 3-19 Build up area
The areas adjacent the build up areas have good conditions of labor resources and trade. So, the areas close to the build up areas have high suitability. Five variables have been identified to show the suitability changes by using the tool of *multiple ring buffer*. The scores of five variables are shown in the Table 3-4:

<table>
<thead>
<tr>
<th>Buffer Area (Unit: meters)</th>
<th>Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-200</td>
<td>9</td>
</tr>
<tr>
<td>200-400</td>
<td>7</td>
</tr>
<tr>
<td>400-600</td>
<td>5</td>
</tr>
<tr>
<td>600-800</td>
<td>3</td>
</tr>
<tr>
<td>800-1000</td>
<td>1</td>
</tr>
<tr>
<td>Nodata</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 3-4: Build up area scores**

![Figure 3-20 Standardization map for Build up area](image)

**3.6.2.1.3 Streets**

The factor of the streets includes the roads go through the urban area of Panzhihua (Figure 3-21).

![Figure 3-21 streets](image)

The areas close to the street have good traffic condition. The products can be delivered to any places of the urban area by the streets. So areas close to the street have higher suitability than other places. Because the width of the street is about 35 meters to 50 meters, I defined the width of effect areas being 50 meters. There
are five variables have been identified to show the suitability changes by using the tool of multiple ring buffer. The scores of five variables are shown in the below Table 3-5:

<table>
<thead>
<tr>
<th>Buffer Area (Unit: meters)</th>
<th>Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>0- 50</td>
<td>9</td>
</tr>
<tr>
<td>50-100</td>
<td>7</td>
</tr>
<tr>
<td>100-150</td>
<td>5</td>
</tr>
<tr>
<td>150-200</td>
<td>3</td>
</tr>
<tr>
<td>200-250</td>
<td>1</td>
</tr>
<tr>
<td>Nodata</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 3-22 Standardization map for streets

3.6.2.1.4 Country Road

The factor of the country road includes the roads connect the whole region of Panzhihua (Figure 3-23).

The areas close to the country roads also have good traffic condition. The products can be easily and cheaply delivered to any places in the region of Panzhihua by the country road. So the areas close to the country road
roads could have higher suitability than other places. So I have defined the width of the effect areas being one hundred meters. There are five variables that have been identified to show the suitability changes by using the tool of multiple ring buffer. The scores of five variables are shown in the Table 3-6:

Table 3-6: Country Road scores

<table>
<thead>
<tr>
<th>Buffer Area (Unit: meters)</th>
<th>Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>9</td>
</tr>
<tr>
<td>100-200</td>
<td>7</td>
</tr>
<tr>
<td>200-300</td>
<td>5</td>
</tr>
<tr>
<td>300-400</td>
<td>3</td>
</tr>
<tr>
<td>400-500</td>
<td>1</td>
</tr>
<tr>
<td>Nodata</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 3-24 Standardization map for country roads

3.6.2.1.5 High way

The factor of the high way includes the high ways go through Panzhihua (Figure 3-25).

The areas close to the high way also have very good traffic condition. The products can be delivered to other places out of Panzhihua by the high way. So the areas close to the high way could have higher suitability than other places. Because the high way is also a higher level road than street, its effect to the adjacent area
can be wider than streets. So I defined the width of the effect areas being one hundred meters. There are five variables have been identified to show the suitability changes by using the tool of *multiple ring buffer*. The scores of five variables are shown in the Table 3-7:

<table>
<thead>
<tr>
<th>Buffer Area (Unit: meters)</th>
<th>Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>9</td>
</tr>
<tr>
<td>100-200</td>
<td>7</td>
</tr>
<tr>
<td>200-300</td>
<td>5</td>
</tr>
<tr>
<td>300-400</td>
<td>3</td>
</tr>
<tr>
<td>400-500</td>
<td>1</td>
</tr>
<tr>
<td>Nodata</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 3-26 Standardization map for High way

### 3.6.2.1.6 Rail way

The factor of the rail way includes the rail ways go through Panzhihua (Figure 3-27).

Figure 3-27 Rail way

Rail way is an important and economical way of delivering industrial products. The products can be delivered to other places in and out of Panzhihua by the rail way. So the areas close to the rail way could have higher suitability than other places. I have defined the width of the effect areas being one hundred
meters. There are five variables have been identified to show the suitability changes by using the tool of *multiple ring buffer*. The scores of five variables are shown in the Table 3-8:

Table 3-8: Rail way scores

<table>
<thead>
<tr>
<th>Buffer Area (Unit: meters)</th>
<th>Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>9</td>
</tr>
<tr>
<td>100-200</td>
<td>7</td>
</tr>
<tr>
<td>200-300</td>
<td>5</td>
</tr>
<tr>
<td>300-400</td>
<td>3</td>
</tr>
<tr>
<td>400-500</td>
<td>1</td>
</tr>
<tr>
<td>Nodata</td>
<td>0</td>
</tr>
</tbody>
</table>

3.6.2.1.7 Slope

Slope describes the terrain changes (Figure 3-29).

Always, the flat terrain is better to build up plant than sharp terrain. There are five variables are specified for slope factor in the scales of 0 to 15 degree, 15 to 30 degree, 30 to 45 degree, 45 to 60 degree and 60 to 69 degree. When the degree is above 70 degree, it is considered as constrains (Table 3-9).

Table 3-9: Slope scores

Figure 3-28 Standardization map for High way

Figure 3-29 Slope
### Slope Degree (%) Scores

<table>
<thead>
<tr>
<th>Slope Degree (%)</th>
<th>Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 15</td>
<td>9</td>
</tr>
<tr>
<td>15 - 30</td>
<td>7</td>
</tr>
<tr>
<td>30 - 45</td>
<td>5</td>
</tr>
<tr>
<td>45 - 60</td>
<td>3</td>
</tr>
<tr>
<td>60 - 69</td>
<td>1</td>
</tr>
<tr>
<td>&gt;= 70</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 3-30 Standardization map for Slope

The area with slope degree from zero to fifteen is rather flat and is assumed to be easy for construction, so a value of nine was assigned to this range. The area with slope degree from fifteen to thirty is almost flat and is also easy for plant construction, so a value of seven was assigned to this range. The area with slope degree from thirty to forty-five is not flat and is a little difficult for plant construction, so a value of five was assigned to this range. The area with slope degree from forty-five to sixty is a little precipitous and is difficult for plant construction, so a value of three was assigned to this range. The area with slope degree from sixty to sixty-nine is more precipitous and is difficult for plant construction, so a value of one was assigned to this range. The area with slope degree above seventy is the most precipitous area and this area is not suitable for plant construction. So it was signed as constrains and the value of zero was given to it.

### 3.7 Analytical Hierarchy Process and Factor map

In MCE analysis, the simple additive weight method and the Boolean constrains were used to combine to suitability map. In the simple additive weight method, the sum of weight should be one. In Saaty’s technique (1997; quoted in J. Ronald Eastman, 1995), weights can be derived by taking the principal eigenvector of a square reciprocal matrix of pairwise comparisons between the criterias. So, in the project, a pairwise comparison in AHP analysis was used to define the weights of factors.

#### 3.7.1 Analytical Hierarchy Process of the suitability map

The AHP hierarchy of a decision problem is the objective of the decision at the top level and then descends towards lower level of decision factors. Each level is linked to the next higher level (Malczewski, 1999).
The AHP hierarchy for suitability map is in the Figure 3-31:

![AHP hierarchy for suitability map](image)

From the AHP hierarchy for suitability map, we can design a pairwise comparison matrix. The comparisons ratings are provided on a nine-point continuous scale, which was proposed by J. Ronald Eastman, 1995(Figure 3-34). The comparisons ratings and factors were shown to experts and made the pairwise comparison matrix (Table 3-10).

Saaty (1980) proposed the averaging over normalized columns method for calculate the weights from the pairwise comparison matrix, that involves the following steps: 1) calculate the sum of the values in each column; 2) divide each element in the matrix by its column sum; 3) compute the average of the elements in each row of the normalized matrix, divide the sum by the number of factors. These averages provide an estimate of the relative weights of the factors (Table 3-11). The consistency ratio was also estimated and it was 0.051. The defined value of CR<0.10 (Malczewski, 1999), the consistency ratio was smaller than the defined value and it indicated a reasonable level of consistency in the pairwise comparisons.

![Continuous rating scale](image)

<table>
<thead>
<tr>
<th></th>
<th>1/9</th>
<th>1/7</th>
<th>1/5</th>
<th>1/3</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>extremely</td>
<td>very</td>
<td>strongly</td>
<td>moderately</td>
<td>equally</td>
<td>moderately</td>
<td>strongly</td>
<td>very</td>
<td>extremely</td>
<td>more important</td>
</tr>
</tbody>
</table>

Table 3-10: pairwise comparison matrix

<table>
<thead>
<tr>
<th></th>
<th>Build up areas</th>
<th>street</th>
<th>country road</th>
<th>high way</th>
<th>rail way</th>
<th>factories</th>
<th>slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build up areas</td>
<td>1</td>
<td>1/3</td>
<td>1/5</td>
<td>1/7</td>
<td>1/7</td>
<td>1/9</td>
<td>1/9</td>
</tr>
<tr>
<td>street</td>
<td>3</td>
<td>1</td>
<td>1/3</td>
<td>1/5</td>
<td>1/5</td>
<td>1/7</td>
<td>1/7</td>
</tr>
<tr>
<td>country road</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>1/2</td>
<td>1/5</td>
<td>1/3</td>
<td>1/5</td>
</tr>
<tr>
<td>high way</td>
<td>7</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1/3</td>
<td>1/3</td>
</tr>
</tbody>
</table>
### Table 3-11 Weights of Factors

<table>
<thead>
<tr>
<th>Factors</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build up areas</td>
<td>0.021</td>
</tr>
<tr>
<td>street</td>
<td>0.038</td>
</tr>
<tr>
<td>country road</td>
<td>0.076</td>
</tr>
<tr>
<td>high way</td>
<td>0.137</td>
</tr>
<tr>
<td>rail way</td>
<td>0.137</td>
</tr>
<tr>
<td>factories</td>
<td>0.296</td>
</tr>
<tr>
<td>slope</td>
<td>0.296</td>
</tr>
</tbody>
</table>

#### 3.7.2 Factor map

The simple additive weight method was used to combine the criterias to yield the factor map.

The *Raster calculation of Factor map* is:

\[
\text{Raster calculation of Factor map} = \text{[Street]} \times 0.038 + \text{[Country road]} \times 0.076 + \text{[High way]} \times 0.137 + \text{[Railway]} \times 0.137 + \text{[Factories]} \times 0.296 + \text{[Buildup areas]} \times 0.021 + \text{[Slope]} \times 0.296
\]

The *Factor map* is in the Figure 3-33:

![Figure 3-33 Final factor map](image)

In the figure 3-33, we can find out that with the color from black to white, the weight of factors are from low to high.

#### 3.8 Suitability map of industrial land use

The Boolean constrains was applied with the simple additive weight method to yield the suitability map. The raster calculation was:

\[
\text{Suitability map} = \text{[Water]} \times \text{[Green land]} \times \text{[Slope]} \times \text{[Factor map]}
\]
Water, Green_land and Slope are constrains.

The suitability map is shown in the Figure 3-34:

![Suitability map](image)

From the Figure 3-34, we can see that with the color from green to yellow and red, the suitability of land use for industry is from high to low, and the dark red areas are not suitable areas.

### 3.9 Land cost map

The land cost in this project is defined as the land occupancy fee for the construction of factories. It is paid by the investors (can be both local and international) of factories to the government.

The land cost map/data is used to be divided by the suitability map to get the suitable-cost ratio/map, which shows the ratio between land suitability and cost. The high ratio area means that the area has both high suitability and low cost and it is the best choice place to build up a factory.

The land cost paper map, land cost documents and other data layers were used to make a digital map. Then the vector map was changed to raster and reclassified to get the result map. The workflow chart is in the Figure 3-35.
3.9.1 The land cost map

The land cost data used in this project is original from the reference land cost map and documents of Panzhihua and land occupancy cost data.

3.9.1.1 Vector map

The government land cost map of Panzhihua is a paper map. And the map just has the value of land plots, but it does not include the value of streets, country roads, high way, rail ways and water body. So, I referred to the land occupancy cost data from land management documents to calculate the cost of streets, country roads, high way, rail ways and water body.

The steps of cost calculation involves: 1) collecting the land occupying cost and the occupying areas; 2) Classifying the land occupying cost and areas by different land uses, for example, the street, the rail way and etc.; 3) Sum the land occupying cost and areas for each kind of land use; 4) Calculating the average cost of each kind of land occupying cost in the unit of ten thousand yuan per square kilometer. 5) Converting the unit to yuan per square meter. Because the land occupancy cost data are the statistical data, so the calculated land cost are just the reference cost used to do the analysis of the project. The real land cost should be the dealing price in real time.

The land costs are shown in the Table 3-12.

Table 3-12: The land costs
<table>
<thead>
<tr>
<th>Layers</th>
<th>Land cost (yuan/ m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other land</td>
<td>80</td>
</tr>
<tr>
<td>Fifth class industrial land</td>
<td>170</td>
</tr>
<tr>
<td>Fourth class industrial land</td>
<td>280</td>
</tr>
<tr>
<td>Third class industrial land</td>
<td>400</td>
</tr>
<tr>
<td>Second class industrial land</td>
<td>450</td>
</tr>
<tr>
<td>First class industrial land</td>
<td>510</td>
</tr>
<tr>
<td>Street</td>
<td>800</td>
</tr>
<tr>
<td>Country road</td>
<td>850</td>
</tr>
<tr>
<td>Rail way</td>
<td>900</td>
</tr>
<tr>
<td>High way</td>
<td>950</td>
</tr>
<tr>
<td>Water</td>
<td>1000</td>
</tr>
</tbody>
</table>

Figure 3-36 Land costs map

3.9.1.2 Vector to raster
The vector map of land cost has been transferred to raster, with the resolution of 90 meters.

![Figure 3-37 Raster map of land costs](image)

From the Figure 3-37 we can see that the large areas are in the cost of 80. The water area is in highest cost.

The costs changes are mainly in the middle part of study area and they are also the urban area of Panzhihua.

**CHAPTER 4 RESULT AND DISCUSSION**

### 4.1 Standardization of suitability map and cost map

Because the weights of suitability map and cost map are in different scales. In order to compare them, the weight scales of the two maps should be standardized to the same scale.
4.1.1 Standardization of suitability map

The original value of land suitability map is from 0 to 8.325. I used the raster calculation tool to change the values of raster in the range from zero to one hundred. The equation is:

\[ \text{Land suitability standardization map} = \frac{\text{land suitability raster map} \times 100}{m}, \text{where } m \text{ is the largest value of land suitability map} \] (Figure 4-1).

![Figure 4-1 Standardization of land suitability map](image)

4.1.2 Standardization of cost map

The original value of the land cost raster map is from 80 to 1000. I changed the values of raster in the range between zero to one hundred. The equation is:

\[ \text{Land suitability standardization map} = \frac{\text{land cost raster map} \times 100}{m}, \text{where } m \text{ is the largest value of cost map} \] (Figure 4-2).
4.2 Result—Land Suitability-Cost Map

The equation of the land suitability-cost ratio is \( \text{land suitability-cost ratio} = \frac{\text{land suitability standardization map}}{\text{land cost standardization map}} \times 100 \% \). The scale of the ratio is from 0 to 100 %. The high ratio shows the both high suitability and low cost land. It is the best choice of industry factory build up place. The details of relationship between land suitability-cost ratio, land suitability weight and land cost standardization weight are in the Table 4-1.

Table 4-1 Relationship between land suitability-cost ratio, land suitability weight and land cost standardization weight

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Suitability weight</th>
<th>Cost weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>high</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>middle</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>low</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td></td>
<td>high</td>
<td>high</td>
</tr>
</tbody>
</table>
In the Figure 4-3, we can see that with the color from black to white, the ratio is from low to high. The high ratio areas are buffer areas of factories, streets, country roads, highways and railways. The low ratio areas are the dark areas, distributing on the middle part of study areas and rivers.

4.3 Reclassification of the ratio

The ratio of the suitability-cost map is from 0 to 1158.63%. We can reclassify the ratio into three parts to define the preference degree of plant siting choice. The detail is in the Table 4-2:

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Preference Degree</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 — 60%</td>
<td>Low</td>
<td>1</td>
</tr>
<tr>
<td>60% — 100%</td>
<td>Acceptable</td>
<td>2</td>
</tr>
<tr>
<td>100% — 500%</td>
<td>Moderate</td>
<td>3</td>
</tr>
<tr>
<td>500% — 1000%</td>
<td>Good</td>
<td>4</td>
</tr>
<tr>
<td>&gt;=1000%</td>
<td>Excellent</td>
<td>5</td>
</tr>
</tbody>
</table>

From the Figure 4-4, we can see that the large areas are in moderate degree, small areas are in low, acceptable and good degrees. Very few areas are in excellent degree.
CHAPTER 5 CONCLUSION

![Comparison of land suitability map, land cost map and land suitability-cost map](image)

Figure 5-1 comparison of land suitability map, land cost map and land suitability-cost map

From the Figure 5-1 we can see that:

- The suitable areas are not the suitable-low cost areas. Land cost places an important effect on the choice of plant siting. The land costs have an important influence to the plant siting. Comparing the picture a) and c), we can find out that the high suitability areas in picture a) are distributed more widely than picture c). Some places have very high value in picture a), but they are in very low value in Figure picture c). This is because that the land plots, water body, streets, country roads, highways and railways have high cost. When the suitability values of these areas were divided by the cost values in picture b), the result ratio would be low. So they are not the good choice for plant siting. Just the high value/ ratio areas in picture c) are the both suitable and low cost areas. This is answer we try to find out in this project.

- The most suitable- low cost areas mainly contain the buffer areas of factories and railways.

- The second best class mainly contains the buffer areas of factories, streets, country roads, high ways, railways and water body.

- The moderate class mainly contains the build up areas with low cost and the areas where the slope is less than 30 degrees.

- The acceptable class mainly contains the build up areas with high cost.

- The unsuitable class mainly contains the areas of green land, water body, street, country road, highway and railway.
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