Surface modelling of human population distribution in China

Tian Xiang Yue a,∗, Ying An Wang a, Ji Yuan Liu a, Shu Peng Qiu a, Xiang Zheng Deng a, Ming Liang Liu a, Yong Zhong Tian a, Bian Ping Su a

a Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, 917 Building, Datun, Anwai, Beijing 100101, China
b College of Science, Xi'an University of Architecture and Technology, Xi'an 710055, China

Received 24 March 2003; received in revised form 23 April 2004; accepted 4 June 2004

Abstract

On the basis of introducing major data layers corresponding to net primary productivity (NPP), elevation, city distribution and transport infrastructure distribution of China, surface modelling of population distribution (SMPD) is conducted by means of grid generation method. A search radius of 200 km is defined in the process of generating each grid cell. SMPD not only pays attention to the situation of relative elements at the site of generating grid cell itself but also calculates contributions of other grid cells by searching the surrounding environment of the generating grid cell. Human population distribution trend since 1930 in China is analysed. The results show that human population distribution in China has a slanting trend from the eastern region to the western and middle regions of China during the period from 1930 to 2000. Two scenarios in 2015 are developed under two kinds of assumptions. Both scenarios show that the trends of population floating from the western and middle regions to the eastern region of China are very outstanding with urbanization and transport development.

© 2004 Elsevier B.V. All rights reserved.

Keywords: Surface modelling; Population distribution; Grid generation; Geographical information system

1. Introduction

A surface model is the mathematical representation of a surface in such a form that it can be used in design calculations. Since the first digital terrain model for road design was produced by the Massachusetts Institute of Technology in 1957, surface modelling has begun to be developed (Scott, 1977; Yue et al., 2004). Surface modelling includes development of digital terrain models, spatial interpolation models, area-based matching models and a multi-resolution approach. Three widely used principal ways of structuring a digital terrain model are triangulated irregular networks, regular grid networks and contour-based networks (Moore et al., 1992). Spatial interpolation models include interpolation by drawing boundaries, trend surface analysis, moving averages, Kriging interpolation, spline curves and finite element method (Stein, 1999; Sabin, 1990; Shipley, 1990). Area-based matching models include radiometric model and least
squares correlation (Mustaffar and Mitchell, 2001; Heipke, 1997; Gruen, 1985; Foestner, 1982). The multi-resolution approach is an image-driven surface estimation, which is characterized by three phases that are shape modelling, multi-resolution model construction and variable resolution representations (Sarti and Tubaro, 2002; Cignoni et al., 1998).

Surface modelling of population distribution (SMPD) that was developed on the basis of grid generation method (Yue et al., 2003) is aimed at formulating population in a regular grid system, in which each grid cell contains an estimate of total population that is representative for that particular location. Compiling population data in grid form is by no means a new approach. For instance, Adams (1968) presented a computer generated grid map of population density in west Africa; Population Atlas of China presented grid population data for several regions in China (Institute of Geography of Chinese Academy of Sciences, 1987); transforming population data from census to grid (Tobler et al., 1997), apportioning census counts to each grid cell based on probability coefficients (Dobson et al., 2000), and estimating population using nighttime light data (Sutton, 1997; Sutton et al., 1997, 2001; Lo, 2001; Sutton et al., 2003).

2. Background of major data layers

In addition to total population in every province, the major data layers that are matched with their corresponding SMPD variables include net primary productivity (NPP), elevation, city distribution and transport infrastructure distribution. The elevation is a natural factor and has a slow change with time so that it is spatial variable and could be regarded as a temporal
constant within 100 years. Although NPP is based on climate and soil, it could be modified by human activities so that it is a spatial and temporal variable. City distribution and transport infrastructure distribution are spatial and temporal variables, which are determined by both natural factors and human activities, have a rapid change with time in China during recent 100 years.

2.1. Spatial distribution of cities in China

Urbanization is a process of the concentration of population in cities. Spatial distribution of cities and proximity to cities are essential factors for human population distribution of China. The spatial distribution of cities in China has had the feature that city density is much higher in eastern China than in western China in modern history. During the period from 1843 to 1893, urban population proportion had slow growth, which was increased from 5.1% to 6.0% averagely in China; in the area of lower reaches of Yangtze River the urban population proportion was increased from 7.4% to 10.6%, in the coastal area of south China from 7.0% to 8.7%; in inland area the proportion paced up and down between 4.0% and 5.0%. From 1895 to 1931, in areas along coast and Yangtze River, northeast China and north China cities were developed rapidly, while in inland area cities were developed very slowly, even at a standstill. In the early 1930s, urban population proportion was about 9.2% in China. From 1931 to 1949, the turbulent and unstable situation led to slow population growth in China and the urban population proportion increased to 10.6% (Zhang, 1997). Cities in China spatially concentrates...
in coastal area, especially Yangtze River Delta, Pearl River Delta and Beijing–Tianjin–Tangshan area. In 2000, 42.1% of the 667 major cities of China distributed in eastern China where area accounts for 9.5% of the whole area of China; 34% distributed in middle China where area accounts for 17.4%; 23.8% distributed in western China where area accounts for 70.4% (Urban Society and Economy Survey Team of National Bureau of Statistics of People’s Republic of China, 2001). The distribution densities of cities in eastern China and in middle China were respectively 13.1 times and 5.8 times the one in western China (as seen in Fig. 1). The urban population proportion was 36.22% in 2000 (National Bureau of Statistics of People’s Republic of China, 2001). According to National Report of China Urban Development (China Mayor Association, 2002), the urban population proportion would be 46.9% in 2015. If the urban population proportion would increase at the average rate in recent 5 years, annually 1.44%, it would be 57.82% in 2015.

2.2 Spatial distribution of transport infrastructure in China

Transport infrastructure is a primary indicator of human population distribution (Dobson et al., 2000). Roads and railways are especially indicative because of their vital role in human well being. Construction of a piece of railroad in 1881, which was from Tangshan city to Feng-Nan county about 9.7 km, initiated railroad development in China. There was 14,411 km of railroad in China in 1930 (Fig. 2) and 21,800 km in 1949 (Fig. 3). Length of railway in operation was 68,700 km in 2000 (Fig. 4) (Year Book House of China Transportation and Communications, 2001). However,
relative research results showed that the appropriate length of railroad should be 100,000 km in China, from which current railroad length has a great gap (Chen and Zhang, 2000). To implement the western development strategy, railroad building in China is paying attention to strengthening the linkage between eastern region and western region of China, speeding up construction of accesses to central Asia and southeast Asia and improving connection within the western region of China. Total length of railroad in China would reach 81,653 km in 2015 (Fig. 5).

In 1902, the first automobile was imported in China and in 1906 the first piece of road was constructed. In 1949, length of highways that automobiles could go through was 80,700 km (Fig. 6). After construction for 50 years, total length of highways was about 1.4 million km in 2000 (Fig. 7) (Year Book House of China Transportation and Communications, 2001). In recent 10 years, major projects of highway construction include seven east–west main trunk roads and five south–north main trunk roads as well as three important sections, of which total length is about 35,000 km (Fig. 8). The seven east–west main trunk roads include highways from Suifenhe to Manzhouli, from Dandong to Lasa, from Qingdao to Yinchuan, from Lianyungang to Huerguosi, from Shanghai to Chengdu, from Shanghai to Ruili and from Hengyang to Kunming. The 5 south–north main trunk roads include highways from Tongjiang of Heilongjiang province to Sanya of Hainan province, from Beijing to Fuzhou, from Beijing to Zhuhai, from Erlianhaote to Hekou and from Chongqing to Zhanjiang. The 3 important sections include highways from Beijing to Shenyang, from Beijing to Shanghai and passageway going abroad from southwestern China.
2.3. Land use and spatial distribution of NPP in China

Land use is a good indicator of spatial human population distribution. In most regions, population would range from extremely low density in desert, water, wetlands, ice or tundra land cover to high density in developed land cover associated urban land cover, between which arid grasslands, forests and cultivated lands would range (Dobson et al., 2000; Liu et al., 2003). The land-use database of China during the period of 1980s and 1990s (Fig. 9), which is derived from Landsat Thematic Mapper (TM) imagery at 30-m resolution (Liu et al., 2003b).

Net primary productivity is the difference between accumulative photosynthesis and accumulative autotrophic respiration by green plants per unit time and space (Lloyd and Whittaker, 1975). Terrestrial Ecosystem Model (Liu, 2003) is employed for analysing spatial distribution of NPP in China (Fig. 10). It integrates different data types that include the land-use change data, daily climatic data and soil data. The analysis results show that the mean annual NPP of terrestrial ecosystems in China was $3.588 \times 10^{15}$ gC year$^{-1}$ in 1990s, which is greater than the one in 1980s. In other words, the mean annual NPP increased by $0.49$ gC m$^{-2}$ year$^{-1}$ during the 20 years.

The general situation in China is that from southeast to northwest NPP becomes smaller and smaller gradually. Most of the NPP is distributed in the East of the rainfall line where the annual precipitation is 410 mm, except that there is higher NPP in the southern slopes of Tianshan mountains and Altai mountains in Xinjiang. The maximum NPP appears in Xiaoxinganling mountain and Changbai.
mountain in the northeast China, Yunnan–Guizhou Plateau, Guangxi, Hainan, Chongqing and provinces along middle and lower reaches of Yangtze River.

In terms of land-use types, on the average, NPP of shrub and open forest is 1071 gC m$^{-2}$ year$^{-1}$, evergreen broad-leaved forest 975 gC m$^{-2}$ year$^{-1}$, deciduous broad-leaved forest 928 gC m$^{-2}$ year$^{-1}$, coniferous and broad-leaved mixed forest 870 gC m$^{-2}$ year$^{-1}$, farmland system 752 gC m$^{-2}$ year$^{-1}$, evergreen coniferous forest 587 gC m$^{-2}$ year$^{-1}$, deciduous coniferous forest 585 gC m$^{-2}$ year$^{-1}$ and grassland 271 gC m$^{-2}$ year$^{-1}$ (Liu, 2001).

2.4. Elevation

Elevation is an important variable of human population distribution because most human settlements occur on lower elevation in China. For instance, area of plains and hills with an elevation lower than 500 m accounts for about 28% of total land area of China, where 74% of total population in China inhabit (Zhang, 1997). The terrestrial parts of China are broadly divided into three steps (Fig. 11) from Qinghai–Xizang Plateau eastward (Zhao, 1986). The lofty and extensive Qinghai–Xizang Plateau is the first great topographic step. Its eastern and northern borders roughly coincide with the 3000 m contour line. It generally has an elevation of 4000 m to 5000 m and hence is called the roof of the world.

From the eastern margin of the Qinghai–Xizang Plateau eastward up to the DaHinggan–Taihang–Wushan mountains lies the second great topographic step. It is mainly composed of plateaus and basins with elevations of 1000–2000 m, such as the Nei Mongol, Ordos, Loess and Yunnan–Guizhou Plateaus and the Tarim, Junggar and Sichuan basins.

Fig. 6. Spatial distribution of roads in 1949 in China.
2.5. Population growth

Since 1930, population in China has increased about three times (Table 1). Hu’s result (1935, 1983) showed that total population of China was 452.8 million persons in 1930 and 541.67 million persons in 1949. Both fertility rate and death rate were higher and natural rate of population growth was lower in the period from 1930 to 1949. During the period from 1950 to 2000, total population increased by 725.74 million persons, of which the annual mean growth rate was 2.7%. The population growth underwent a rapid increase stage from 1950 to 1973, in which fertility rate was higher and death rate was lower and a relative slow stage after birth control policy, only one child for one couple, has been carried out in China in 1973, in which both fertility rate and death rate were lower. Although the birth control policy has restrained rapid population growth, annual newborn children are still more than 9.5 million in recent years in China because of the huge base number (Research Center for Population of CASS, 1985; Institute of Population and Labor Economics of CASS, 2001). The projection results (Jiang, 1998), on the basis of comprehensively analysing all factors that affect population growth in China, show that population in China under assumptions of higher total fertility rate and lower total fertility rate would be 1457.84 million persons and 1417.78 million persons, respectively, in the year 2015.
3. Methods and results

3.1. SMPD

By means of grid generation method (Morrison, 1962; Sidorov, 1966; Ahuja and Coons, 1968; Liseikin, 1999), the simulation model for population distribution (SMPD) is developed (Yue et al., 2003), which is a transformation between computational domain \((i,j)\) and physical domain \((i,j,\text{MSPD}_{ij}(t))\).

\[
\text{MSPD}_{ij} = G(n,t) \frac{p_i(t)}{\sum p_j(t)} (1)
\]

\[
p_i(t) = W_{ij}(t)NPP_{ij}(t)^{0.0001}\left(\text{DEM}_{ij}(t)^{0.2}\right)
\times (\text{Tran}_{ij}(t))^{1.2} \sum_{j} \frac{S_k(t)}{d_k(t)} (2)
\]

\[
\text{NPP}_{ij}(t) = \exp\left\{-\frac{(\text{MNPP}_{ij}(t) - 760)^2}{10^6}\right\} (3)
\]

\[
\text{Tran}_{ij}(t) = \frac{\text{ra}_{ij}(t) + \text{ro}_{ij}(t)}{\max\{\text{ra}_{ij}(t) + \text{ro}_{ij}(t)\}} (4)
\]

\[
\text{DEM}_{ij}(t) = \begin{cases} 500 & \text{if } \text{dem}_{ij}(t) \geq 3500 \text{ m} \\ 500 & \text{if } 500 \text{ m} < \text{dem}_{ij}(t) < 3700 \text{ m} \\ 1 & \text{if } \text{dem}_{ij}(t) \leq 500 \text{ m} \end{cases} (5)
\]

where \(t\) is a time variable; \(G(n,t)\) is total population in province \(n\) at time \(t\), in which grid cell \((i,j)\) is located, or whole China; \(W_{ij}(t)\) is an indicative factor of water area, when grid cell \((i,j)\) is located in water area \(W_{ij}(t) = 0\), or else \(W_{ij}(t) = 1\); \(\text{Tran}_{ij}(t)\) is a transport infrastructure factor of grid cell \((i,j)\); \(\text{NPP}_{ij}(t)\) is a factor of net primary productivity of grid cell \((i,j)\); \(\text{DEM}_{ij}(t)\) is...
Fig. 9. Land cover of China in 2000.

Fig. 10. Spatial distribution of the mean NPP in 1990s in China (unit: gC m\(^{-2}\) year\(^{-1}\); after Liu, 2001).
an elevation factor of grid cell \((i,j)\); \(S_k(t)\) is size of the \(k\)th city; \(M(t)\) is the total number of cities; \(d_{ik}(t)\) is the distance from grid cell \((i,j)\) to the core grid cell that has the highest population density in the \(k\)th city; \(r_{ai}(t)\) and \(r_{oi}(t)\) represent, respectively, rail density and road density at grid cell \((i,j)\); \(\text{MNPP}_{ij}(t)\) is the mean annual net primary productivity at grid cell \((i,j)\); \(\text{dem}_{ij}(t)\) is elevation at grid cell \((i,j)\).

### 3.2. Simulation process

SMPD simulates population distributions at four times-points that are the years of 1930, 1949, 2000 and 2015. Because population data in every province are available in 1930, 1949 and 2000, \(G(n,t), n = 1, 2, \ldots, 31\), represent provincial population in the process of population distribution simulation at the first three times-points. Population projection for 2015 is only carried out on national level so that \(G(n, t), n = 1\), represents population of the whole China, in the process of developing scenarios at the last times-point.

The major auxiliary tools of grid generation include ArcInfo GIS and Delphi computer language. Nine data layers are involved, which are NPP (net primary productivity), LU (land use database), DEM (digital elevation model), WA (water area), GridRail (railway network), GridRoad (road network), Chbnd (administrative boundary), Chzh (urban area) and Cityshp...
Table 1
The provincial population of China excluding Taiwan, Hong Kong and Macao temporarily

<table>
<thead>
<tr>
<th>Region</th>
<th>Area (km²)</th>
<th>Population size (million persons)</th>
<th>Population density (person per km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western China</td>
<td>672546</td>
<td>110.63</td>
<td>174.57</td>
</tr>
<tr>
<td>Inner Mongolia</td>
<td>114327</td>
<td>4.40</td>
<td>37.88</td>
</tr>
<tr>
<td>Guangxi</td>
<td>236544</td>
<td>11.50</td>
<td>18.42</td>
</tr>
<tr>
<td>Qinghai</td>
<td>82990</td>
<td>Belong to Sichuan</td>
<td>Belong to Sichuan</td>
</tr>
<tr>
<td>Sichuan</td>
<td>457539</td>
<td>51.34</td>
<td>57.30</td>
</tr>
<tr>
<td>Guizhou</td>
<td>176109</td>
<td>11.03</td>
<td>14.16</td>
</tr>
<tr>
<td>Yunnan</td>
<td>383101</td>
<td>11.52</td>
<td>15.95</td>
</tr>
<tr>
<td>Tibet</td>
<td>1201453</td>
<td>0.76</td>
<td>1.00</td>
</tr>
<tr>
<td>Shaanxi</td>
<td>205732</td>
<td>10.39</td>
<td>13.17</td>
</tr>
<tr>
<td>Gansu</td>
<td>406422</td>
<td>5.49</td>
<td>9.68</td>
</tr>
<tr>
<td>Qinghai</td>
<td>716677</td>
<td>1.28</td>
<td>1.48</td>
</tr>
<tr>
<td>Ningxia</td>
<td>57165</td>
<td>0.39</td>
<td>1.20</td>
</tr>
<tr>
<td>Xinjiang</td>
<td>164011</td>
<td>2.51</td>
<td>4.33</td>
</tr>
<tr>
<td>Middle China</td>
<td>1670726</td>
<td>150.15</td>
<td>161.41</td>
</tr>
<tr>
<td>Shanxi</td>
<td>156565</td>
<td>11.30</td>
<td>12.81</td>
</tr>
<tr>
<td>Anhui</td>
<td>140165</td>
<td>21.92</td>
<td>27.86</td>
</tr>
<tr>
<td>Jiangsu</td>
<td>166960</td>
<td>17.16</td>
<td>12.68</td>
</tr>
<tr>
<td>Hunan</td>
<td>165619</td>
<td>31.92</td>
<td>41.74</td>
</tr>
<tr>
<td>Hubei</td>
<td>189590</td>
<td>25.94</td>
<td>28.36</td>
</tr>
<tr>
<td>Hunan</td>
<td>211815</td>
<td>29.54</td>
<td>29.97</td>
</tr>
<tr>
<td>Shandong</td>
<td>191093</td>
<td>7.82</td>
<td>10.09</td>
</tr>
<tr>
<td>Hefei</td>
<td>45261</td>
<td>4.55</td>
<td>1.01</td>
</tr>
<tr>
<td>Eastern China</td>
<td>1203528</td>
<td>187.23</td>
<td>205.68</td>
</tr>
<tr>
<td>Beijing</td>
<td>16386</td>
<td>1.52</td>
<td>4.14</td>
</tr>
<tr>
<td>Tianjin</td>
<td>15820</td>
<td>1.47</td>
<td>3.99</td>
</tr>
<tr>
<td>Hebei</td>
<td>15111</td>
<td>30.29</td>
<td>30.86</td>
</tr>
<tr>
<td>Liaoning</td>
<td>146316</td>
<td>16.06</td>
<td>18.31</td>
</tr>
<tr>
<td>Shanghai</td>
<td>8013</td>
<td>3.91</td>
<td>5.06</td>
</tr>
<tr>
<td>Jiangsu</td>
<td>103405</td>
<td>30.29</td>
<td>35.12</td>
</tr>
<tr>
<td>Zhejiang</td>
<td>103196</td>
<td>20.07</td>
<td>20.83</td>
</tr>
<tr>
<td>Fujian</td>
<td>122468</td>
<td>13.99</td>
<td>11.88</td>
</tr>
<tr>
<td>Shandong</td>
<td>157119</td>
<td>36.67</td>
<td>45.49</td>
</tr>
<tr>
<td>Guangdong</td>
<td>179776</td>
<td>32.93</td>
<td>30.00</td>
</tr>
</tbody>
</table>

(geographical coordinate of city). The data are first pre-processed as follows: (1) converting NPP into vector data, (2) overlaying Chbnd with GridRoad and GridRail by Intersect and creating a data layer, ChBndNew, (3) adding fields, CityFlag for urban code and rural code and CityArea for areas of urban districts, in Chzh, (4) overlaying Chzh with ChBndNew by Intersect and creating a data layer, Chzh, (5) overlaying NPP with Chzh by Intersect and creating a data layer, NppNew, (6) overlaying LU with NppNew by Intersect and creating a data layer, Lnp, (7) overlaying DEM with Lnp by Intersect and creating a data layer, DLNpp and (7) overlaying WA with DLNpp by Intersect and creating a data layer, WDNLnp.

Every grid cell in 1 km x 1 km resolution is generated on the basis of WDNLnp, which includes six steps: (1) to read the attribute values of natural and socioeconomic indicators at every grid cell, (2) to calculate the contribution of NPP and elevation to the generating grid cell, (3) to define a search radius of 200 km and to search cities and transport infrastructures that have considerable effects on the generating grid cell,
(4) to calculate the contribution of the searched cities and transport infrastructures to the generating grid cell, (5) to operate the SMPD and (6) text file of the calculated result is converted into point vector data and grid data is created from the point vector data.

3.3. Results

According to current ecological and economical situation, China could be geographically analysed in three regions that are western, middle and eastern China. The western region of China consists of five provinces in southwest China, five provinces in northwest China, Inner Mongolia Autonomous region and Guangxi Zhuang Autonomous region. The five provinces in southwest China are Sichuan province, Chongqing city, Yunnan province, Guizhou province and Tibet Autonomous region. The five provinces in northwest China are Shaanxi province, Gansu province, Ningxia Hui Autonomous region, Xinjiang Uygur Autonomous region and Qinghai province. Area of the western region of China is about 6.7546 million km$^2$, accounting for 70% of the whole of China. The middle region of China consists of eight provinces that are Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan, Jilin and Heilongjiang, of which area is 1.67 million km$^2$ and accounts for 17.4% of the Whole of China. The eastern region of China consists of 11 provinces that are Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan, of which area is 1.2 million km$^2$ and accounts for 12.5% of the whole of China.

A comparison of the simulation results shows that the ratios of population in the western region of China to total population of China were 24% in 1930 (Fig. 12), 32% in 1949 (Fig. 13) and 29% in 2000 (Fig. 14); the ones in the middle region were 33% in 1930, 30% in 1949 and 34% in 2000; the ones in the eastern region were 41% in 1930, 38% in 1949 and 37% in 2000. Human population had a slanting trend from the eastern region to the western and middle regions of China during the period from 1930 to 2000. From 1930 to 1949, on an average, annual growth rate of population was 3% in the western region, 0.4% in the middle region and 0.5% in the eastern region; from 1949 to 2000, annual growth rates of population were
Fig. 13. The human population distribution of China in 1949 (unit: persons per square kilometer).

Fig. 14. The human population distribution of China in 2000 (unit: persons per square kilometer).
Table 2
Population change of in different regions of China excluding Taiwan, Hong Kong and Macao temporarily

<table>
<thead>
<tr>
<th>Years and scenarios</th>
<th>The western region</th>
<th>The middle region</th>
<th>The eastern region</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Population</td>
<td>Ratio (%)</td>
<td>Population</td>
</tr>
<tr>
<td>1930</td>
<td>110.63</td>
<td>24</td>
<td>150.15</td>
</tr>
<tr>
<td>1949</td>
<td>174.57</td>
<td>32</td>
<td>161.42</td>
</tr>
<tr>
<td>2000</td>
<td>354.6</td>
<td>29</td>
<td>419.41</td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario I</td>
<td>180.86</td>
<td>12</td>
<td>427.56</td>
</tr>
<tr>
<td>Scenario II</td>
<td>196.55</td>
<td>14</td>
<td>439.31</td>
</tr>
</tbody>
</table>

respectively 2%, 3.1% and 2.5% in the western, middle and eastern region (Table 2).

From now to 2015, all of urban population proportion, large-scale highway construction and population growth have at least two possibilities in China. If the increase of urban population proportion at the average rate in recent 5 years, annually 1.44%, the urban population proportion would be 57.82% in 2015; but in terms of the National Report of China Urban Development, the increase rate will be 1.0% annually and the urban population proportion will be 46.9% (China Mayor Association, 2002). The major highway construction projects will be completed in 2010. During the period from 2010 to 2015, construction length of highways might be continued at the increase rate, 0.25% annually, as in the period from 2000 to 2010; it is also possible that large-scale highway construction stagnate temporally. In terms of the projection (Jiang, 1998), population would be 1457.84 million persons at higher total fertility rate and would be 1417.78 million persons.
at lower total fertility rate in 2015 in China. Therefore, as an example of SMPD advantage for scenario development, two scenarios are here developed under assumptions that railway construction planning would have been successfully carried out, increase rate of NPP would be 0.49 gC m\(^{-2}\) year\(^{-1}\) and elevation on national level has little change. The two scenarios are distinguished into I and II. In the scenario I, it is supposed that the urban population proportion would be 57.82% in 2015, annual increase rate of highway construction would be 0.25% during the period from 2010 to 2015, and population would be 1457.84 million persons in 2015 (Fig. 15). In the scenario II, the urban population proportion would be 46.9%, large-scale highway construction during the period from 2010 to 2015 would be temporal stagnation and there would be 1417.78 million persons in 2015 (Fig. 16). Both scenarios show that population might greatly float from the western and middle regions to the eastern region of China (Table 2). The more rapid the urbanization and transportation development would be, the bigger the population floating speed would be.

### 4. Discussions

The translation of model results into geographical patterns is already under rapid development by use of geographical information system (GIS) (Jørgensen, 2002). SMPD is such a method that integrates spatial and non-spatial information from various sources such as remote sensing, statistics, ecosystem research network, various monitoring systems, and investigation on-the-spot by means of GIS. In addition to SMPD, GIS-based methods that have been developed for integrating economic and ecological information in recent years include spatial detailed Biotope Landscape Model (Muenier et al., 2004), GIS-extended nitrate pollution model (Matějček et al., 2003), FORRUS-S model for forest management (Chumachenko et al., 2003), Model of Hierarchical Patch Dynamics (Burnett and Blaschke, 2003), GIS-based Erosion Productivity Impact Calculator Model (Tan and Shibasaki, 2003), Optimisation Methodology for land use patterns (Seppelt and Voinov, 2002), the multi-disciplinary integrated model system...
consisting of the models ProLand, ELLA and SWAT (Weber et al., 2001), and Spatial EPIC (Priya and Shibasaki, 2001). Comparing with other GIS-based methods, SMPD not only pays attention to the situation of relative elements at the site of generating grid cell itself but also calculates contributions of other grid cells by searching the surrounding environment of the generating grid cell. For instance, in the case of this paper, a search radius of 200 km is defined in the process of generating each grid cell. Although the Optimisation Methodology adopted a grid search strategy and performed a grid search through the entire control space assuming a homogeneous land use and identical fertilizer amounts for each cell, it aimed at searching temporal change in information of each grid cell in a series of maps during the simulation period of 551 days instead of searching the surrounding environment of the grid cell.

Human population distribution in China is mainly determined by geographical location such as distance from cities and transport infrastructures and environmental conditions such as net primary productivity and elevation. Research results of wildlife population distributions (Ji and Jeske, 2000; Krivan, 2003; Westerberg and Wennergren, 2003) show that distributions of wildlife population are characterized by geographical location and seasonal variations of movement patterns. Movement behaviour of wildlife populations is impacted by environmental conditions and land uses. In addition to predator-prey dynamics and interspecific competition, physical texture, food resources, weather conditions and landscape structure as well as differences in the magnitude of these factors have a direct effect on wildlife population distributions. Therefore, wildlife population distribution is also determined by geographical locations and environmental conditions generally. But some specific factors such as urbanization and transportation infrastructures, which might negatively contribute to some wildlife population distributions, have a positive effect on human population distribution; other factors such as net primary productivity have a similar effect on both human population and wildlife population. It seems that grid generation method employed in SMPD could be used to simulate wildlife population distribution.

Acknowledgments

This work is supported by National Basic Research Priorities Program (grant no. 2002CB4125) of Ministry of Science and Technology of the People’s Republic of China and by Projects of National Natural Science Foundation of China (grant no. 40371094).

References


Keenen, V., 2003. Idea free distributions when resources un-
depth population dynamics. Theor. Population Biol. 64, 25–
38.

Loth, H., Wittmayer, R.B., 1975. Primary Production of the Bio-
sphere. Springer-Verlag, New York.


ical Sciences and Natural Resources Research of CAS.

Liu, M.L., 2001. Land-use/Land-cover Change and Vegetation Car-
bon Pool and Productivity of Terrestrial Ecosystems in China. Doctoral thesis of Institute of Geographical Sciences and Natu-
ral Resources Research of CAS.

Lo, C.P., 2001. Modelling the population of China using DMSIS op-


Moore, J.D., Grayson, R.B., Ladson, A.R., 1992. Digital terrain mod-
elling: a review of hydrological, geomorphological, and biologi-
cal application. In: Creasy, C.F.M., Craggs, C. (Eds.), Applied Surface Modelling. Ellis Hor-


time satellite imagery. Int. J. Remote Sens. 22 (16), 3061–
3076.


Sutton, P., 1997. Modelling population density with night-time satel-
lite imagery and GIS. Comput. Environ. Urban Syst. 21 (5),
227–244.


Westergaard, L., Wimmenager, U., 2003. Predicting the spatial distribu-


