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APPLICATIONS OF GAME THEORY AND GIS FOR URBAN PLANNING ANALYSIS IN MONGOLIA

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ABSTRACT: The aim of this study is to investigate the city management in Ulaanbaatar, specifically in the district-13 area, using modern game theory and a GIS. Initially, a primary digital database is developed using available (spatial and attribute) data sets, and then updated through processing of a very high resolution satellite image. Applying "The Tragedy of the Commons" framework we have found that the private incentives among the construction companies drove the supply of apartments higher. We estimated that if the construction companies cooperated instead of competed with each other, it would have been socially optimal.

1. INTRODUCTION

In recent years, as a result of the uncontrolled planning, lots of new buildings have been built in the Ulaanbaatar city (Chinbat *et al.* 2006, Amarsaikhan *et al.* 2011). As demand for housing in the city was high in the 1990s, many companies built many buildings for all kinds of purposes without much economic analysis and due to such over-supply of buildings, the current state of the city has left almost no recreational or green space. Hence, the quality of living and working in the existing apartments and offices has decreased considerably. There are studies (Bolormaa 2010) that estimate that crammed buildings and traffic congestion are, in part, responsible for some of the health problems in Ulaanbaatar.

At present, in many parts of Ulaanbaatar city, it is highly dense with buildings and without any recreational spaces. In this study, we analyzed the cause of such density and provide possible remedies for future rise of building density. In order to do so, we borrowed the concept of externality from the economic literature and using the framework of "The Tragedy of the Commons", we analyzed the density problem. We have used the statistical data provided by the National Statistical Office of Mongolia, to estimate the tragedy of the common land in district-13 area in Ulaanbaatar. Since the advent of the market economy, the right to construct buildings in the city has been transferred to private companies. To create the initial database used for the further study, a topographic map of the study area and attribute descriptions of the spatial objects were used. Then the developed database was updated through processing of remote sensing (RS) images.

Applying "The Tragedy of the Commons" framework we have found that the private incentives among the construction companies drove the supply of apartments higher. We estimated that if the construction companies cooperated instead of competed with each other, it would have been socially optimal from the economic perspective. Moreover, we believe that less buildings and more parks, green spaces and public space would increase the quality of living in the city.

2. TEST SITE AND DATA SOURCES

As a test site, district-13 area of Ulaanbaatar, the capital city of Mongolia has been selected. Although, Ulaanbaatar is extended from the west to the east about 30km and from the north to the south about 20km, the study area chosen for the present study covers a small area in more central eastern part of the capital city. Figure 1 shows a Quickbird image of the test site.

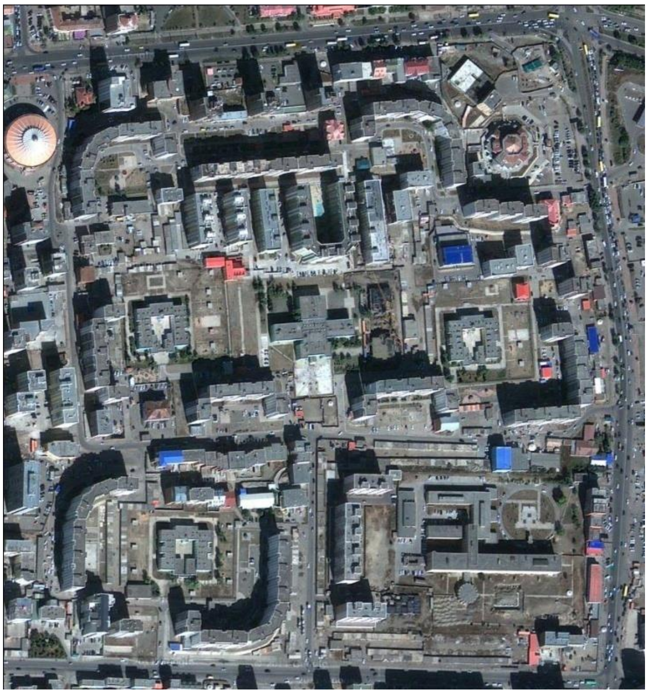

Figure 1: 2006 Quickbird image of the selected part of Ulaanbaatar

In the current study, 1:5000 scale topographic map of 2000, Quickbird images of August 2011 have been used. The Quickbird data has four multispectral bands (B1: 0.45–0.52μm, B2: 0.52–0.60μm, B3: 0.63–0.69μm, B4: 0.76–0.90μm) and one panchromatic band (Pan: 0.45-0.9μm). The spatial resolution is 0.61 m for the panchromatic image, while it is 2.4 m for the multispectral bands. In the current study, panchromatic, green, red and near infrared bands have been used.

3. INTEGRATION OF PANCHROMATIC AND MULTISPECTRAL IMAGES

At the beginning, the panchromatic Quickbird image has been georeferenced to a Gauss-Kruger map projection using a topographic map of 2000, scale 1:5000. The ground control points (GCP) have been selected on well defined crossings of roads and streets and in total, 12 regularly distributed points were selected. For the transformation, a second order transformation and nearest neighbor resampling approach (Richards and Xia 1999) have been applied and the related root mean square (RMS) error was 0.82 pixel. Likewise, the multispectral Quickbird image has been georeferenced to a Gauss-Kruger map projection using the same topographic map of the test area. For the transformation the same number of GCPs has been used and the related RMS error was 0.98 pixel. In each case of the georeferencing, an image was resampled to a pixel resolution of 1m.

Then, the integrated image was enhanced using two different image fusion methods such as Brovey transform and Gram-Schmidt fusion (Pohl and Van Genderen 1998, Teggi *et al.* 2003, Amarsaikhan *et al.* 2009). In order to obtain a good colour image that can illustrate spectral and spatial variations of the classes in the selected image frame, different band combinations have been used. The image created by the Gram-Schmidt fusion method was good, but it contained too much color variations of objects belonging to the same class. Compared to the result of the Gram-Schmidt fusion, the Brovey transformed image gave a superior result in terms of the spatial separation between different objects and classes. Therefore, for the further interpretation of the building class, the image created by the Brovey transform has been used.

4. DATABASE DEVELOPMENT AND LAND USE ANALYSIS

Initially, a topographic map of the study area has been georeferenced to a Gauss-Kruger map projection using 9 GCPs. For the transformation, a linear transformation and nearest-neighbour resampling approach were applied and the related RMS error was 0.52 pixel. In order to acquire primary digital data, the buildings were digitized from the georeferenced topographic map of 2000, scale 1:5000 using ArcGIS system. Then, for each building entity, the attributes such as use, built_year, storey, etc. were entered.

After creation of the database, it was necessary to update it and for this purpose, the Brovey transformed Quickbird image of 2011 has been used. At the beginning, the coordinates of the Quickbird image were transformed to the coordinates of the topographic map using 12 ground GCPs. For the transformation, a second order transformation and nearest-neighbour resampling approach were applied and the related RMSE was 0.79 pixel. Then, on the georeferenced Quickbird image, the buildings were screen digitized and updated the database of 2000. After that for all new building entities, the attributes such as use, built_year, storey, etc. were entered. The digitized and updated features are shown in Figure 2.

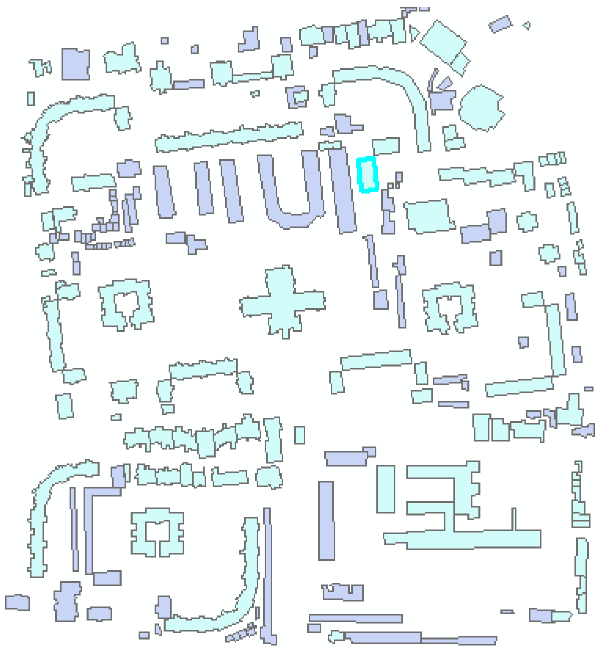

Figure 2: A digitized and updated features of district-13 area

As could be seen from the interpretation and conducted spatial analysis, in this area, there are 43 apartment buildings having 32988.6м^2, 8 recreational places having 39501.0м^2, 56 garages having 9181.7м^2, 7 hospital and chemist buildings having 2643.2м^2, 11 hotel, restaurant and pub buildings having 2279.1м^2, 25 (private and government) office buildings having 8538.6 м^2, 8 school and kindergarten buildings having 9408.2м^2, 28 individual trade buildings having 5003.6м^2, 12 combined trade and apartment buildings having 7475.3м^2, and 8 service centers having 1832.6м^2, respectively. In addition, in this area, green area occupies 61836.1 м^2, while other class that includes other land use types occupies 2805.6 м^2.

As the district-13 area is located in a very prestigious location of the capital city, the available empty areas of this site are in a center of attention of many businesses and other wealthy people. Recently, the planners have found out that the residential neighborhood in this area is very dense and there is no more available space to build more buildings. Also, they have determined that the currently existing buildings and their occupying areas exceed the given standard by 5%.

5. TRAGEDY OF DECENTRALIZED CITY MANAGEMENT

As it can be gathered from above, district-13 area is very densely populated by buildings of all purposes and we propose that the main reason for this outcome is “decentralized city management.” The over-utilization of shared natural resources is a well established phenomenon, named the “Tragedy of the Commons” (Hardin, 1968). The logic of the “Tragedy of the Commons” is that any rational company seeks to maximize its gain from each unit of land. The utility of one unit of land accrues to the company alone, and it is derived from the sale of the building constructed on the land or the usage of buildings constructed on the land by the company itself, however, the cost imposed on the society by the additional buildings is borne by everyone living and working in the neighborhood.

Before the 1990s, urban planning was managed by the government, and due to such centralized planning, the number of buildings was optimal for the society. The reason is that, all the negative externalities related to

additional buildings were internalized by the one planner. However, after the advent of market economy commencing from 1992, the right to construct new buildings was transferred to private companies and as private companies maximized their profit by constructing new buildings in their given land, the resulting number of buildings became not optimal for the society. We will use a hypothetical example to support our claim, and later, we will use existing data to confirm it.
During the centrally planned era, the government planned the city and as such, was maximizing their profit given the land area. The maximization problem that the construction company faced was

$$\max_{X} Xv(X) \tag{1}$$

where X denotes the total number of buildings and $v(X)$ is a function of the total number of buildings, X and denotes the value per building to the residents. $v(X) = p(X) - c(X)$, where $p(X)$ is the price per building and $c(X)$ is the cost per building.

Since the first few buildings have plenty of room to build, adding one more does little harm to the quality of living in the area, but when so many buildings have been built, then adding one more dramatically harms the quality of living in the area, that is, $v^{'}(X) < 0$ and $v^{''}(X) < 0$. The first order condition for this problem is

$$v(X) + Xv^{'}(X) = 0 \tag{2}$$

The optimal number of buildings in this setting is obtained from the equation. This maximization problem is the problem of a monopolist, and also, it may also be interpreted as the cooperative problem of many companies.

In the present site, there are 12 construction companies in operation and they are all maximizing their profit given the land and such actions are resulting in overcrowded buildings. The maximization problem that construction companies face is

$$\max_{x_i} x_i v(X) \tag{3}$$

where x_i denote the number of buildings constructed by construction company i and $X = x_1 + \cdots + x_n$. The first order condition for this problem is

$$v(x_1^* + \cdots + x_i + \cdots + x_{12}^*) + x_i v^{'}(x_1^* + \cdots + x_i + \cdots + x_{12}^*) = 0 \tag{4}$$

As all construction companies face the same problem, in equilibrium, x_i must satisfy this condition, when all the other companies construct according to this equation, that is, the other companies construct their equilibrium number of buildings. When every company follows their equilibrium strategies, on average, this condition becomes

$$v(X^*) + \frac{1}{12} X^* v^{'}(X^*) = 0 \tag{5}$$

The first order condition above indicates the incentives faced by construction companies who have already built x_i buildings but is considering adding one more. The value of an additional building is $v(x_1^* + \cdots + x_i + \cdots + x_{12}^*)$. The harm to the quality of living in the construction company's existing buildings is $v^{'}(x_1^* + \cdots + x_i + \cdots + x_{12}^*)$ per building. The optimal number of buildings for every company is obtained from the symmetric problem of the companies. It is obvious that $X < X^*$ holds, that is, non-cooperative outcome is larger than cooperative outcome. The common resource is over-utilized because each company considers only their own incentives, not the effect of their actions on the other companies.

6. ANALYSIS AND RESULTS

The cooperative and non-cooperative solutions presented above are illustrated with district-13 area data. Two situations are considered in searching for optimal construction strategies. The first concerned is the non-cooperative companies, that is, the companies that are in operation in the present. The second situation is the cooperative companies, that is, the situation when the present companies cooperatively construct buildings.

Before 1992, the total land area used as building sites was 34,207.4 sq.m compared to the total land area of 183,493.6 sq.m. However, from 1992 to 2007, an additional 51,350.2 sq.m of land was used for buildings. It was reported in the Bank of Mongolia data that the price of 1 sq.m of a building is US$900, meaning it accrued US$203,985,108 to the construction companies.

However, if the companies cooperated to build all the constructions, the total area of land used for buildings would be 27,857.1 sq.m and the price of 1 sq.m of a building would be US$5850, meaning the total profit accrued to the construction companies would be US$162,964,035 when all the buildings were one-storey high. As it is unlikely that the buildings on this site would all be one-storey high, the total profit of the construction companies would have been high. Moreover, the total land area used for buildings is almost half the area of the land that is being used in the present. This analysis shows that when companies cooperatively construct buildings, it would greatly increase the land used for green space and for open space but it would also increase the building cost.

7. CONCLUSIONS

The aim of this study was to investigate the city management in the district-13 of Ulaanbaatar using modern game theory and GIS. Using the GIS and National Statistical Office data, we have demonstrated that cooperation among construction companies resulted in socially optimal number of buildings. At the present, the companies are in a non-cooperative equilibrium, and as such, are causing the present state of overcrowded buildings. It is explained by the "Tragedy of the Commons," for the over-usage of common land leads to overcrowding. However, it must be noted that for cooperation to be sustainable, enforcement must be effective, in which case economic efficiency is theoretically provable. Although it begs for more complete study, we believe that the less number of buildings must help reduce some of the health problems in Ulaanbaatar city.

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