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An Integrated Land Use and Transport Model to Examine Polycentric Policies of Beijing

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Abstract: Beijing's fast urban growth has caused serious traffic congestion and great environmental damage. The government plans to develop sub-centres in its metropolitan area to ease the pressures associated with being a sole, centralized city service provider. This has been formalized in its recently published master plan, the 'Beijing City Master Plan (BCMP), 2004-2020' (BCMP), which targets the formation of the city plan up to 2020. This study develops a general land-use and transport interaction model to forecast the housing rent distribution based on the present land-use policies and examines whether the objective of decentralized multi-centres can be achieved based on a 'business as usual' scenario. Modelling results show that as of 2020 there will be no sub-centres formed around urban Beijing. Some zones demonstrate the potential to become sub-centres with higher rent increases than the surrounding zones. However, the distribution of these potential zones has a different spatial pattern from what the master plan anticipates. This work may well provide a modelling tool for China's decision makers to examine land-use policies before putting them into practice.

1. INTRODUCTION

China is undergoing rapid and large-scale urban expansion (Jiang, Deng, & Seto, 2012; Liu et al., 2012; Gu & Pang, 2009; Lu et al., 2007). The urban sprawl or 'pie style' development has become one of the most widely discussed issues in China's urban studies. Rapid economic develop.0pment greatly improves people's welfare, but also brings serious challenges. As the capital and largest city, Beijing is a leading example of this trending expansion, and its migrant population has been increasing for decades. These changes have caused serious environmental and social problems, especially as they put stress on traffic congestion. The government intends to develop multi-centres to solve these issues. According to its newly published master plan, the 'Beijing City Master Plan (BCMP), 2004-2020', the government intends to restructure Beijing's urban spatial structure to decentralize its services (Beijing Municipal Planning Committee (BMPC), Beijing Institute of City Planning, & Beijing Academy of Urban Planning, 2006) by 2020. However, questions, such as whether the polycentric structure can be achieved based on present development trends and whether the corresponding policies planned are adequate, remain unanswered.

Polycentric development in metropolitan areas attracts a great deal of academic attention. The urban spatial economy up until the 1970s has generally been considered a conformation of employment concentration in Central Business Districts (CBDs), middle-class residential neighbourhoods and industries in suburbs (Fernández-Maldonado et al., 2014). Since then, metropolitan areas have stretched out into discontinuous, borderless and decentralized urban forms with a growing number of sub-centres accommodating new economic activities (Lang, 2003; Garreau, 1991). During urban decentralization, jobs are relocated following the rapidly increasing scale of residential suburbanization, accompanied by all kinds of service sectors (Muller, 1981; Fernández-Maldonado et al., 2014). Since the early 1980s, ever-expanding suburbanization, together with growing automotive dependency, expanding road systems, and non-spatial trends such as widespread use of information and communications technology (ICT), and the emergence of the global service economy, has led to a post-industrial form of urban agglomeration (Phelps & Ozawa, 2003), a fundamentally new spatial form and organization of polycentric metropolitan areas.

As an urban economic activity, this relocation trend is explained as the result of the tension between two economic forces, agglomeration economies and diseconomies, which are both dependent on the spatial proximity of economic activities and coexist in large cities, but act in opposition to each other. Agglomeration economies are regarded as cost saving whereas diseconomies increase costs, although both result from the concentration of production at a given location. Firms tend to cluster in urban cores to take advantage of agglomeration economies. When congestion costs tend to exceed these advantages, firms move outward to suburban areas. The scaling up of polycentric structures is explained by increasing geographical scales of agglomeration economies (Parr, 2002a, 2002b) or of specific industries due to changes in technologies of production, transport and communication (Phelps & Ozawa, 2003).

Most of the research on urban polycentricity has been focusing on cities or regions in developed countries, with little attention paid to rapidly growing cities in developing countries such as China (Yue, Liu, & Fan, 2010). Although research has recently begun to emerge in China, it predominately concentrates on urban geographic land-use patterns (Long et al., 2013; Wang, H. et al., 2013; Yue, Liu, & Fan, 2010), analysing polycentric urban development based on the direction of urban expansion, urban-rural gradients, growth type and physical urban land-use dynamics. Long et al. (2013) forecast the distribution of future sub-centres in Beijing based on present land-use trends. Qin and Han (2013) study the relationship between real estate prices and location characteristics in Beijing and concludes that there are new sub-centres emerging, such as Zhongguancun and Olympic Park.. Rarely is there research focusing on how these centres function rather than on their geomorphological aspects, despite the likelihood that in studies of urban polycentricity, economic and other functional aspects are likely to carry more meaning. Furthermore, the existing studies usually focus on demonstrating the mechanisms, characterizations and dynamics of the formation of polycentric urban structures, or apply methods to identify the polycentricity of a metropolitan area, which both draw heavily on historical data to form conclusions. Questions faced by China's policy makers, such as 'Could polycentric spatial structures be formed under present land-use or transport policies?' have not been well answered. China's economic boom has empowered growth-oriented local governments, and urban land-use has become a major concern for local officials aiming at economic growth and reductions in rent-seeking (Ding & Lichtenberg, 2011; Wei, 2012). In China, urban development and specialization are neither accidental nor purely market-driven, but rather they emerge as a consequence of state priorities (Liao & Wei, 2014). The government decides the pattern of physical land-use to a large extent, overseeing the urban activity distribution. Thus, it is more practical to model the evolution of the functional polycentric structure of a city based on land-use policy scenarios instead of the rigid physical land-use pattern change.

In order to identify the extent of polycentric urban structure formation by 2020, under a continuation of current land-use policies, this research develops a Beijing Land-Use/Transport Interaction model (LUTI) to simulate the urban spatial evolution and predict activity distributions (e.g. household and employment locations). The paper is organized into five sections, including this introduction. Section 2 reviews the approaches used in sub-centre identification. Section 3 presents a detailed description of the Beijing LUTI (BJLUTI) model, followed by a Beijing case study in Section 4. The paper ends with discussion and conclusions in Section 5.

2. SUB-CENTER IDENTIFICATION

Polycentricity was conceptualized in the early 20th century (Burgess, 1925; Harris & Ullman, 1945). It has been interpreted using various criteria at different spatial scales (Yue, Liu, & Fan, 2010; Waterhout, Zonneveld, & Meijers, 2005). Although traditionally it referred to intra-urban agglomeration (the outward diffusion from big cities to smaller cities within their urban fields or spheres of influence), recently it has been used at interurban or interregional scales to denote polycentric urban regions (Kloosterman & Musterd, 2001) or mega-city regions (Scott, 2002).

Sub-centres are defined as locations with larger job concentration and density than their surrounding areas. A sub-centre, should be large enough to significantly influence the functioning of cities, especially their transportation systems, land value and population distribution (McMillen, 2003). For example, Giuliano and Small (1991) define an employment centre as having a minimum 10,000 jobs and 5000 jobs per square mile. Currently there are no standard methods or measures to identify sub-centres. García and Muñiz (2005) distinguish five different approaches to identify sub-centres as shown in Table 1: the thresholds approach uses job concentration and density (Giuliano & Small, 1991); the density peaks approach uses the peaks of job density, or the ratio of jobs to the resident population; the mobility approach focuses on mobility flows; and the residues approach is a relative method developed based on the size of deviations from the density of employment functions of the city. Some studies use econometric regressions, which may be better suited to comparing regional urban systems than applied to metropolitan areas.

Table 1. Approaches for identification of sub-centres

Approaches	**Criteria**
Thresholds	Density of jobs per hectare. Appropriate cut-off points vary across urban areas.

Mobility	Commuting flows
Density peaks	Peak of job or ratio of jobs to resident population
Residues	Exponential job density, weighted regression, Flexible Fourier with distance to sub-centre, etc.
Spatial econometrics	Total and local Moran index (job density or job/population)

Source: García and Muñiz (2005)

These approaches are all concerned with densities whose thresholds usually vary across urban areas and are inherently difficult to define. In China, the statistical data for cities like Beijing is usually collected at smaller scales (e.g., towns) with more variation – the outer towns often have a much larger area than the inner ones. The average densities of activities may not accurately reflect the distribution of sub-centres; on the other hand, the commuting patterns of cities in China are different from those in developed countries. For instance, residents in Beijing prefer to live in zones with better transport accessibility over better environmental quality if there is a choice between the two. Previous studies in urban location and transport cost modelling (Von Thünen, 1826; Alonso, 1964; Muth, 1969; Mills & Hamilton, 1972) show that rent (or property price) plays a key role in defining the sub-centre distribution of a metropolitan area. In the following sections, we develop a LUTI model to simulate the urban spatial evolution process, forecast housing rent distribution, and analyse the extent of polycentric urban structure change under the present land-use policies.

3. MODEL DEVELOPMENT

The urban development of a city is the process of spatial evolution of various activities interacting with each other via transport, during which the spatial distribution of activities changes continuously, leading to the changing distribution of demand for floor space and property rent.

The urban Land Use/Transport Interaction model (LUTI) is an effective tool for modelling the described interaction process (Coppola et al., 2013; Simmonds & Feldman, 2011; Wegener, 2004). It provides an abstract representation of the interaction between two main components of urban areas, transport and land-use (Torrens, 2000). ‘Land-use’ in the LUTI model does not commonly refer to the physical use of land dominated by buildings and transport, rather the social and economic activities occupying floor space. In a LUTI model the two components are inter-linked: the land-use indicators, such as the population and employment forecast, are used by the transport component to generate demands for transport; the travel time and costs forecast by the transport component, derived from the demand and supply of transport, are used in the land-use model to calculate urban accessibilities, which in turn leads to land-use change. LUTI models have traditionally been used to simulate the possible effects of new policies or projects (especially those related to transport) on existing urban systems (Zondag et al., 2015; Aljoufie, 2014; Echenique et al., 2012; Wegener, 2004; Foot, 1981; Lowry, 1964). This research is intended to develop an activity-based LUTI model to forecast the change of urban activity and rent patterns and test polycentric development policies. The current research assumes that urban activities, including both residential and business activities, abide by the location utility maximization rule.

3.1 Beijing Land-Use/Transport Interaction Model

The proposed model will be called the Beijing Land-Use/Transport Interaction Model (BJLUTI). As a universal model, it is developed from an urban activity perspective with two categories of activities, household activities and non-household (or employment) activities, which generally provide jobs for households. The BJLUTI model simulates and projects variations of property rent, and subsequently identifies future sub-centres based on the present policies.

The model, as shown in Figure 1, comprises two main components, a land-use model and transport model. While the transport model estimates accessibility by zone, based on generalized transport cost and the spatial distribution of urban activities, the land-use model estimates the distribution of activities based on zonal accessibility and floor space distribution and utility of consumption.

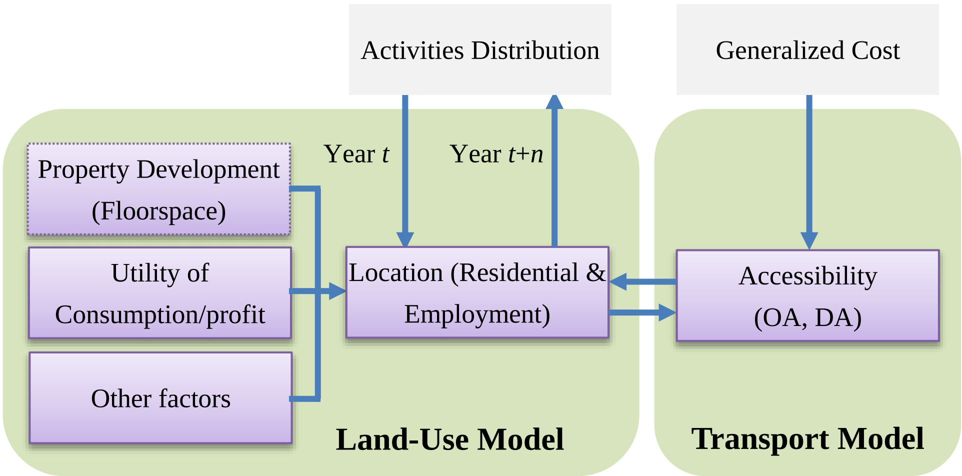


Figure 1. BJLUTI model

The BJLUTI model consists of five sub-models as shown in Figure 1: Property or Floor space Development model, Utility of Consumption model, Location model (Residential and Employment) and Transport Accessibility model. Activity distribution and generalized cost are two exogenous variables used by the Land-Use model and Transport model respectively. The model is solved by an equilibrium solution as illustrated in the following section, where any changes that occur in the territorial system will subsequently lead to a new equilibrium state. As this study is intended to test land-use policies, the Property Development model is not implemented and the property development index is taken exogenously.

3.2 Transport Model and Zonal Accessibility

Zonal accessibility is an indicator measuring one's ease of access to the collective opportunities, such as all jobs available from the zone, and how well the transport system can help one to reach these opportunities.

Two primary factors affect zonal accessibility, which are the transport costs between zones and the opportunity distribution within zones. The number of opportunities in a zone gives weight to the expression of the zone in equation (1) (Niu & Li, 2017). The definition of opportunity depends on the purpose of a trip. For instance, the number of jobs in one zone is used as the weight of that zone to calculate the accessibility of other zones in terms of home-work commuting. The transport cost between zones is estimated by time cost, determined by the distance between zones, and the road types in the model. A connection between two zones may involve a few segments of different road types, such as national, provincial and county roads. In contrast to the traditional methods used to calculate the transport accessibility (Wang, Y., Monzon, & Di Ciommo, 2015; Zondag et al., 2015), this model develops a logsum formula associated with a logit model of destination/origin choice as follows,

$$A_i = \frac{1}{-\lambda}\left(\ln\left\{\sum_j W_j \exp\left(-\lambda\ g_{ij}\right)\right\}\right) \qquad (1)$$

where,

Ai	is the accessibility of zone i;
j	refers to a zone connecting with i in the area of study;
gij	is the generalised cost of transport from zone i to zone j; and
Wj	represents the importance of the connection for Ai.

3.3 Location Cost: Utility of Consumption

We define the utility of consumption as the per household level of satisfaction obtained from their income and expenditure on two goods, namely housing space, and other goods and services (*ogs*), and this is calculated based on the Cobb-Douglas function (Cobb & Douglas, 1928),

$$U_{pi} = \left(a_{pi}^{H}\right)^{\beta_p^H} \cdot \left(a_{pi}^{O}\right)^{\beta_p^O} \qquad (2)$$

where,

Upi is the utility that households consume during period p in zone i;

a_{pi}^{H} is the average housing space per household;

aO is the average expenditure spent on ogs; and

β_p^H and β_p^O are the propensities to spend the income available on housing space and ogs respectively.

Households are assumed to prioritise their expenditure on housing space and *ogs* to maximize their utility of consumption. Here, the sum of the two variables (β_p^H , β_p^O) equals 1.

3.4 Location Model

3.4.1 Residential and Employment Location Model

The Location model includes two components, the Residential Location model and Employment Location model. The residential location model forecasts the number of residents by zone in future years. It is developed based on the hypothesis derived from the random utility theory that individuals choose the locations that maximize their overall utility (*V*). As the processes whereby individuals evaluate locations is an unknown variable, a probabilistic discrete choice model is postulated in which households evaluate zones as a function of factors such as transport accessibility and location attributes relative to their places of work, and the error terms are assumed to be independently and normally distributed. The model assumes that it is the changes of the factors such as transport accessibility and rent that cause the variation (e.g. household location or relocation) of urban activities. These changes can be weighted and summarized as the location utility change, i.e.,

$$\Delta V^{H}_{t+1,i} = \theta^{U}_{p}\,(U^{H}_{t+1,i} - U^{H}_{ti}) + \theta^{A}_{p}\,(A^{H}_{t+1,i} - A^{H}_{ti}) \qquad (3)$$

where,

$\Delta V_{t+1,i}$ is the location utility change in zone i during period t+1;

θ is the coefficient of change; while

U, and A are the utility of household consumption; and zonal accessibility, from the perspective of households respectively, is used to calculate the changes between periods *t* and *t+1*.

For utility of employment, variable U in equation (4) would be replaced by cost which is calculated by multiplying the average rent per unit of space using the average space area occupied per unit of employment (i.e. one enterprise).

The number of residents that choose zone *i* as their place of residence based on their work zones is given by the following distance-deterred formulation,

$$H(L)_{t+1,i} = H(M)_{t+1} \cdot \frac{H_{ti} \cdot \exp(\Delta V^{H}_{t+1,i})}{\sum_{i} H_{ti} \cdot \exp(\Delta V^{H}_{t+1,i})} \qquad (4)$$

where,

$H(L)_{t+1,i}$ is the increased number of households located in zone i during the time t+1;

$H(M)_{t+1}$ is the total increased number of households in the modelled area;

Hti is the total households in zone i at time t; and

ΔV_{t+1},i is the utility change of the households.

The equation is consistent with the economic theory that any increase in employment of an urban system will have multiplying effects on its population.

The Employment Location model, as a reflection of economic activities in the area, is used to determine the zonal distribution of employment. By replacing the terms of households in equation (6) with those of employment, the residential location model can be transformed into the employment location model, i.e.,

$$E(L)_{t+1,i} = E(M)_{t+1} \cdot \frac{E_{ti} \cdot \exp(\Delta V^{E}_{t+1,i})}{\sum_{i} E_{ti} \cdot \exp(\Delta V^{E}_{t+1,i})} \qquad (5)$$

where,

$E(L)_{t+1,i}$ is the increased amount of employment located at zone I;

$E(M)_{t+1}$ is the total increased amount of employment to be located in the modelled area;

E_{ti} is the total employment in zone i at time t; and

$\Delta V_{t+1,i}$ is the utility change of the employment.

3.4.2 Zonal Rent Estimation

The new activity distributions, or densities, estimated by the Location model, lead to the change of rent distribution in the area – the main factor determining the activity utilities, which is in turn used to calculate the activity distributions of the next period. The model estimates the new average rent by zone as a function of the property supply and demand, and previous rent, constrained by the minimum rent across zones, i.e.,

$$r'^{H}_{t+1,i} = \max\{r(\min)^{H}_{t}, r^{H}_{t,i} \bullet \left[\frac{\sum_{h} a^{H}_{t+1,i} \,.\, H(L)_{t+1,i}}{F(A)^{H}_{t+1,i}} \right]\} \qquad (6)$$

where,

$r'^{H}_{t+1,i}$ is the new average housing floor space rent of zone i, estimated at time t+1;

$r^{H}_{t,i}$ is the previous rent;

the coefficient α is averaged housing space occupied by one household;

F(A) is the floor space available; and

$H(L)_{t+1,i}$ is the increased number of households.

The employment floor space adjustment can be deduced in the same way.

3.4.3 Flow Diagram of the Location Model

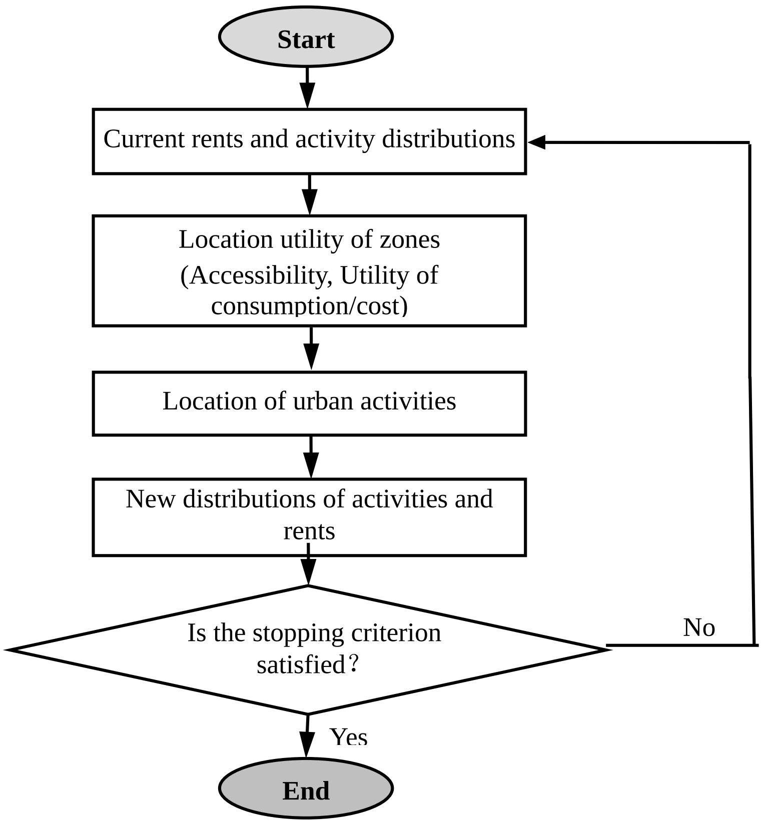


Figure 2. Flow diagram of Location model

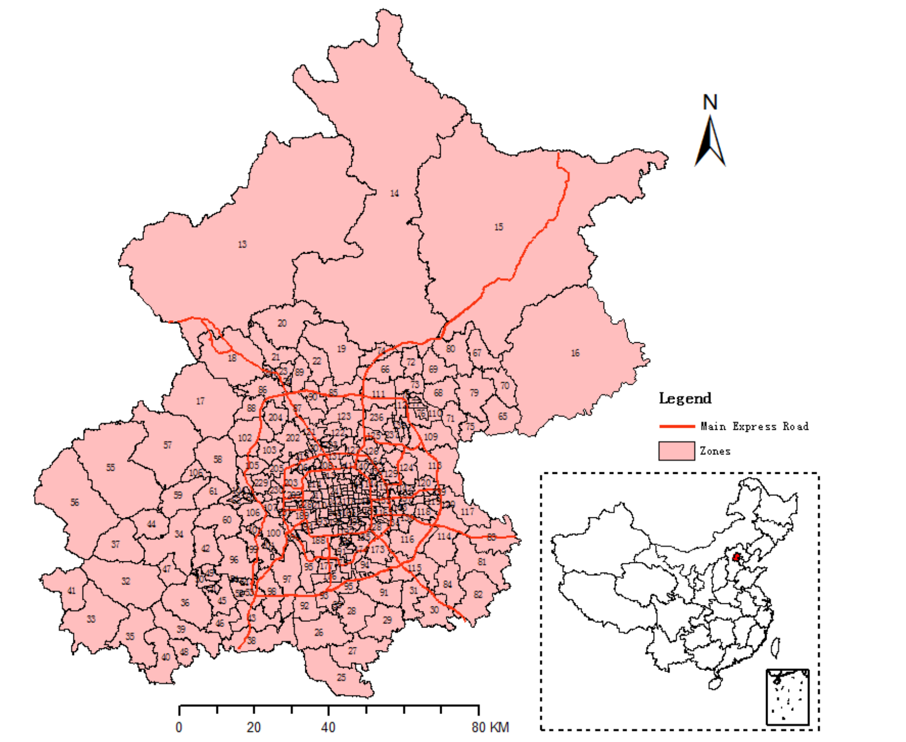
Figure 2 shows the calculation of the Location model where it first calculates the utility and activity changes by zone, based on the changes of transport accessibility and utility of consumption. Then it calculates the location of activities for new activity distributions and tests if the stopping criterion is satisfied. The model stops if the activity distribution changes between two iterations are below the predefined thresholds. Figure 2 is applied to both activities, housing and employment.

4. BEIJING CASE STUDY

4.1 Beijing Metropolitan Area

The BJLUTI model is subsequently applied to the Beijing Metropolitan Area (BMA) with an area of more than 16,410 km^2, as shown Figure 3A. As the capital of China, the BMA has experienced rapid urbanization with population growth and urban land expansion since the 1978 Country Reform and Opening-Up government policies. Its urban area is around 2,400 km^2 (495 km^2 in 1978) with a residential population of 14.91 million, as of 2010 (8.71 million in 1978). Its urban growth trend is expected to continue.

The recent Beijing City Master Plan (BCMP 2004-2020) proposes an urban spatial structure of 'two axes, two belts and polycentricity' as shown in Figure 3B. The model is applied here to test whether the current urban land-use policies are adequate to meet the polycentricity target made by the plan. There are eighteen districts in Beijing in total, among which there are four remote mountainous suburban districts, Huairou, Miyun, Pinggu, and Yanqing. We study the central urban area at the scale of townships (or so-called *jiedao*), and the remote districts at the district level. This way, 243 zones are obtained (Figure 3A).



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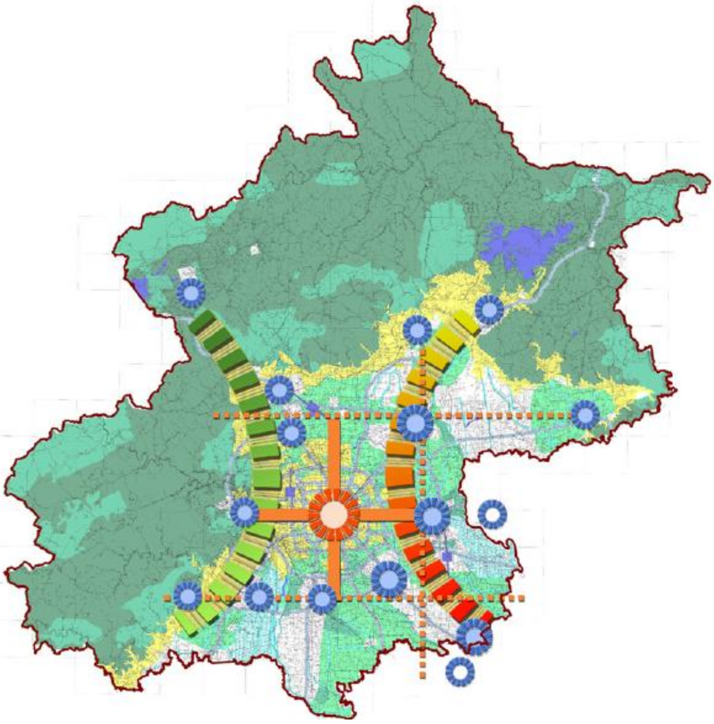


3B

Figure 3. The Planned Spatial Structure of BCMP (Source: BCMP)

4.2 Study Data

The study data comprises two parts: (1) the GIS database of traffic lines and administrative divisions obtained from the Thematic Database for the Human-earth System of the Chinese Academy of Sciences and the 1:4M database from the National Fundamental Geographic Information System of China; and (2) the socio-economic data including demographic data, average household income, floor space, and rent distributions and business distributions, sourced from the China City Statistical Yearbook (2011), China's Regional Economic Statistical Yearbook (2011), China Population and Employment Statistical Yearbook (2011), China's Sixth Census Data (2010), *Sofang* Real Estate Agent (Sofang, 2014), and the Beijing Businesses Information Survey (2011) data.

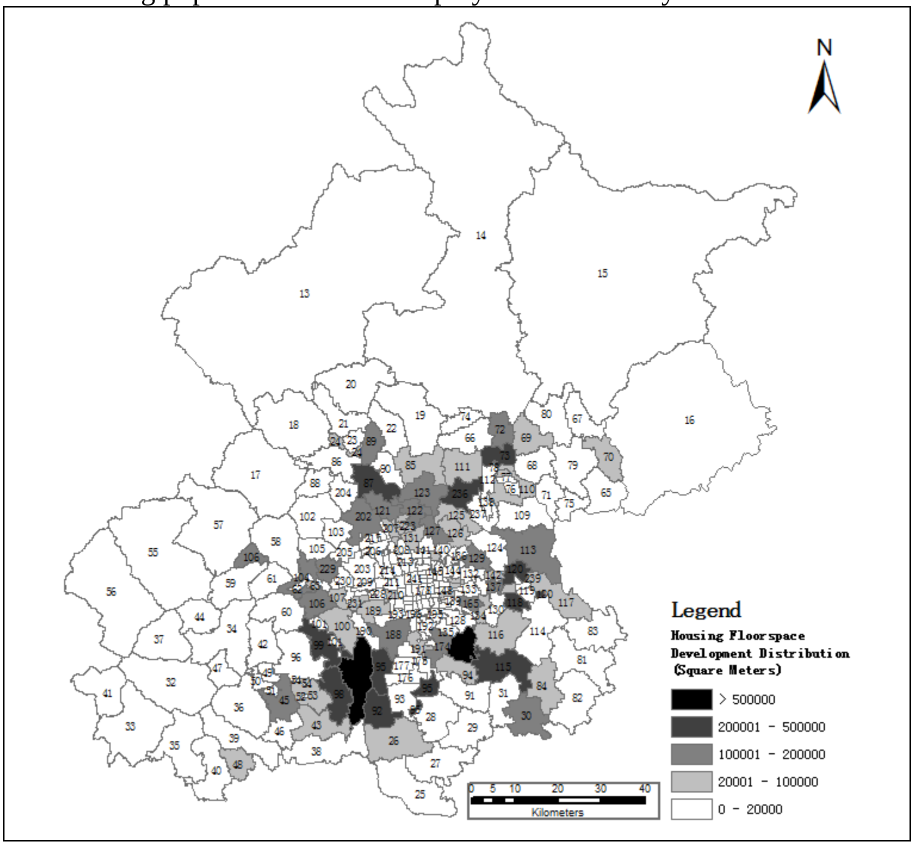
The floor space and rent data is collected from *Sofang* Real Estate Agent (Sofang, 2014), one of the most authoritative websites in publishing periodic property sale and rent prices in China. The 2010 census data used is the latest and most detailed demographic data available, including the full spatial distribution of households by generations. The Beijing Businesses Information Survey has more than 700,000 records, covering all the work units from companies and institutes to schools with respect to their locations, worker numbers and scales.

The average income is used for the household income in the model. Time cost is determined here by the distance between zones and the road type. Based on the transport network in the area, the shortest trip between each two zones is calculated and a 243*243 time cost matrix is generated. The property rent for each zone is actually determined by both the demand and supply of market and non-market factors. In order to remove the effects of non-market factors, the rent data is pre-processed to smooth the extremely high and low rent cases. In practice, the model allows the rent to vary between 0.5 and 2 times the average income. Doing it this way would allow for the majority of citizens to afford the prices; in other words, the property rent in a zone would not over-exceed the purchasing power of the citizen in that zone.

4.3 Policy Scenario

As Beijing's subway development plan currently has not been completed and there will be limited change to transport within the foreseeable future (reasonably, within five years), the modelling here concentrates on the spatial structure simulation based on the current land-use trend given an unchanged transport network.

Based on the activity categories previously defined, Beijing land-use, valued by floor space is classified into housing floor space and employment floor space. The government sells land to developers on a yearly basis with restrictions on type of floor space and the permissible degree to which each piece of land can be developed. These land sales reflect the spatial policies of the government. The model takes the average permissible floor space development from the land trade data between 2009 and 2013 as the floor space development trend. Figure 4 shows the average spatial distributions of housing and employment floor space development. The household and employment growth rates are set to 0.023 and 0.20 respectively, based on the average rates of increasing population size and employment in recent years.



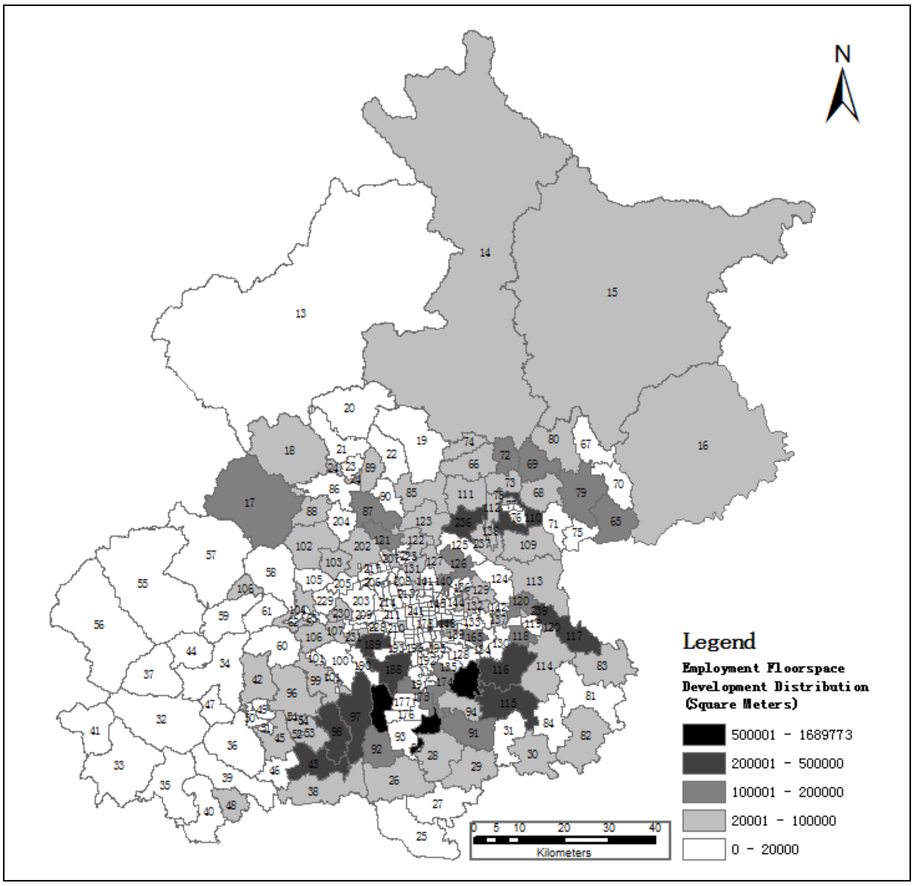
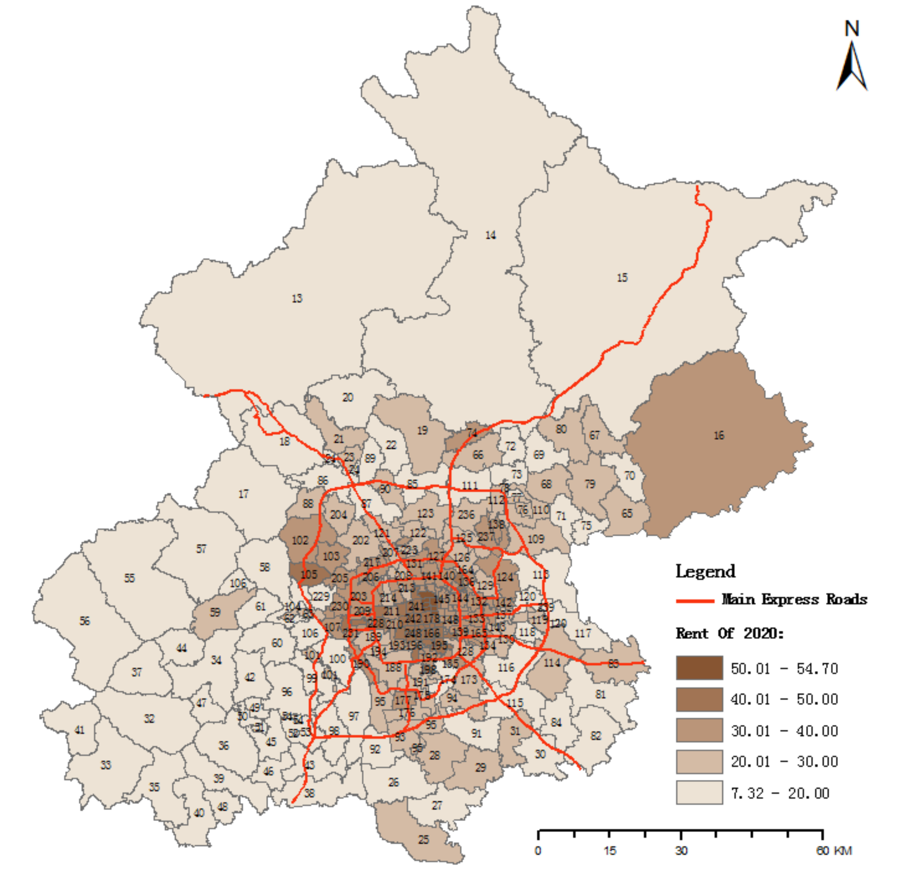


Figure 4. Development of housing and employment floor space

4.4 Rent Distribution in 2020 and the Growth Pattern

The rent distribution forecast for 2020 is shown in Figure 5. The majority of zones with higher rents are still located in the city. Although some suburban towns adjacent to the 6th Ring Road, such as the *Shisanling* (21), *Chengbei* (23) and *Chengnan* (24) clusters, and *Fatou* (25), *Datai* (59), *Beishicao* (74), Xiji (83), *Junzhuang* (105), *Airport* (138) and *Qingyuan* (177) have slightly higher rents than their surrounding areas, their spatial distribution patterns show no distinct sign of change from the current statistic. Figure 6 also demonstrates that of the four remote counties, *Yanqing (No. 13)*, *Huairou (No. 14)*, *Miyun (No. 15)* and *Pingu (No. 16)*, *Pinggu* has higher rent, largely because it is closer to the centre of the city.



A: Housing rent distribution of 2020 (Yuan/Square Meters)

Figure 5. Housing rent distribution for 2020

The rent change of a zone indicates the zone's potential to become a sub-centre, given the continuation of current development into the future. To check the difference of rent change across zones, the forecast rents in 2020 with the rents in 2010 are compared in Figure 6. It shows that housing rents in some zones decrease, partly due to government policy incentives towards the city's suburban areas. According to the household location utility maximization assumption of the model, the households will likely move to zones with lower rents, causing the decrease of their original zones' rents. This implies that developing more suburban floor space may decentralize the oversaturated activities in the city. By comparing the housing rent change pattern in Figure 6 with the housing development pattern in Figure 4, we can see that the pattern of zones with increasing rent clearly differs from the pattern of housing development. This is expected, as the rents of zones with more housing developments tend to decrease more as other variables remain unchanged. In Figure 6, there are some zones shown with black and white dots whose rents increase more significantly than the surrounding zones, which could potentially be developed into sub-centres. The BJLUTI model assumes that the transport accessibility change determines the location preference of the households, while employment rises as employment floor space is developed and subsequently the transport accessibility is improved. To develop more sub-centres, sophisticated polices towards employment increases should be enhanced.

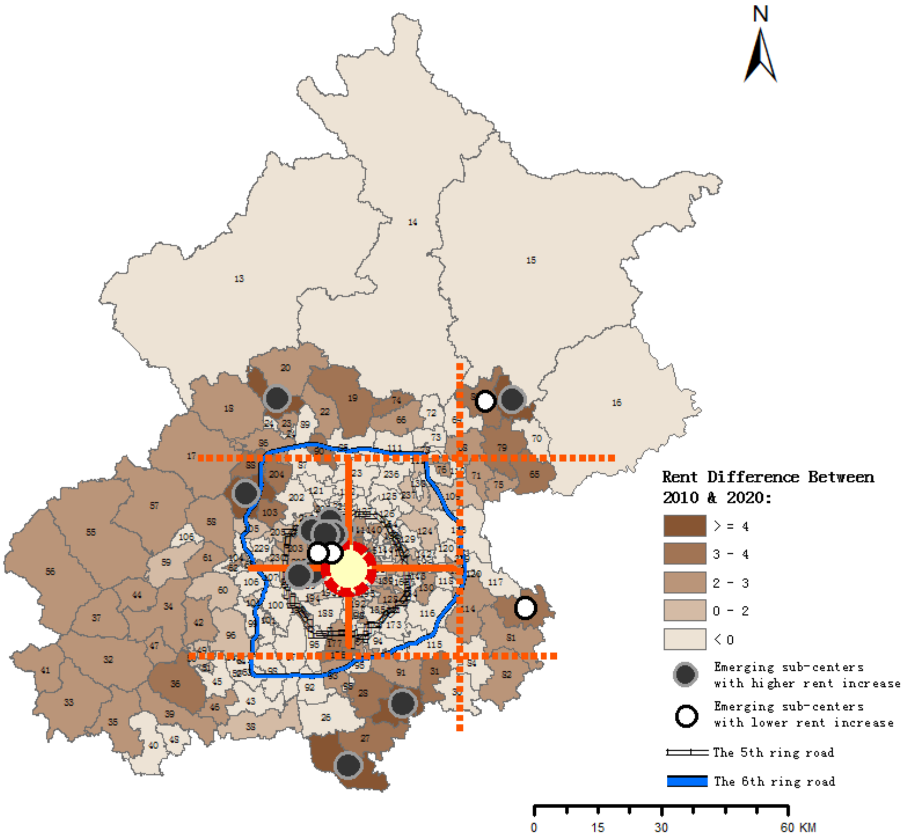


Figure 6. Housing rent change pattern between 2010 and 2020 (Yuan/Square Meters)

As the BCMP plans to develop sixteen more sub-centres by 2020 (see Figure 3), sixteen zones are grouped into two categories based on the scale of rent increases as shown in Figure 6. Zones in the first category with the highest rent increases are marked by black dots, and others are marked by white dots. Among these sixteen potential sub-centres, nine of them are inside the 5th Ring Road of the city, while the others are in the outskirts, outside the 6th Ring Road, which has a similar spatial pattern to the employment floor space development distribution shown in Figure 5. This is justified as more employment floor space will lead to more employment and ultimately increase the housing rent.

To check the extent of the planned polycentric spatial structure formation, the forecast result in Figure 6 is compared with the one planned by the BCMP in Figure 3. It shows most of the potential sub-centres forecasted are located in the outskirts, which is consistent with the plan. However, the exact locations or spatial patterns differ. Only seven potential zones outside the 6th Ring Road are a reasonable distance from the centre of the city to form a polycentric structure. Nine potential zones inside the 5th Ring Road are too close to the city centre to form polycentric-cities. As both the transport system and land use system could affect the spatial structure, in order to achieve the planned goal of sixteen sub-centres, the current policies need to be revised to develop more employment floor space and public transportation in the target locations.

The modelling results demonstrate that, given the present land-use development trend, the polycentric structure will not be formed by 2020 and the zones with the potential to become sub-centres form a very different spatial pattern from the plan. In order to reach these objectives, land-use policies need to be adjusted, accompanied by enhanced transport policies. More employment floor space development and improved transport will be critical for achieving the 2020 goal.

5. DISCUSSION AND CONCLUSIONS

Due to the lack of census data for the forecasted years, rents are used and validated against the observed data of 2014 (Sofang, 2014). The results between the two show an encouraging correlation, R^2=0.74. Appropriate data pre-processing (stated above) also plays an important role in achieving this .fit. The model states that the rent positively correlates with the income level of households. In the model, the observed rents are calculated as the household expenditure on the unit of floor space based on the household's income level, adjusted by a ratio factor, (the total household expenditure by floor space over the total floor space value), such that rents that are extremely high or low are dropped before the modelling process starts.

The nature of the present analysis has been primarily exploratory with regard to the methodology. This study develops an integrated land-use/transport interaction model to forecast housing rent distribution based on floor space development. The model is then applied to the case study of Beijing to forecast the rent distribution for 2020 and measure whether the present land-use policies can achieve the polycentric planning objective. The results show that: 1) by 2020, the polycentric spatial structure planned by BCMP will not be achieved; 2) some zones have the potential to be sub-centres based on the present land-use policies; 3) however, these zones form a different spatial distribution from those sub-centres planned by the BMCP. The results provided have implications for the government regarding how it may intervene in urban spatial development in order to achieve its goal of forming a polycentric city in the Beijing metropolitan area.

The model does not introduce any transport policies as transport systems usually change more slowly, although it is definitely within the capacity of the model to examine transport policies. The transport accessibility and generalized cost variables ensure that the BJLUTI model provides strong functionality for transport policy simulation. Meanwhile, the generalized transport cost variable provides an interface for other transport tools such as START, TRAM and TRIPS. Integration with these tools may potentially enhance the BJLUTI model's capacity to evaluate the impact of new transport interventions.

The proposed model is useful in examining current polycentric policies and forecasting urban spatial development, and could be a baseline for modellers in this area in China.-The model can also be used to simulate urban growth or other policy scenarios based on various urban strategies, through which the best scenario or policies can be identified. The next version of the model is already under development, and will include more variables, such as traffic, household categories, and green land ratio and population density. To the best of our knowledge, there are few successful precedents in China using the LUTI model of development and application. This research forms a good basis for applying quantitative LUTI models to urban planning studies in China.

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An Evacuation Simulator for Exploring Mutual Assistance Activities in Neighborhood Communities for Earthquake Disaster Mitigation

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Abstract: Japan is at great risk of being struck by huge earthquakes. When a strong earthquake occurs, various other disasters such as fire, collapsing buildings, and road blockages simultaneously occur as a result. In such a situation, it is difficult to ensure that the local emergency activities by, for example, the public fire company and community volunteers, are sufficient. Considering this issue, mutual assistance among residents, such as firefighting, evacuating victims, and helping those in need of assistance to designated safety sites, is extremely important. This paper proposes the development of an evacuation activities simulator, considering the capability of mutual assistance under various earthquake disasters to support exploration of community-based activities. In particular, the simulator calculates the time that local resident agents take to evacuate to the designated safety site, and the number of agents that can and cannot evacuate. Users can change the ratio of those who cannot evacuate to the designated safety site based on whether they are without some support or with persons who support them. Therefore, users can compare the simulation results of various outcomes. Through the experimental demonstration the following findings were obtained. Confirming the simulation results, users can understand that human suffering is reduced by mutual assistance activities. In addition, users can distinguish when the capability of mutual assistance is high or low, and when the capability of mutual assistance is changed according to the time of day due to the presence of the commuting population. Therefore, users can explore the countermeasures used to reduce human suffering when the capability of mutual assistance is low.

1. INTRODUCTION

1.1 Back ground and objective

Japan is at great risk of damage from very large earthquakes. To minimize the damage caused by earthquakes, the improvement of safety in built-up areas is an urgent issue. Although the improvement of physically built-up environments is important, improving disaster response techniques by community associations is significant for the safety of those built-up areas. To improve the capability for disaster response, enhancing self-help, mutual assistance, and public help for disaster mitigation is important.

However, an issue of concern is the increasing elderly population, who cannot evacuate without assistance from others. Another concern is that of the disastrous activities that result from earthquakes. Due to these issues, it can be difficult to ensure efficient emergency responses. Thus, mutual assistance between local residents is extremely important. To improve the capability of mutual assistance among neighborhood communities, it is necessary to develop techniques to evaluate the mutual assistance capabilities of neighborhood communities for disaster mitigation, visually display the results, and support further exploration of this topic based on the results.

This paper utilizes a simulator of evacuation activities, and this simulator is developed by using a multi-agent based model. Through the simulator, this paper considers the capability of mutual assistance under various earthquake disasters in order to explore the contents of community-based activities. As resident agents take action through mutual assistance to respond to various emergencies, the simulator calculates the time that resident agents evacuate to the designated safety site, the number of agents that can evacuate, and the number of agents that cannot evacuate.

1.2 Study method

First, to understand the issues surrounding the mutual assistance of neighborhood communities in disaster mitigation activities and the required techniques to address those issues, a survey was distributed to local government staff. Second, the detailed capability of mutual assistance was explored and evaluated to better comprehend the degree of mutual assistance capabilities and to identify areas displaying high or low capabilities of residents. Third, to explore the contents of community-based activities considering mutual assistance, a large earthquake (higher than magnitude 6 on the Richter scale) was simulated. Finally, to verify the usability of the developed simulator, experimental usage was conducted. The results of some simulations reflected scenarios in which residents performed activities related to mutual assistance, as well as cases in which they did not perform those activities. The results also showed scenarios in which mutual assistance changed according to the time of day due to the commuting population.

1.3 Related study

Very few previous studies have used an evaluation method to explore mutual assistance for disaster mitigation. Akiyama and Ogawa (2013) suggested an evaluation method to quantitatively estimate mutual assistance as the initial response ability during large earthquake disasters. However, the estimated values utilize mesh data to analyze large-scale attributes such as the urban scale. Another related study approach is model development, which simulates human behaviors such as evacuation responses to natural disaster. One of the most popular methods is using the multi-agent system (MAS). Uhrmacher and Weyns (2009) described how MAS has been used to understand the interaction among and between agents as well as their dynamic environment. For example, D'Orazio et al. (2014) proposed an innovative approach to earthquake evacuation, presenting an agent-based model to describe phases and rules of motion for pedestrians. Wagner and Agrawal (2014) presented a prototype of a computer simulation and decision support system that uses agent-based modeling to simulate crowd evacuation in the presence of a fire disaster, and provides testing of multiple disaster scenarios at virtually no cost. Takabatake et al. (2017) developed an agent-based tsunami evacuation model which considers the different behaviour of local residents and visitors, which can estimate the evacuation time, number of individuals reaching each evacuation area, the location of bottlenecks and the number of casualties. Wang et al. (2016) presents a multimodal evacuation simulation for a near-field tsunami through an agent-based modelling framework to investigate how the varying decision time impacts the mortality rate, how the choice of different modes of transportation (i.e., walking and automobile) and how existence of vertical evacuation gates impacts the estimation of casualties.

This current study is unique because it attempts the development of a simulation of evacuation activities that considers the capability of mutual assistance under various earthquake disaster scenarios. Further, this paper promotes exploring the contents of community-based activities.

2. SURVEY

To comprehend the issues related to neighborhood communities' mutual assistance in disaster mitigation activities as well as the required techniques to solve those issues, a survey distributed to local government staff was conducted. The following opinions were obtained as a result of the survey.

- If there were a map to understand the capability of mutual assistance by building units, residents would more easily understand the capability of their living area. In addition, a map may promote residents' awareness and the discussion of community-based activities for disaster mitigation.
- It is ideal that residents understand that the capability of mutual assistance is changed according to the time of day due to the commuting population.
- Local governments want to discuss urban improvement and support contents to promote the capability of mutual assistance, using methods such as those mentioned above.

Based on these responses, we think that the following two points are important for the required techniques to support issues related to mutual assistance for disaster mitigation.

1) Information in map-form to enable understanding of the capability of mutual assistance by neighborhood community; and

2) Information to promote the discussion of community-based activities for disaster mitigation considering mutual assistance activities.

To provide this necessary information, we developed a tool to calculate the capability of mutual assistance by neighborhood community, using GIS techniques and a simulator to simulate evacuation behaviors in response to earthquake disasters, including collapsing buildings, road blockages, and fire spreads. Further, to express the human suffering resulting from these simulations, a multi-agent model was required, and a support technique to address the concerns mentioned above was developed.

3. MAP DEVELOPMENT SHOWING THE CAPABILITY OF MUTUAL ASSISTANCE

3.1 Evaluation method

To evaluate the capability of mutual assistance by neighborhood communities, the evaluation method suggested by Akiyama and Ogawa (2013) was utilized. First, the expected value for the rescue of each person was calculated by using Table 1. The expected value for rescue is the numerical value showing the ability to rescue the victims (e.g., pulling a survivor from a wreckage) in accordance with gender, age and strength. This table was organized based on the actual rescue activities in the Great Hanshin-Awaji Earthquake in 1995 in Japan. For example, the expected value of a 40-year-old man is calculated by the following formula:

strength (0.93) * executing rate (0.298) * activity rate (0.72) = 0.1995

Strength: This value is calculated in accordance with age and gender based on the strength value of a man in his teens through to his twenties being set at 1.

Executing rate: This value is set in accordance with the condition of actual rescue activities in the Great Hanshin-Awaji Earthquake.

Activity rate: This value is the ratio showing residents can perform rescue activities considering the degree of daily activities.

The expected value *Rrj* of building *j* is calculated as the total of the residents' expected value at building *j*. However, in this paper, elementary school students and junior high school students have no capability for rescue. Second, the expected value is weighted by distance because of the assumption that residents take some time to discover (recognize) the person who cannot evacuate without some assistance in accordance with the distance. Therefore, the range limit in which residents can discover a person who cannot evacuate the building *i* is set at 100m. The resident's expected value is decreased with the increasing distance from building *i*. The weighted value *dwi* of building *j*, having *dj* [m] distance from building *i*, is calculated by formula (1), below. The evaluation unit of the mutual assistance capability is the building unit, based on the assumption that it is easy for residents to understand the capability.

$$dwj = \frac{1.502}{\log(1+dj)+1} \quad (0 \leqq dj \leqq 100) \quad (1)$$

$$\text{The capability of mutual assistance} = \frac{\sum Rr_j \times dw_j}{5} \quad (2)$$

Table 1. The expected value in accordance with age and gender

Age	Men's strength	Women's strength	Executing rate	Men's activity rate	Women's activity rate	Men's expected value	Women's expected value
10	1	0.85	0.228	0.76	0.24	0.1733	0.0465
20	1	0.76	0.228	0.76	0.24	0.1733	0.0416
30	0.96	0.76	0.229	0.72	0.28	0.1583	0.0487
40	0.93	0.73	0.298	0.72	0.28	0.1995	0.0609
50	0.9	0.72	0.228	0.63	0.37	0.1293	0.0607
60	0.84	0.7	0.191	0.74	0.26	0.1187	0.0348
70-	0.78	0.65	0.129	0.75	0.25	0.0755	0.021

3.2 Creating a mutual assistance map

To evaluate the capability of mutual assistance by using the evaluation method, detailed population data such as the family structure within each building and the age and gender of each resident was necessary. To obtain such detailed data, cooperation from local government and residents was also necessary. To experimentally develop a mutual assistance map, a virtual space was created.

The concept of the virtual space is as follows. Each building had one household. Young generations and elderly persons were uniformly distributed in the entire space. Residents' living space was changed according to the time of day in order to represent the commuting population. Thus, evaluating the capability of mutual assistance was conducted for each case. When calculating the capability of mutual assistance of the building at the edge of the virtual space, the buildings located outside of the virtual space were not considered. The mutual assistance value of commercial facilities was set at 0 because mutual assistance activities by commercial facility users were not anticipated as the local residents' activities were. The age structure of the whole virtual space was set based on the result of the national population census by the Ministry of Internal Affairs and Communications (MIAC) (2011). There were five types of households (one-person household, married-couple household, and two-generation households with one, two, or three unmarried children). The ratio of two-generation households with over four children is under 10 percent. In this study, therefore, the limit of unmarried children in each two-generation household was set at three.

3.3 Evaluation of the capability of mutual assistance

The capability of mutual assistance was calculated following three cases considering commuting times: 1) the morning hours, 2) afternoon, and 3) early evening. In the morning hours, all household members are in each of their buildings. In the afternoon, almost all residents in the virtual space are stay-at-home wives and elderly persons, with almost all students and workers being outside of the virtual space (commuting). The commuting rate of each age was set based on the result of national population census data. In the early evening, almost all students are back home, and almost all residents in the virtual space are stay-at-home wives, students and elderly persons.

Figure 1 shows the evaluation results. By using this map, users can distinguish the areas with low capability of mutual assistance by neighborhood community, as well as the change of capability in accordance with the time change. Thus, by using this map, residents may better understand the capability for initial response to earthquake disasters, the issues surrounding mutual assistance activities, and the necessity of mutual assistance.

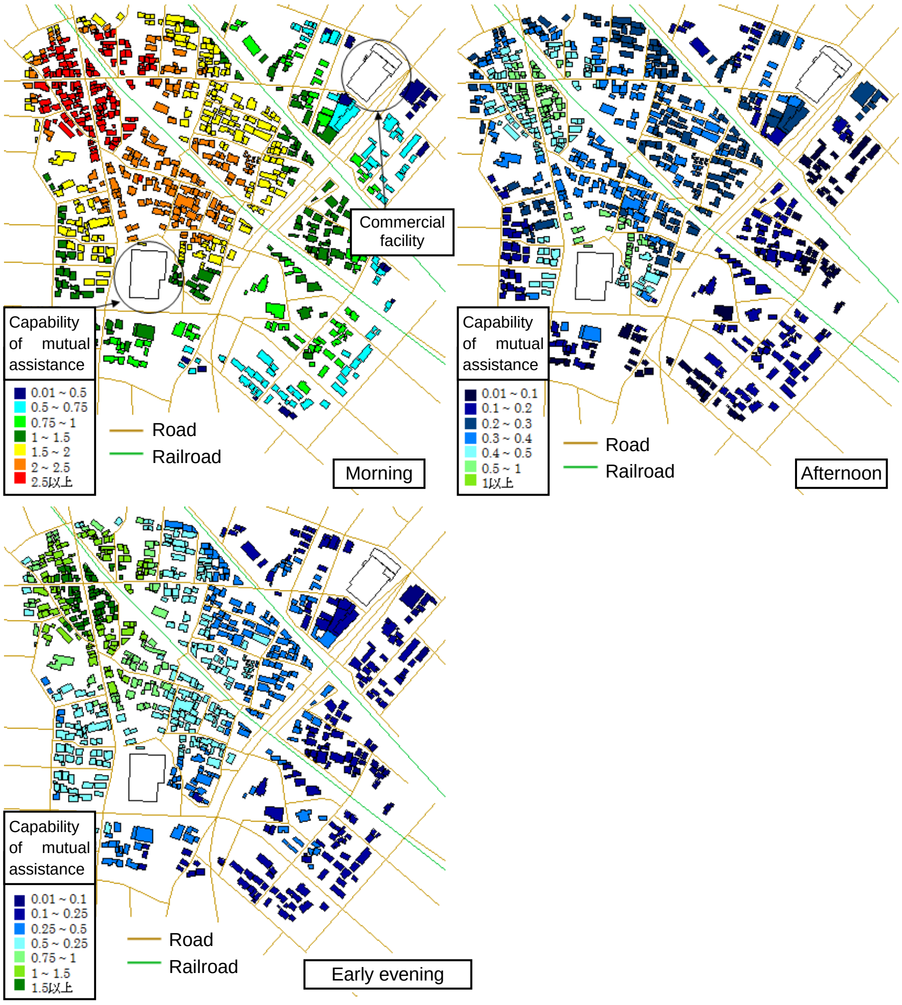

Figure 1. Maps showing the capability of mutual assistance for each time period.

4. MODEL DEVELOPMENT

4.1 Model structure in virtual space

The model was set to simulate a large earthquake (intensity higher than magnitude 6 on the Richter scale). Collapsing buildings, road blockages, and fire spreads were generated. Residents are evacuated to the designated evacuation site. Six attributes as the components of a simplified virtual urban area (urban area, roads, fire origins, fire extinguishers, rubble and the designated evacuation site) and resident agents were generated. The virtual urban space consisted of 3m by 3m grid cells.

4.2 Resident agents

One resident agent represented one person. Each agent was given an age, gender and expected value as the initial setting for beginning the simulation. The age structure, household distribution and expected value were set according to the mutual assistance map.

4.3 Road blockage model

For the road blockage model, the model proposed by Gohnai (2007) was incorporated. After setting the probability of building collapse for each building based on structure, floor number and year of construction, collapsed buildings were generated by using random numbers. When the rubble was spread on a road with a width under 0.6m, resident agents could not go through the road.

4.4 Fire spread model

The model proposed by Ohgai, Gohnai, and Watanabe (2007) was incorporated as the fire spread model. Fire origins were set by using random numbers. Users could set the wind velocity and wind direction. According to the conditions, a fire spread simulation was conducted

4.5 Behaviour of resident agents

The resident agents performed the following seven actions.

4.5.1 Evacuation

Each resident agent evacuated from each building to the designated evacuation site. In this model, middle-class children above elementary-school age (8 and older) could evacuate alone. Children less than 8 years old evacuated with his/her parent.

4.5.2 Firefighting at initial period of fire

When there was a fire origin within 100m from a resident agent, the resident agent battled the fire with fire extinguishers. After firefighting, the resident agent reinitiated evacuation.

4.5.3 Waiting for rescue

A resident agent who was buried under a collapsed building would wait for help. A resident agent who was in a burning building had no support from other resident agents because in the real world it is difficult for residents to rescue someone who delays escape from a fire.

4.5.4 Rescue victims

When resident agents discovered a victim in need of help within 100m from him/her during evacuation, he/she took part in the rescue activity. However, a resident agent with an agent older than 65 years old or a child less than 8 years old (early elementary school years) was given priority in evacuation. When the total expected value of resident agents participating in rescue activities exceeded 1, they could rescue a victim. When the total expected value was not greater than 1 after a lapse of 5 minutes from earthquake generation, the resident agent gave up rescue and restarted evacuation.

4.5.5 Those in need of evacuation support

According to the Ministry of Health Labour and Welfare (MHLW) (2014), 5% of the agents aged from 65 to 74 years old and 34% of the agents over 74 years old were set as agents who were in need of evacuation assistance.

4.5.6 Those supporting evacuation

When resident agents discovered a resident in need of evacuation support within 100m of the evacuation site, he/she provided evacuation support. However, a resident agent with an agent older than 65 years old or a child less than 8 years old (early elementary school years) was given priority.

4.5.7 Awaiting public support

In the following three situations, resident agents could evacuate even when performing mutual assistance activities. Therefore, when residents are in the following situations, they would wait on support from public institutions, such as the local fire or rescue teams:

1) A resident agent in a burning building;

2) A resident agent who cannot be rescued by another in situations where the total expected value is not greater than 1 (see Section 3.1);

3) A resident agent who cannot reach the designated evacuation site due to road blockage.

4.6 Simulation flow

Figure 2, below, shows the simulation flow. First, the virtual space was generated, and then resident agents were generated under certain conditions. Second, a large earthquake higher than magnitude 6 was generated, followed by the simulation of a road blockage caused by simulated collapsed buildings and fire spread. Third, resident agents judged their actions (evacuation, firefighting, rescue and support for evacuation). In this phase, initial firefighting by residents was simulated up to ten minutes after the fire simulation was initiated. Fourth, resident agents went to the destination he/she chose from the aforementioned options. In the case of firefighting, resident agents went to the fire origin with an extinguisher. In the case of supporting evacuation, resident agents went to the individual in need of evacuation assistance. In the case of rescue, resident agents went to assist a victim. In the case of evacuation, resident agents went to the designated evacuation site. Fifth, after finishing each mutual assistance activity, resident agents restarted the evacuation process. Finally, resident agents reached the evacuation site.

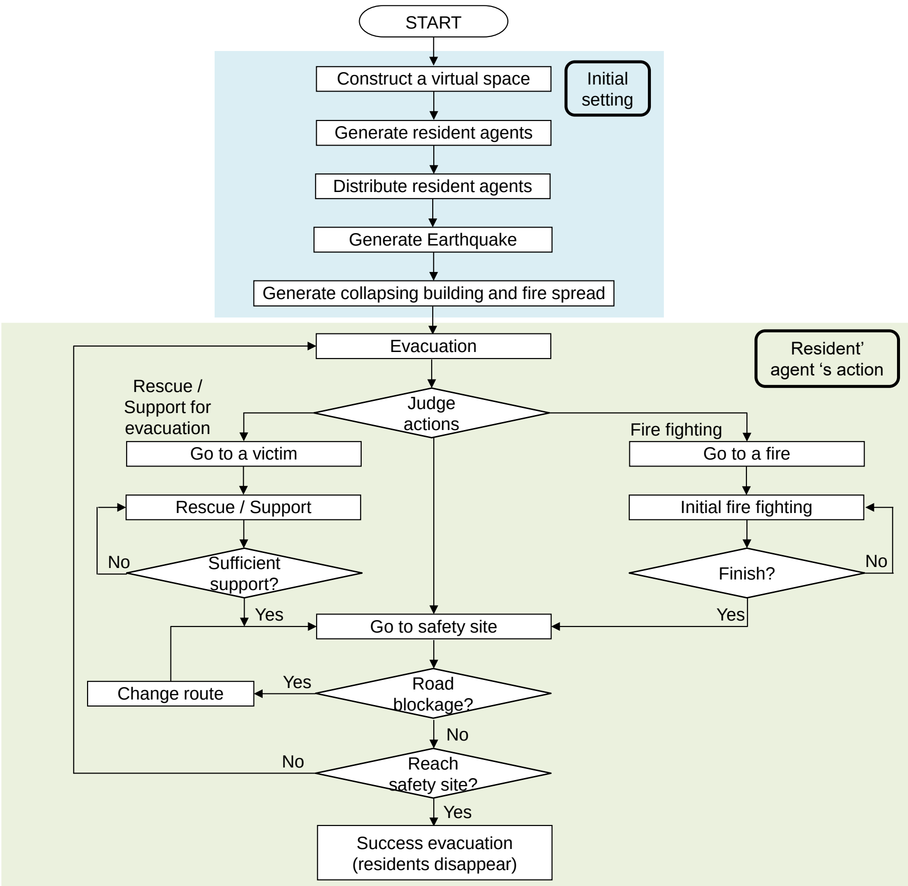

Figure 2. Simulation flow

4.7 Change of simulation conditions

As this simulator observes community-based activities for disaster mitigation, a function to change some of the simulation conditions was added. Figure 3, below, shows the pane to change the following conditions:

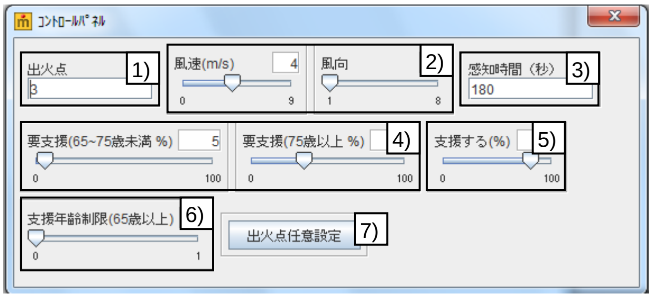

Figure 3. The pane to change simulation conditions.

1) Fire origin: The users of this simulator can set the number of fire origins in the virtual urban space.

2) Wind velocity and direction: The users can set the wind velocity from 0 m/s to 9 m/s, and set the wind direction from eight directions.

3) Waiting time: The users can set the time from earthquake generation to starting evacuation.

4) The ratio of resident agents who need some help for evacuation: The users can set the ratio of resident agents who need some evacuation assistance in the 65-year-old to 74–year-old range and the range of over 75 years old.

5) The ratio of residents who perform mutual assistance activities: The users can set the ratio of residents who perform mutual assistance activities.

6) The age limit of residents who perform mutual assistance activities: The users can set a limit that designates whether residents over 65 years old can perform mutual assistance activities or not.

7) Setting the point of fire origin: The users can set the point of fire origin freely.

5. EXPERIMENTAL USE OF DEVELOPED SIMULATOR

5.1 Perspective of evaluation

In the experimental use of the developed simulator, the following three scenarios were set: 1) The presence or absence of mutual assistance activities during evacuation; 2) The altering of the ratio of resident agents in need of evacuation assistance (this suggests the promotion of the declining birth rate and a growing population of elderly people in the future); 3) The capability of mutual assistance was changed according to the time of day caused by the commuting population.

The simulation results reflecting each scenario were evaluated following three points:

1) The time that all residents who could evacuate reached the designated evacuation site.

2) The number of residents who could reach the evacuation site.

3) The number of residents who could reach the evacuation site. This number refers to the number of residents who were waiting for help from a fire or rescue team in a collapsed or burning building, or who were on a blocked road.

The simulations reflecting each scenario were conducted ten times. After that, the average values were calculated and compared. The time it took to pull a survivor from a wreckage was not considered. The basic setting of values for simulating an evacuation are shown in Table 1. The simulation results are shown in Figure 3 and Table 3.

5.2 The presence or absence of mutual assistance activities during evacuation

Comparing the results of the scenarios, the evacuation time of all residents who could reach the evacuation site was longer when mutual assistance activities were considered than when they were not. However, the 20 resident agents who needed evacuation assistance (about 2% of the number of all residents in the virtual space) could reach the evacuation site when mutual assistance activities were considered. Following these results, users (local residents) can easily understand the effects of the mutual assistance activities. In addition, users can understand where to locate residents who cannot evacuate, as well as the disasters that cause entrapment such as collapsed buildings, road blockages, fire spreads, and a lack of neighborhood support. From these effects, users can better comprehend areas in need of improvement such as urban infrastructure or lacking mutual assistance activities. Furthermore, these results seem to promote the discussion of community-based, mutual assistance activities.

Table 3. The numerical value of simulation results

	Without mutual assistance	With mutual assistance	Over 75 years old	Over 65 years old	Morning	Afternoon	Early evening
Time [s]	574	657	621	635	657	607	630
Number of those reached	651	675	662	631	675	231	396
Number of those who could not evacuate	199	175	188	219	175	66	108

5.3 Changing the ratio of resident agents who needed evacuation assistance

Comparing the results of the residents over 75 years old who could not evacuate with the results of the residents over 65 years old who could not evacuate, the former showed 31 more residents (about 4% of the number of all residents in the virtual space) who could reach the evacuation site by mutual assistance activities than the latter. An increase in the number of residents who could not evacuate shows that rescuing all neighborhood residents who cannot evacuate by mutual assistance activities is impossible. In the future, when a declining birth rate and a growing population of elderly people are promoted, some countermeasures will be needed. In addition, this result reveals the risk to districts with a high ratio of elderly people such as local city and rural areas. Therefore, users can understand the necessity for promoting mutual assistance activities. Further, it seems that the discussion for exploring some countermeasures of community-based activities is promoted through this simulation.

5.4 Changing the timeframe

As mentioned in Section 3.3, in the morning hours, all household members are in their respective buildings. In the afternoon, almost all residents in the virtual space are stay-at-home wives and elderly persons, and almost all students and workers are outside of the virtual space (commuting), with the total population being 297 residents. In the early evening hours, almost all students are back home, almost all residents in the virtual space are stay-at-home wives, students and elderly persons, and the total population is 504 residents.

Comparing the results of the morning, afternoon and early evening hour simulations, in the afternoon, mutual assistance activities become fewer because students and workers who could contribute to the promotion of mutual assistance activities are commuting. Therefore, the ratio of the residents who could not reach the evacuation site was higher in the afternoon than in the morning hours.

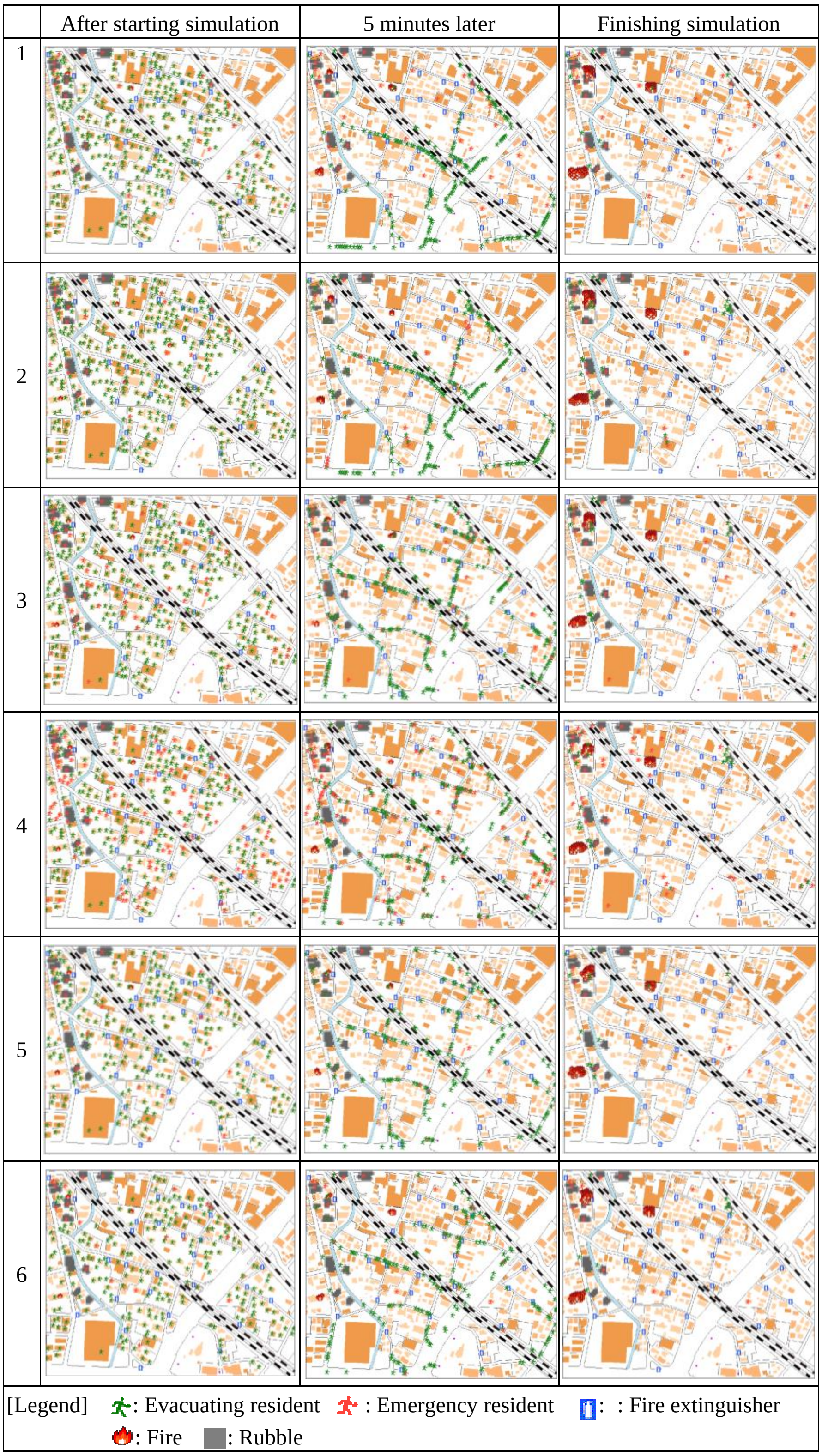

Figure 4. Simulation results

In the case of the early evening, the residents who could contribute to the promotion of mutual assistance activities increased because students had returned back home. Therefore, the ratio of the residents who could not reach the evacuation site was lower in the early evening than in the afternoon. In this way, the capability of mutual assistance activities by neighborhood was changed in accordance with the timeframe. Users can thus understand the need for countermeasures such as the promotion of mutual assistance activities for timeframes when the capability is low.

6. CONCLUSION

In this paper, simulation of evacuation activities considering mutual assistance under various earthquake disaster scenarios was developed and conducted to support exploring the contents of community-based activities by using a multi-agent based model. To verify the usability of the developed simulator to support the discussion for exploring community-based activities and mutual assistance, experimental usage was conducted. The results of some simulations reflected scenarios such as whether the residents performed activities related to mutual assistance or not, and cases wherein mutual assistance was changed according to the time of day due to the presence or absence of the commuting population.

The following results were obtained from this study:

1. Through confirming the simulation results of the case wherein mutual assistance activities by residents were not performed, users can understand the number of people that cannot evacuate to the designated safety site and the areas where there are many people that cannot evacuate.

2. Through confirming the simulation results of the case wherein mutual assistance activities by residents were widely performed, users can understand that human suffering is reduced by mutual assistance activities even when evacuation times are longer. In addition, users can distinguish between neighborhoods with high and low mutual assistance capabilities. Further, users can more fully comprehend the importance of mutual assistance. Therefore, users can explore the countermeasures to ensure there are sufficient mutual assistance activities for areas where mutual assistance capability is low.

3. Users can understand that the capability of mutual assistance is changed according to the time of day caused by the commuting population. Therefore, users can explore countermeasures to reduce human suffering in the cases where the capability of mutual assistance is low.

Users can simulate cases where the ratio of those unable to evacuate the designated safety site without some support will be increased due to population aging in the future. Therefore, users can explore both short- and long-term countermeasures to ensure sufficient mutual assistance activities.

The developed simulator provides users with information for exploring countermeasures to ensure sufficient mutual assistance activities. Therefore, the simulator is useful to explore different community-based activities considering mutual assistance activities. Improvement of the simulation model is required to reproduce more accurate mutual assistance activities, and some demonstrations in a full-scale model district is required to verify the usability of the developed tool.

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Runoff Behavior on Urban Road Intersection based on Flow Profile Simulation

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Abstract: There have been various technologies developed to solve the inundation problem that occurs in almost all urban areas. Some of these technologies, such as low impact development (LID), are developed through the concept of source control. The first step of LID practice is to know the runoff behavior on a certain surface of an area, following that, the LID practice is then designed. One of the objectives of LID is to decrease inundation depth on the road. This study aims to learn the profile and behavior of storm water flow along roads before they reach an intersection of a road system in Purwantoro region, Malang City, Indonesia. The study design consisted of field measurements and analytical activities as follows: determination of the independent and dependent variables; field measurements and data collection; simulation of flow profiles with various return periods of rainfall using Hydraulic Simulation Model HEC-RAS ver. 4.1; and verification of the simulation result of flow profiles using observation data. This research concluded that slopes on the branch road and runoff discharge on the main road significantly influenced flow depth at the road intersection. The relationship was expressed by power equations. In contrast, the runoff velocity at the branch road was more influenced by the discharge on the branch road and the main road, and the relationship followed a linear equation. A further study is required to decrease the runoff discharge on the road using LID technology such as concrete block pavement as a replacement for asphalt pavement.

1. INTRODUCTION

1.1 Background

As a consequence of urbanization, cities have undergone huge developments in order to facilitate settlements with housing, office buildings and shopping malls, roads, schools, and other public facilities. The availability of open space in urban areas decreases as a result of the development. This causes a reduction of the soil’s ability to absorb rain water, so that the runoff depth and peak discharge increases and the peak time becomes shorter (Olivera & DeFee, 2007). Therefore, urban planning should be based on a green city approach (Wikantiyoso & Tutuko, 2013).

In the last few decades, there has developed a new concept known as source control, which aims to control runoff at its source or in its surroundings (Jones, 2001). Low impact development (LID) is an alternative to source control implementation. One of the technologies associated with LID is the use of porous paving (Guillette, 2010), which is as an alternative road paving and provides many advantages (Yi, Yeo, & Kim, 2005). In particular, concrete block paving can slow surface runoff, particularly on steep slopes (Sedyowati et al., 2017). The research indicates that an increase in surface slope angle leads to an increase in friction force, so that water flowing downstream will be delayed and the inundation depth can be minimized. The first step of LID is the analysis of runoff behavior through a certain surface over a given area. Following that, the LID is then designed.

As runoff depth increases, it directly causes flooding and inundation (Harisuseno, Bisri, & Yudono, 2012). Changes in surface characteristics also have a direct impact on the characteristics of hydrology and hydro-metrology (Huong & Pathirana, 2013). Unfortunately, in Indonesia and elsewhere, increasing runoff discharge has not been followed by an improvement in the capacity of drainage systems. During every rainy season, affected major cities, particularly those in Indonesia, experienced inundation with an average depth of 20-40cm. This condition interferes with societal activity and causes problems, especially for road users.

However, the road itself can serve as a floodway (Melbourne Water Technical Working Group, 1996). Floodways are sections of roads which have been designed to be submerged under floodwater during relatively low average recurrence interval (ARI) floods (Department of Transport and Main Roads, 2010). They provide passage across a shallow depression that is subject to flooding, and they are specifically designed to resist the damaging effects of submersion (Smith, 2006).

A study conducted on some major roads in the city of Malang, East Java, found that inundation usually occurred where roads intersected at lower elevations. However, inundation did not always occur at every intersection. At junctions with larger differences of longitudinal slope, there was higher inundation. The condition was thought to be a backwater effect that resulted from the joining of two or more surface flows at the road intersection (Sedyowati et al., 2015). However, further information is required about the flow velocity and change in runoff depth along the road in order to design effective storm water management.

1.2 Problem statement

The urban drainage system in Malang and its surroundings areas has been overwhelmed by a number of problems. In spite of the fact that Malang is a plateau region, during every rainy season there are certain areas, especially at road intersections, that tend to always flood at a depth of 40-60cm , exceeding the maximum permitted depth of 30cm (Melbourne Water Technical Working Group, 1996). This condition was thought to be caused by backwater flow. The main problems this study aims to resolve are as follows:

1) What is the runoff profile upstream of a road intersection?
2) What is the runoff velocity and flow depth before the intersection?
3) How is the runoff velocity and flow depth influenced by road slope and runoff discharge at the intersection?

1.3 Objectives

The main objective of this study is to analyze the runoff profile and behavior at road intersections, with a major review of the slope factor. To achieve the main objective, this study is also designed with several specific objectives, as follows:

1) To learn the runoff profile upstream of an intersection.
2) To learn the runoff velocity and flow depth before an intersection.
3) To learn the effects of road slope and runoff discharge on runoff velocity and flow depth at the intersection.

2. LITERATURE REVIEW

In the last few decades, streets, in downtown or residential areas, have also functioned as integral components of the major drainage system when pipe and channel capacities have been exceeded (Smith, 2006). Flow velocity and flow depth limits shall be considered with regard for the safety of children and stability of cars. Car stability is significant because of the potential for increased flood levels due to floodway blockage. The recommended safety limits for road intersections are $V_{av}.d_{av}$ <= 0.35 m^2/s and d_{av} <=0.30m, (using the cross-section at the kerb on the downstream side of the intersection on the floodway route, where V_{av} is the average velocity of channel flow, and d_{av} is the average flow distance in the channel network), subject also to d_{max} < 0.30 m, measured at the intersection point of the road centerline with the crown. Floodway hydraulics may be determined using Manning's Equation (Melbourne Water Technical Working Group, 1996).

A diffusion wave numerical model was used to simulate storm water runoff at super elevation transitions. It was found that maximum ponding depth did not depend significantly on the longitudinal gradient, but the location of maximum ponding depth was very sensitive to it, moving from the outside pavement edge for small longitudinal slopes, to the center of the roadway for moderate slopes, and to the inside pavement edge for large longitudinal gradients (Charbeneau, Jeong, & Barrett, 2008). A Laser Mobile Mapping System (LMMS) made it possible to identify sinks on the roadside, i.e. locations where water flow accumulated and potentially entered the road. In addition, the method was used to analyze the surface flow over the road's surface. The new method has been demonstrated on a stretch of 153 meters along the Galician mountain road (Wang et al., 2014).

Simulating homogeneous and non-homogeneous network types to estimate the effect of road networks, and building groups with the use of a two-dimensional runoff flow model and a one-dimensional slot-model, can be used to simulate ground surface runoff flow and sewer pipe flow, showing that a non-homogeneous case could calculate more reasonable results (Lee et al., 2016). Simulation in this study is performed with the use of a KINEROS-based hydrology model, using Geographical Information Systems (GIS) software.

3. MATERIAL AND METHOD

3.1 Research Location

In this study, observation was undertaken in Purwantoro region, Malang City, Indonesia. The study area included Sulfat Highway and a road system at the Taman Sulfat residential area that had some intersections. There was a total of ten road intersection observation points located in the eastern part of the Taman Sulfat residential area. Each intersection consisted of two roads, namely Puskesmas from the north and Taman Sulfat (TS) from the west. The ten road intersections were defined as TS1, TS3, TS5, TS7, TS9, TS11, TS13, TS15, TS17, and TS19. The lowest area at the eastern part, which was the outlet of runoff for the whole study area, was around TS 13, TS 15 and TS 17. The major land cover at the study area was houses, roads equipped with drainage channels, open space covering about 10% of the study area. Formerly, the study site was farmland with an irrigation system. Along with the development of the city, the area was converted into medium density residential areas.

Figure 1 presents the situation map of the study area. It can be seen that the runoff flows from west to east and ends in the south of the eastern part of the observation area.

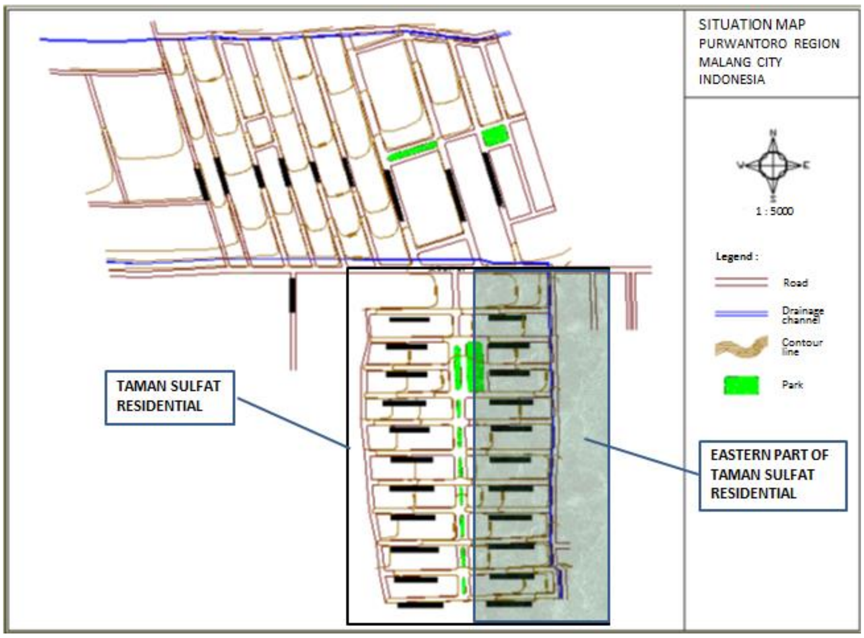

Figure 1. Situation map of the study area

3.2 Methodology

This study consisted of observation and data collection in the field, analysis of flow profiles using a hydraulic model, and development of the relationship function between road slope, flow velocity, and flow depth at various road intersections. The modelling data was then verified by the field observation data based on certain conditions in accordance with rainfall events.

The concept of flow in open channels with a wide cross-section was used to analyse the runoff flow on the road. Geometrical data of the roads included cross-sectional and longitudinal slopes. The data was obtained through direct measurements in the field. Flow profile data resulting from the backwater phenomenon included data of flow velocity and flow depth. The data was obtained using HEC-RAS hydraulic model version 4.0. Verification was done using the data model of water level observations from several rain events. The intersection observed was between a residential street and the main road in the Bhumi Purwantoro Malang housing area, which was an outlet of surface runoff.

3.2.1 Data Collection

There are two kinds of data used in this study, primary data and secondary data**.** The primary data consists of topographic maps, road geometry and inundation depths. As it was not possible to obtain a topographic map of the study area at a scale of 1: 10,000, direct measurements were taken using a theodolite. The road geometry data includes cross and longitudinal sections. Cross-section measurements were performed on each interval of 20m. Measurements of the cross and longitudinal profiles were obtained by passing water. Water level data was obtained by direct measurements at points of observation that experienced inundation during the rainy season in the study period.

The secondary data consisted of daily rainfall data from three rainfall stations, namely Abdul Rahman Saleh Station, Ciliwung Station and UB Station. Rainfall intensity data is determined from the maximum daily rainfall data analyses.

3.2.2 Calculation of runoff discharge

Runoff discharge was calculated using the Rational Method. The maximum daily rainfall at various return periods was estimated following the Log Pearson III distribution. After that, the discharge drainage system was identified based on the network of drainage systems in the study area.

3.2.3 Simulation of runoff profile

Simulation of the runoff profile, using the HEC-RAS hydraulic model version 4.1, was conducted to determine the flow profile before the intersection center. The simulation was undertaken during various return periods of rainfall at various road slopes. This step was also used to determine the length of the backwater curve from the intersection to a point upstream, so that it is possible to see the spread of inundation that occurs at the return periods for various rainfall periods and various slopes.

This activity consisted of several stages: first was the preparation of geometric data and flow rates at the various return periods of rainfall, then data input and running the program to achieve the defined boundary conditions; secondly, the hydraulic model test data was processed to obtain flow depths at the road intersection across the rainfall periods; thirdly, the calibration factor had to be determined using field measurement data and water level observations. This activity was intended to ensure that the data could be used with HEC-RAS software, and, in the case of deviations, that it could be adjusted using the calibration factor. Lastly was viewing the results. Several output features were available under the view option from the main window. These options included cross section plots, profile plots, rating curve plots, X-Y-Z perspective plots, tabular output at specific locations

(Cross Section Table), tabular output for many locations (Profile Table), and the summary of errors, warnings, and notes.

Boundary conditions were required in order to perform the calculations. If a subcritical flow analysis is going to be performed, then only the downstream boundary conditions are required. If a supercritical flow analysis is going to be performed, then only the upstream boundary conditions are required. If a mixed flow regime calculation is to be performed, then both upstream and downstream boundary conditions are required (US Army Corp of Engineers, 2010).

3.2.4 Verification of Simulation Result

Verification was conducted to ensure that the model was representative of all of the existing parameters corresponding to the basic theory. In this research, verification was performed using the data model of water level observations based on several rainfall events. Observation data was sourced from the intersection as mentioned above, particularly at the outlet of surface runoff for the entire study area. The data included rainfall intensity, rainfall duration and inundation depth at the center of the intersection. The center of the intersection was the lowest point of Taman Sulfat road at each intersection.

4. RESULTS AND DISCUSSION

4.1 Road system discharge

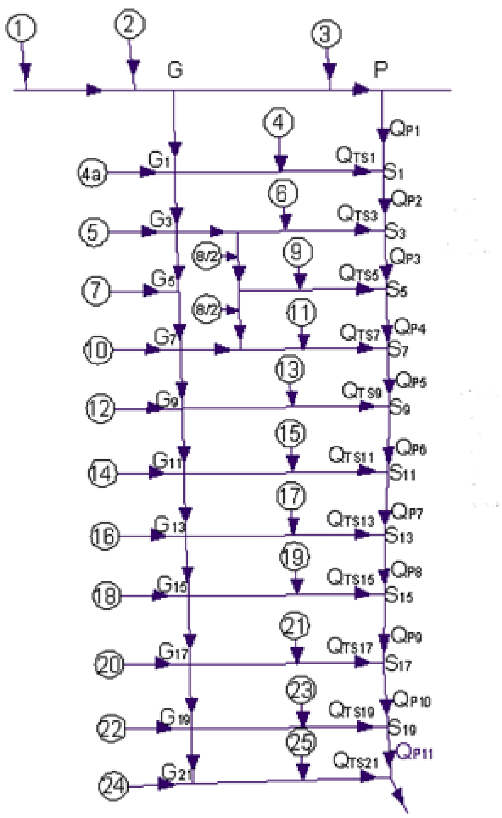

Figure 2. Road system at the study area

Based on the condition of the road network in the study area, the road system discharge network was made, as illustrated in Figure 2. First, the amount of discharge runoff that flows in each catchment was calculated. The catchment boundaries were defined as the streets in the scheme. Runoff discharge and discharge from the road system were calculated at various return periods that were 2, 5, 10, and 25 years respectively. Calculation of runoff discharge can be seen in Table 1, below. P stands for Puskesmas, which was the main road, and TS stands for Taman Sulfat, which was the branch road.

Table 1. Maximum Design Rainfall using Log Pearson III Method

Intersection Point	Road Segment	Discharge of Road System (m^3/s), in Return Period (T) year							
		2	**5**	**10**	**25**	**50**	**100**	**200**	**1000**
S1	P1	2.69	3.17	3.44	3.78	3.97	4.17	4.36	5.46
	TS1	0.69	0.81	0.88	0.97	1.02	1.07	1.12	1.40
S3	P2	3.38	3.97	4.33	4.75	4.99	5.24	5.48	6.85
	TS3	0.43	0.51	0.55	0.61	0.64	0.67	0.70	0.88
S5	P3	3.81	4.48	4.88	5.36	5.63	5.91	6.18	7.73
	TS5	0.17	0.20	0.22	0.24	0.25	0.27	0.28	0.35
S7	P4	3.98	4.69	5.10	5.60	5.88	6.18	6.46	8.08
	TS7	0.16	0.18	0.20	0.22	0.23	0.24	0.25	0.32
S9	P5	4.14	4.87	5.30	5.82	6.11	6.42	6.71	8.40
	TS9	0.39	0.46	0.50	0.55	0.58	0.61	0.64	0.80
S11	P6	4.53	5.33	5.81	6.37	6.69	7.03	7.35	9.19
	TS11	0.35	0.41	0.45	0.49	0.52	0.54	0.57	0.71
S13	P7	4.88	5.75	6.25	6.86	7.21	7.57	7.92	9.90
	TS13	0.24	0.28	0.30	0.33	0.35	0.37	0.38	0.48
S15	P8	5.12	6.03	6.56	7.20	7.56	7.94	8.30	10.39
	TS15	0.23	0.28	0.30	0.33	0.35	0.36	0.38	0.48
S17	P9	5.36	6.30	6.86	7.53	7.91	8.30	8.68	10.86
	TS17	0.26	0.31	0.34	0.37	0.39	0.41	0.43	0.53
S19	P10	5.62	6.61	7.20	7.90	8.30	8.71	9.11	11.40
	TS19	0.28	0.32	0.35	0.39	0.41	0.43	0.45	0.56
	P11	5.89	6.94	7.55	8.29	8.70	9.14	9.56	11.96

Discharge from the road system was determined by adding the discharge runoff captured by each road, corresponding to the lane of the road network. Table 1 can be explained as follows: at road intersection point S15, between P8 and TS 15 segments, the runoff discharges were significantly different. Runoff on the Puskesmas road was 2.5 times larger on average than on the Taman Sulfat road. Therefore, Puskesmas road served as the main channel and Taman Sulfat road served as the tributary. This condition also applied to other intersections.

4.2 Simulation data

Table 2 presents the datafrom the Hydraulic Simulation Model HEC-RAS ver. 4.1 with the 2-year flood design. The data was taken from five intersections in the downstream part of the road network system that represented the higher inundation. The intersections chosen were also at the lowest area where all runoff from the upper area at the Purwantoro region (Figure 1) accumulated.

The data in Table 2 was sorted from downstream to upstream. Table 2 indicates that the intersection on Puskesmas 10 and Taman Sulfat 17 had the largest flow depth and lowest velocity, and the Froude number was almost the same as the intersection on Puskesmas 11 and Taman Sulfat 19. Road slope data was calculated by using bottom elevation data; according to that data, it seems that runoff velocity and flow depth might be influenced by road slope and runoff discharge.

Table 2 also indicates that the runoff discharge on the main road was much greater than the discharge on the branch road. The runoff on the main road slowed the flow from the branch road to the main road, especially at the intersection located at the end of the main road, where the discharge was greatest and its flow depth was at its maximum.

Table 2. Simulation data at five intersections with higher inundation with 2-year flood design

Road segment	Section	Discharge (m^3/s)	Bottom elevation (m)	Water level elevation (m)	Water depth (m)	Velocity (m/s)	Froude number
Puskesmas 11	35	8.29	440.73	441.24	0.51	1.21	0.56
Puskesmas 11	34	8.29	440.58	441.01	0.43	1.38	0.71
Puskesmas 11	33	8.29	440.33	440.80	0.47	1.28	0.62
Tmn Sulfat 19	12	0.39	440.73	441.32	0.59	0.09	0.04
Tmn Sulfat 19	6	0.39	440.39	441.32	0.93	0.05	0.02
Tmn Sulfat 19	1	0.39	440.13	441.32	1.19	0.03	0.01
Puskesmas 10	32	7.90	440.79	441.43	0.64	1.10	0.44
Puskesmas 10	31	7.90	440.75	441.36	0.61	0.92	0.38
Puskesmas 10	30	7.90	440.74	441.25	0.51	1.13	0.52
Tmn Sulfat 17	12	0.37	440.96	441.49	0.53	0.09	0.04
Tmn Sulfat 17	6	0.37	440.52	441.49	0.97	0.05	0.02
Tmn Sulfat 17	1	0.37	440.25	441.49	1.24	0.04	0.01
Puskesmas 9	29	7.53	440.88	441.58	0.70	1.10	0.44
Puskesmas 9	28	7.53	440.84	441.51	0.67	0.97	0.39
Puskesmas 9	27	7.53	440.79	441.43	0.64	1.03	0.43
Tmn Sulfat 15	12	0.33	441.27	441.64	0.37	0.13	0.07
Tmn Sulfat 15	6	0.33	440.89	441.64	0.75	0.06	0.02
Tmn Sulfat 15	1	0.33	440.78	441.64	0.86	0.05	0.02
Puskesmas 8	26	7.20	441.04	441.70	0.66	0.71	0.29
Puskesmas 8	25	7.20	441.01	441.66	0.65	0.74	0.30
Puskesmas 8	24	7.20	440.92	441.58	0.66	1.13	0.46
Tmn Sulfat 13	12	0.33	441.52	441.74	0.22	0.19	0.14
Tmn Sulfat 13	6	0.33	441.17	441.73	0.56	0.08	0.04
Tmn Sulfat 13	1	0.33	440.95	441.73	0.78	0.06	0.02
Puskesmas 7	23	6.86	441.30	441.87	0.57	0.93	0.39
Puskesmas 7	22	6.86	441.19	441.78	0.59	1.01	0.46
Puskesmas 7	21	6.86	441.09	441.69	0.60	1.00	0.44
Tmn Sulfat 11	12	0.49	441.83	441.93	0.10	0.37	0.43
Tmn Sulfat 11	6	0.49	441.37	441.91	0.54	0.12	0.05
Tmn Sulfat 11	1	0.49	441.09	441.91	0.82	0.08	0.03

4.3 Flow depth characteristics

Figures 3(a), (b) and (c) show the cross sectional plot of the road intersection obtained from the Hydraulic Simulation Model HEC-RAS ver. 4.1. The road intersection was in the downstream part of the road network, namely Taman Sulfat 15. The plot describes three points of flow depth at the branch road (tributary), namely RS 12, RS 6 and RS 1, where RS 12 was the upper part. It can be seen that towards the downstream direction, the flow depth increased gradually and the flow profile formed a backwater curve.

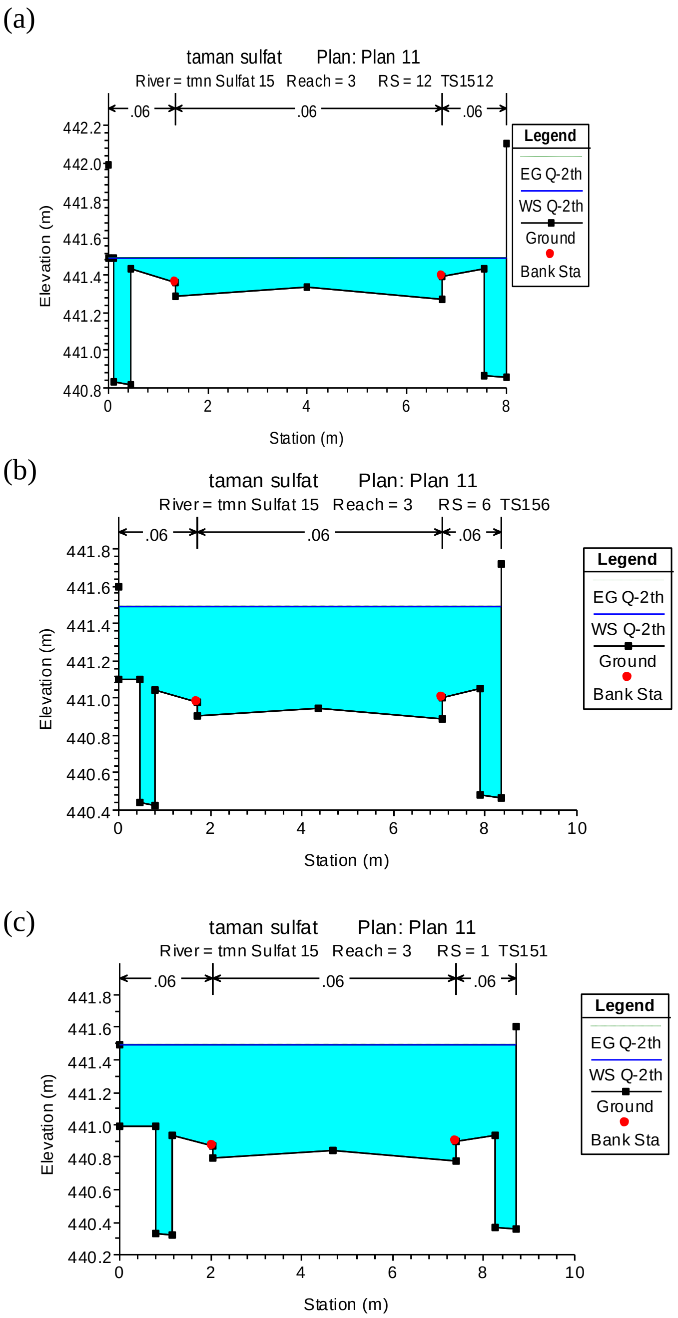

Figure 3. Cross sectional plot of the road intersection at Taman Sulfat 15

The water surface elevation at the three points (Figure 3) were almost all the same. It indicated that the runoff flow from Taman Sulfat was influenced by the runoff flow from Puskemas (the main road). It meant that the flow depth at the main road was greater than at the branch road. It also indicated that the main road delivered runoff from other catchment areas at the upper end of the observation site.

4.4 Runoff velocity behavior

There were two series of velocity data at each intersection. The first set of data was collected at points along the main road, whereas the second set of data was collected at three points along the branch road. Table 2 shows the velocity data at the main road, namely Puskesmas, and the velocity data at the branch road, namely Taman Sulfat. It can be seen that along the branch road the velocities do not always reach close to zero at every intersection. This means that a backwater curve occurred only on some road intersections with certain criteria. In contrast, the velocities recorded on Puskesmas road were much greater than at the branch road. This phenomenon was caused by the difference in the runoff source; at the branch road, the source was from local rainfall, while at the main road (Puskesmas road) the source was not limited to local rainfall. The major runoff was from other catchments at the upper end of the Taman Sulfat residential area. This happened because there was no source control on those locations. Runoff was flowing down to the lower area through Puskesmas road, which served as a huge channel.

In line with the velocity, the Froude number had similar characteristics. The Froude number at the center of the intersection was close to zero. This showed that the flow from the direction of the branch road had stagnated and was not flowing properly. While the Froude number at the main road was greater, it remained a subcritical flow.

4.5 Analyses of road slope at intersection

As mentioned above, road slope at intersections was calculated by subtracting water level elevation from bottom elevation, and was then divided by the distance between the two points. The results are presented in Table 3.

Table 3. Road slope at five intersections in lowest area

Road segment	**Average slope**	**Road segment**	**Average slope**
Puskesmas 11	0.0188	Tmn Sulfat 19	0.0066
Puskesmas 10	0.0029	Tmn Sulfat 17	0.0067
Puskesmas 9	0.0048	Tmn Sulfat 15	0.0045
Puskesmas 8	0.0052	Tmn Sulfat 13	0.0055
Puskesmas 7	0.0089	Tmn Sulfat 11	0.0081

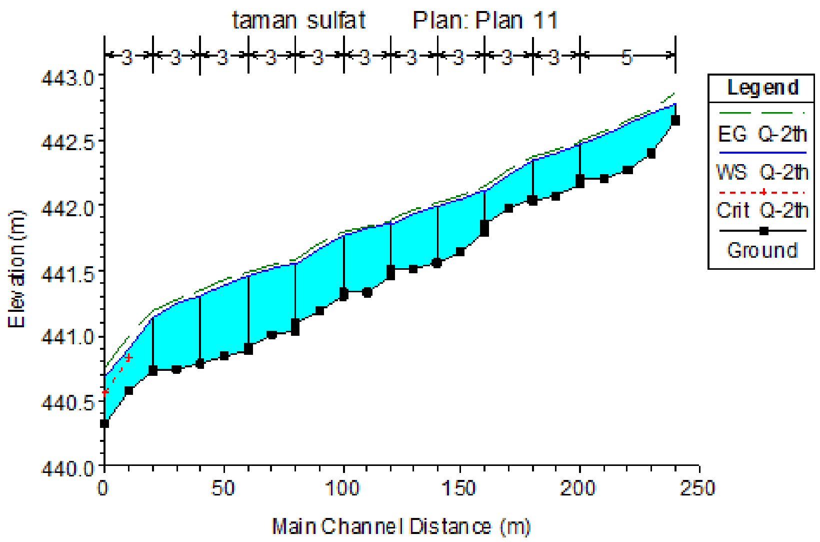

Figure 4. Long section of the main road

Table 3 indicates that there is no specific trend of the slope from the upper to the lower area. The road slope describes the topographical condition of the observed area. Slopes on the branch roads were almost all the same, and were categorized as mild slopes. However, on the main road, the slope slightly fluctuated. In segments Puskesmas 11 and Puskesmas 7, the slopes were steeper than for the other segments which were almost flat. It seems that greater slope led to an increase in the Froude number. Figure 4 below describes the long section of main road and the configuration of the road.

Figure 4 indicates that there was no backwater curve along the main road. At the end of the road there was a steeper slope which led to a drawdown profile.

4.6 Relationship between road slope, runoff discharge, runoff velocity and flow depth

Based on all the data presented in the tables above, the relationship between all parameters were then analysed using the coefficient of correlation, coefficient of determination, and regression analyses. Table 4 and Table 5, below, show the correlation coefficient and determination coefficient between all parameters. It can be seen that the flow depth of the branch road at the intersection was significantly influenced by the discharge at the main road, and by velocity at the main road and branch road. However, the magnitude of the flow depth can be estimated using the slope of the branch road and discharge on the main road. The relationship was expressed by a power function as shown in Equation 1. The R-square was 0.90 and the standard error was 0.09.

Runoff velocity on the branch road at the intersection was significantly influenced by runoff discharge on the main road and the branch road, and by flow depth at the branch road. The relationship was expressed by a linear function as shown in Equation 2. The R-square was 0.99 and the standard error was 0.009. The magnitude of runoff velocity on the main road was significantly influenced by the slope ratio between Puskesmas road and Taman Sulfat road, and by the runoff discharge of Puskesmas road. The relationship was expressed by a linear function as in Equation 3, shown below.

Table 4. Correlation coefficient of all parameters

	Ratio 1	Ratio 2	Slope 1	Slope 2	Q1	Q2	H1	U1
Ratio 1	1.00							
Ratio 2	-0.80	1.00						
Slope 1	0.06	0.11	1.00					
Slope 2	-0.75	0.98	0.32	1.00				
Q1	-0.17	0.14	0.91	0.33	1.00			
Q2	0.01	0.54	-0.17	0.47	-0.36	1.00		
H1	0.34	0.29	0.23	0.32	-0.04	0.87	1.00	
U1	-0.19	-0.24	0.53	-0.11	0.72	-0.90	-0.70	1.00

Table 5. Determination coefficient of all parameters

	Ratio 1	Ratio 2	Slope 1	Slope 2	Q1	Q2	H1	U1
Ratio 1	1.00							
Ratio 2	0.64	1.00						
Slope 1	0.00	0.01	1.00					
Slope 2	0.57	0.95	0.10	1.00				
Q1	0.03	0.02	0.83	0.11	1.00			
Q2	0.00	0.29	0.03	0.22	0.13	1.00		
H1	0.11	0.08	0.05	0.10	0.00	0.76	1.00	
U1	0.04	0.06	0.28	0.01	0.52	0.81	0.49	1.00

where,

Ratio 1 (R1) Slope 1/slope 2

Ratio 2 (R2)	Slope 2/Slope 1
Slope 1 (S1)	Slope of branch road
Slope 2 (S2)	Slope of main road
Q1	Discharge of branch road
Q2	Discharge of main road
H1	Flow depth of branch road
U1	Velocity of branch road
U2	Velocity of main road

The formulas for estimating flow depth and flow velocity at intersections are as follows:

1) Formula of flow depth on the branch road at intersection
$$H1 = 0.03(S1)^{0.4}(Q2)^{2.7184} \qquad \text{Equation1.}$$

2) Formula of flow velocity on the branch road at intersection
$$U1 = 0.497 + (0.378(Q1)) - (0.072(Q2)) \qquad \text{Equation 2.}$$

3) Formula of flow velocity on the main road at intersection
$$U2 = (0.085(R2)) + (0.158(Q2)) - 0.257 \qquad \text{Equation 3.}$$

The equations above show that runoff on the main road significantly influenced both the flow depth and flow velocity on the branch road and on the main road. To reduce the rate of runoff, especially on the sloping road, paving blocks can be used to replace the standard asphalt pavement (Sedyowati et al., 2017).

5. CONCLUSIONS

There was a backwater profile on the branch road at the intersections in which the discharge on the main road was about twenty times greater than on the branch road. However, there was no backwater profile on the main road.

Runoff velocity on the branch road was close to zero. There was a retardance factor when the flow from the branch road flowed to the main road. This factor was led by the greater discharge on the main road. Flow depth on the branch road increased gradually from upstream to downstream before reaching the intersection point.

Flow depth at the road intersection was significantly influenced by the runoff discharge on the main road and slope on the branch road. The relationship was expressed by a power function equation, whereas the runoff velocity at the branch road was more influenced by the discharge on the branch road and the main road, and the relationship followed a linear function.

Further study is required to decrease the runoff discharge on the road using LID technology, such as concrete block paving as a replacement for the asphalt paving. Using this technology, the runoff can be controlled at its source and in its surroundings.

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Willing to pay more for high-quality schools?

A hedonic pricing and propensity score matching approach

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Abstract: Principally, the enrolment of elementary school in China is solely based on residential location. Due to the scarcity of prestigious schools, the household registration (or *hukou* in Chinese) and the territorial-based school admission policy, a feasible approach for parents to provide the children with good education is to purchase the house in the attendance zone of a high-quality school (or *xuequfang* in Chinese). The supply-demand imbalance gives rise to the *xuequfang* phenomenon (much higher prices of *xuequfang* relative to non-*xuequfang)*. Based on 1250 housing samples in 286 multi- or high-storey residential districts, this paper firstly develops two basic and four Box-Cox transformed hedonic price models to estimate the effect of high-quality schools on residential property prices. The consistency of six models greatly enhances the credibility of this study. Moreover, complementary, the propensity score matching technique is used to estimate the treatment effect. The two methods consistently suggest that residential property values are affected by top-tier schools. They reveal that *xuequfang* exhibit values that are between 9.3% and 12.1% higher than non-*xuequfang*, *ceteris paribus*. The negative influences of the *xuequfang* phenomenon and several countermeasures (gradually reforming household registration system, optimizing resource distribution to balance the quality of education, highlighting family education and children's all-round development) are discussed.

1. INTRODUCTION

Education, work and retirement, are three stages of our life. Education is the foundation of a nation and is closely related to the overall quality of citizens as well as the long-term development of a nation. The importance of education to individuals and a state has been universally recognized.

"Residential property is a multidimensional commodity, characterized by durability and structural inflexibility as well as spatial fixity" ((So, Tse, & Ganesan, 1997), p.40). It is distinguished by a number of characteristics (e.g., size, age, transport accessibility), some of which would influence its price. Understandably, high-quality educational resources are unevenly distributed due to scarcity. They would, in theory, affect residential property prices positively. A number of parents tend to live in the properties near attractive schools for access to high-quality education. As a result, they are willing to pay higher prices for those dwelling units, a portion of which are parents' investment in their children's future.

1.1 School and housing prices in the Western context

School quality has been long perceived as a crucial determinant of residential property prices. The externality of prestigious schools has been found to be capitalized in housing prices (Black, 1999; Clapp, Nanda, & Ross, 2008).

How to identify high-quality schools? Western researchers have introduced a number of judging criteria, such as educational outcomes (test scores or pass rates), school expenditure, earning as well as student–teacher ratio.

There is a wide range of previous literature concerned with the capitalization benefits of leading schools in the Western context. Hayes and Taylor (1996) validated a common wisdom: neighborhood school was an important locational attribute associated with residential property price. Black (1999) pointed out that the estimation without sufficiently controlling for neighborhood attributes would overstate the influence of prestigious schools because better schools tended to be located in better neighborhoods. For this reason, he proposed a novel approach (i.e., boundary fixed effect method), compared the prices of properties located on opposite sides of attendance district geographic boundaries, and confirmed parents' willingness-to-pay for prestigious schools. Sedgley, Williams, and Derrick (2008) presented consistent and strong evidence of the capitalization of test scores and demonstrated that properties within good school attendance zones were more expensive than those not situated in these areas. Using panel data of housing transactions in the state of Connecticut spanning eleven years, Clapp, Nanda, and Ross (2008) ascertained the relationship between property values and school attendance zone attributes and supported Black (1999)'s argument that failing to control for unobservable components of neighborhood quality would result in an overestimation of the test score's effect on residential property values.

1.2 School and housing prices in the Chinese context

In China, the entrenched traditional thought of "expectations for their children (or *wangzichenglong* in Chinese)" places education on a more important position in the mindsets of most of the parents. That is, both historically and currently, people have a particular interest in investing in the children's (even grandchildren's) education which is thought to help retain social capital (Wu, Q. et al., 2014). Due to fairly fierce social competition, education has become an important means to enhance competitiveness and pursue social capital, which eventually enhances career prospects.

Principally, the admission policy of public elementary school is territorial-based, meaning that a school enrolls school-age children based on school attendance zone. In other words, in most cases, restricted by household registration (or *hukou* in Chinese), only the children of the owners (rather than the tenants) of properties located in the attendance zone of school A are entitled to be enrolled in school A. A child's elementary school is determined by the location of parents' *hukou* (Wu, Q., Zhang, & Waley, 2016). Fettered by this, school-age children cannot freely attend primary schools in accordance with their parents' willingness. Today, family investment in education shows a very distinctive feature, that is, buying a residential property in the attendance zone of a prestigious school. In order to offer their children the access to high-quality schools, parents strive to pay higher prices to purchase a *xuequfang*. Purchasing a *xuequfang* becomes the most common approach for better education. The *xuequfang* phenomenon, which refers to much higher prices of *xuequfang* relative to non-*xuequfang*, has become a focus of the society. In this study, the *xuequfang* phenomenon refers to the economic aspect of *jiaoyufication*, a new form of gentrification around high-quality schools (Wu, Q. et al., 2014). *Jiaoyufication* has much broader meanings. More distinctive characteristics of *jiaoyufication* (e.g., small household size, high proportion of school-age children, female and old adults, well-off middle-class parents, high residential mobility, low interest in housing refurbishment and neighborhood improvement) can be found in (Wu, Q. et al., 2014; Wu, Q., Zhang, & Waley, 2016, 2017; Wu, Q., Edensor, & Cheng, 2017).

Most pertinent literature concentrated on discussing and analyzing the *xuequfang* phenomenon from the perspectives of sociology, pedagogy or economics (Chen & Tang, 2009; Wu, X., 2006). Relatively little research attention, to date, has been paid to empirically estimate the magnitude of the willingness-to-pay for highly regarded schools. Existing studies were found in a few cities: Beijing (Huang, 2010; Hu, Zheng, & Wang, 2014), Shanghai (Feng & Lu, 2010; Shi & Wang, 2014), Nanjing (Wang, X., Ge, & Zhang, 2010) and Tianjin (Wang, W. et al., 2014; Wang, Z., Mei, & Wang, 2014). Moreover, many of them suffer from a few drawbacks, which reduces the credibility to some degree, such as unsatisfactory explanatory power (low goodness-of-fit) (Nie, 2011; Wang, X., Ge, & Zhang, 2010; Wang, W. et al., 2014), inadequate control variables (Wang, W. et al., 2014) and limited sample size (Wang, W. et al., 2014).

Recently, a few studies have provided empirical cases in China with a more reliable explanation (Hu, Zheng, & Wang, 2014; Shi & Wang, 2014; Wang, Z., Mei, & Wang, 2014; Wen, Zhang, & Zhang, 2014; Jayantha & Lam, 2015). Using data (N=1172) from a housing agency website (*soufang*), Shi and Wang (2014) discussed the impact mechanism of the *xuequfang* phenomenon in Shanghai and found that school factors accounted for 20.6% of the variability in residential property prices. They concluded that housing prices declined by 8.7% with a drop in the level of school grade. Hu, Zheng, and Wang (2014) applied the boundary fixed effect method proposed by Black (1999) to control for neighborhood attributes, and used matching regression techniques to mitigate the omitted variable bias caused by unobservable neighborhood attributes. They reported that the prices of *xuequfang* are 8.1% higher in Beijing. Wang, Z., Mei, and Wang (2014) identified the capitalization of basic educational resources based on the second-hand housing data (N=1700) in Heping District, Tianjin, and reported that an increase of elementary school quality led to an 14.7% increase in housing prices. Using the housing data of 660 communities in Hangzhou, Wen, Zhang, and Zhang (2014) and Wen, Xiao, and Zhang (2017) examined the capitalization effect of the education quality on housing prices, and found that the quality of primary and secondary schools has been capitalized in the surrounding housing prices.

1.3 Research objectives, contributions and paper outline

In this study, based on 1250 housing samples in 286 multi- or high-storey residential complexes in Xiamen Island, China, we develop a set of hedonic price models, more specifically, two basic and four Box-Cox transformed models to answer this question: are there capitalization benefits derived from high-quality schools in Xiamen Island, if so, what is the magnitude? Then, we discussed negative influences of the *xuequfang* phenomenon and proposed several countermeasures.

The main contributions of this paper are: *(1) adding a reliable empirical study in the Chinese context about the quantitative valuation of high-quality schools to previously sparse literature; (2). comparing the performance of pre-specified functional forms with that of Box-Cox transformed models and revealing the great power of the Box-Cox transformation; (3). using propensity score matching technique to estimate the effect of high-quality school on housing prices; (4). shedding light on the mechanism of the xuequfang phenomenon and proposing some tentative countermeasures.*

The remainder of this paper proceeds as follows. Section 2 introduces hedonic price model, Box-Cox transformation and propensity score matching. Section 3 presents the study area, data and variables; Section 4 presents the modeling results based on two pre-specified and four Box-Cox transformed functional forms, and further checks the plausibility of our key findings using propensity score matching. Section 5 discusses the negative influences of the demarcation of school attendance zone, and proposes some tentative countermeasures. Section 6 puts forward conclusions and further research directions.

2. METHODOLOGY

2.1 Hedonic price model

2.1.1 Introduction

From the perspective of the demand side of goods, hedonic price model is a celebrated method to appraise the determinant factors on prices of heterogeneous goods and estimate the implicit prices of attributes (Malpezzi, 2003). Hedonic prices are the implicit values of the attributes of a product, which can be empirically estimated from a multivariate regression equation.

Hedonic price model assumes that, in equilibrium, all consumers with identical preferences can achieve the same level of utility, which is measured as the price a person is willing to pay for the fulfillment or satisfaction of his/her desire. Lancaster (1966) defined utility in terms of the attributes of the goods and stated that what consumers are seeking to acquire is the characteristics embodied in the goods instead of goods themselves. In other words, a property is sold as a package of inherent attributes. Rosen (1974) presented that under the conditions of full market competition, the objectives of producers and consumers are to maximize profit and utility, respectively, and unfolded how markets work for heterogeneous goods.

Normally, the variables incorporated into hedonic price model can be categorized into three categories: structure, location, and neighborhood. Structure variables relate to the direct attributes of a property (e.g., floor area, age, number of bedrooms and bathrooms). Location variables reflect the ease with which amenities can be reached from a property (e.g., distance to city center, shopping center and hospital). Neighborhood variables describe the surrounding area of a property (e.g., income, education level, crime rate, and proximity to attractive school).

Hedonic price model explains the prices of properties in terms of their own characteristics, which are assumed to be implicitly priced. It has been widely used to estimate the implicit values of characteristics of properties and evaluate the contributions of a wide variety of factors, for instance, educational facilities (Sedgley, Williams, & Derrick, 2008), shopping centers (Des Rosiers et al., 1996; Tse & Love, 2000), hospitals (Peng, B. et al., 2015; Yang et al., 2016), public transportation (Cervero & Duncan, 2002; Armstrong & Rodriguez, 2006), green space (Luttik, 2000; Acharya & Bennett, 2001; Kong, Yin, & Nakagoshi, 2007), and population density (Geoghegan, 2002).

Recently, the rapid development of geographic information systems (GIS) has made hedonic price modeling more powerful because "spatial statistics within a GIS, based on digitized remote sensing data, have made possible the development of accurate, consistent, and unbiased explanatory variables…in a fast and efficient manner" ((Kong, Yin, & Nakagoshi, 2007), p.241). With the help of GIS, many geo-related attributes can be precisely measured, which makes hedonic price modeling more easily, thereby increasing our understanding of the variations in residential property prices.

2.1.2 Functional form choice

Typically, hedonic price model applies multivariate regression techniques to relate property price details to diverse characteristics of different goods. Potentially, hedonic price model has a variety of functional forms. The linear model is the simplest model specification and the coefficients associated with independent variables are simply marginal changes, or prices per unit of characteristics, which are easy to be interpreted compared with other model specifications. It is as follows:

$$P = f\left(X_1, X_2, \ldots, X_n\right) + \varepsilon = b + a_1X_1 + a_2X_2 + a_3X_3 + \ldots + a_nX_n + \varepsilon$$

where P is price; X_1, X_2, …, X_n are the characteristics embodied in a property; ε is random error term which reflects the unobserved variations in property prices; a_1, a_2, …, a_n are the regression coefficients; b is a constant.

However, as Rosen (1974) states, there is no reason to assume that the relationship between the price and variables is linear. An apparent shortcoming of the linear model is the failure to reflect diminishing marginal utility. What's more, linear model imposes independence on the chosen explanatory variables (Halstead, Bouvier, & Hansen, 1997). To the best of our knowledge, this model specification has been formulated less and less in the literature published in recent years.

Apart from the linear form, hedonic price model has two basic functional forms, both of which have been employed in a substantive number of studies:

(1). Semi-log model:

$$InP = b + a_1X_1 + a_2X_2 + a_3X_3 + \ldots + a_nX_n + \varepsilon$$

where dependent variables are in natural logarithms.

(2). Double-log model (log-linear model):

$$InP = b + a_1InX_1 + a_2InX_2 + a_3InX_3 + \ldots + a_nInX_n + \varepsilon$$

where both independent and dependent variables are in natural logarithms.

Moreover, hedonic price model has a few flexible functional forms, such as trans-log form, semi-log quadratic form.

2.2 Box-Cox transformation

In some hedonic studies (Goodman, 1978; Halstead, Bouvier, & Hansen, 1997; So, Tse, & Ganesan, 1997; Yang, 2016a), the Box-Cox transformation was used to choose among alternative functional forms in order to obtain the best-fitting non-linear model specification (with the highest goodness-of-fit value). Nevertheless, as Cassel and Mendelsohn (1985) indicate, applying a single "good-fit" criterion to select functional forms does not always lead to more accurate estimates of characteristic prices. As Ben-Akiva and Lerman (1985) pointed out, "a 'good fit' to data does not necessarily mean an adequate model, and it is not unusual to find several alternative model specifications that fit the data equally well. Moreover, a model can duplicate the data perfectly but give erroneous predictions" (p.154).

Although the application of the Box-Cox transformation in hedonic studies has suffered from some objections, it is still favored by a host of researchers as it addresses nonlinearity in model parameters. Very detailed information on the Box-Cox transformation can be found in Hossain (2011). Box-Cox models have a variety of functional forms, such as the simple left-hand-side model, simple right-hand-side model, simple both-side model and separate both-side model.

The simple left-hand-side Box-Cox model is as follows:

$$Y^{(\lambda)} = X\beta + \varepsilon$$

where $Y^{(\lambda)} = (Y^{\lambda} - 1)/\lambda$ for $\lambda \neq 0$, whereas $Y^{(\lambda)} = \ln Y$ for $\lambda = 0$.

The simple right-hand-side Box-Cox model is as follows:

$$Y = X^{(\lambda)}\beta + \varepsilon$$

where $X^{(\lambda)} = (X^{\lambda} - 1)/\lambda$ for $\lambda \neq 0$, whereas $X^{(\lambda)} = \ln X$ for $\lambda = 0$.

The simple both-side Box-Cox model (same parameter for both sides) is as follows:

$$Y^{(\lambda)} = X^{(\lambda)}\beta + \varepsilon$$

where $Y^{(\lambda)} = (Y^{\lambda} - 1)/\lambda$, $X^{(\lambda)} = (X^{\lambda} - 1)/\lambda$ for $\lambda \neq 0$, whereas $Y^{(\lambda)} = \ln Y$, $X^{(\lambda)} = \ln X$ for $\lambda = 0$.

The most general and flexible functional form, the separate both-side Box-Cox model (different parameters for both sides), is as follows:

$$Y^{(\lambda)} = X^{(\theta)}\beta + \varepsilon$$

where $Y^{(\lambda)} = (Y^{\lambda} - 1)/\lambda$ for $\lambda \neq 0$, $X^{(\theta)} = (X^{\theta} - 1)/\theta$ for $\theta \neq 0$, whereas $Y^{(\lambda)} = \ln Y$ for $\lambda = 0$, $X^{(\theta)} = \ln X$ for $\theta = 0$.

2.3 Propensity score matching

Despite the well-recognized usefulness of hedonic price functions, they still suffer from a few challenges, for example, functional form misspecification and omitted variable bias, which could lead to biased and inconsistent estimates. In this study, we decide to use propensity score matching technique to estimate the effect of high-quality school on property prices and compare its result with those of hedonic price models.

Matching is an important nonparametric pre-processing procedure for achieving balance and reducing bias as well as model dependence (Ho et al., 2007). Firstly proposed by Rosenbaum (1984), propensity score matching, which summarizes all explanatory variables with a single variable called propensity score (a balance score *per se*), is a widely used matching procedure in the statistical analysis of observational data. It selects comparable units of observation for estimation of the impacts of interventions by use of comparison group data. If the treatment (*xuequfang* here) and control (non-*xuequfang* here) groups have identical distributions of propensity score, all the covariates will be balanced between the two groups.

Propensity score matching procedures include: (1) dividing treated and control groups; (2) developing a Probit or binary logistic regression model (dependent variable =1 for treated observations; =0 for control observations) and estimating propensity score for each observation; (3) matching treatment and control observations based on their propensity scores according to some methods (e.g., nearest neighbour, kernel, exact, sub-classification); (4) estimating treatment effects, by either directly comparing the means or performing parametric outcome analysis.

3. STUDY AREA AND DATA

3.1 Study area

The study area is Xiamen Island, the central city of Xiamen. Xiamen is known as Amoy historically, located on the southeast coast of China with a total administrative area of 1699.39 km^2 and a permanent population of 3.92 million in 2016 (Xiamen Statistics Bureau, 2017). Being termed as “Sea Garden”, Xiamen is a famous livable and comfortable city in China.

Xiamen Island is the earliest developed area of Xiamen, and still remains the central city of Xiamen now. It is made up of Siming District and Huli District, owning a total of nearly 130 km^2 land. The Jinmen Islands are less than 10 kilometers away. A significant feature differentiating Xiamen’s city profile from the others is its unique status being located on the west coast of Taiwan Strait. Refer to Tang et al. (2013) for more detailed information on Xiamen Island and Xiamen City.

The reasons to choose Xiamen Island as our study area are as follows: on the one hand, traditional hedonic price models suffer from the omitted variable bias. An effective method to circumvent this problem is to focus on narrow geographic areas where many confounding variables can be properly controlled (Brasington, 2003). The scale and geographical features of Xiamen Island make it a tractable and ideal region for this study since the variations in many aspects are easy to control. On the other hand, GDP per person of Xiamen is 81.6 thousand yuan (RMB) in 2014 (Xiamen Statistics Bureau, 2014), which is higher than those of most Chinese cities. The life of residents in Xiamen Island is at a high economic level, which far exceeds the subsistence level. There is more disposable income that can be spent on other aspects such as housing.

3.2 Data

There are very few new-built residential complexes in the highly-developed Xiamen Island now. Therefore, our sample is confined to second-hand residential properties for reasons of comparability. We do not consider terraced housing, villa, removal settlement buildings and affordable housing.

Data for this analysis come from two sources. The housing data set (N=1250) is the same as that in Yang et al. (2015), which was collected from the largest real estate agency websites of China, *soufang.com*, in April 2014. To collect data in a short period of time can effectively avoid the short-term fluctuation in price levels, thereby increasing the accuracy and credibility. 452 observations are from 106 residential complexes in Siming District while 798 observations are from 180 residential complexes in Huli District.

Apart from collecting housing samples, creating a workable GIS database is necessary. We used the data from the government official website or Baidu Map (a publicly available website) to establish the GIS database of Xiamen Island. All geo-related independent variables are quantified within the framework of ArcGIS.

Generally, the appraise of high-quality schools is based on these criteria: entering-school-rate (or *shengxuelv* in Chinese) or test scores of their students, educational outcomes, teachers and supporting facilities. In China, the differentiation between high-quality and normal (that is, medium- and low-quality) schools is substantially simpler relative to Western countries. It is widely accepted that provincial-level demonstration elementary schools granted by the Education Department (or *jiaoyuting* in Chinese) of provincial government are highly regarded schools. We follow this approach in our study.

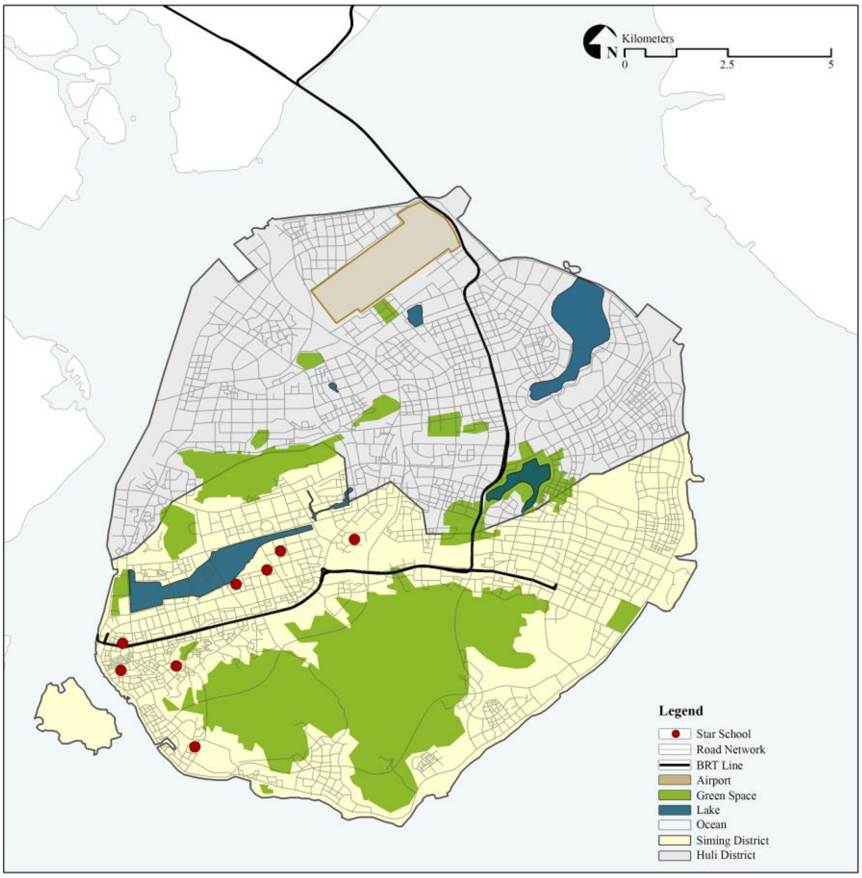

Figure 1. High-quality schools in Xiamen Island

Until 2015, there were eight provincial-level demonstration elementary schools in Xiamen Island (*Fig.1*). They are Yanwu Elementary School, Minli Elementary School, Experimental Elementary School, Second Experimental Elementary School, Datong Elementary School, Affiliated elementary school of Foreign Language School, Bindong Elementary School and Binlang Elementary School. It is noteworthy that all of them are situated in the west of Siming District, which reveals the apparent spatial variations and imbalance.

3.3 Variables

Table 1 shows the definitions and descriptive statistics of twelve independent variables. Except for School, all other eleven independent variables are theoretically important variables that need to be statistically controlled for by being included in our regression models. It should be noted that a variable widely used in the western literature, number of bedrooms, was not included in our regression models, in the interest of model parsimony, because its effect would overlap with floor area, resulting in the presence of multi-collinearity (So, Tse, & Ganesan, 1997). Moreover, job accessibility is not introduced due to the unavailability of data.

Table 1. Variable Definitions and Descriptive Statistics

Variable	Description	Expected sign[1]	Mean	SD
Area	Gross floor area (m^2)	+	105.69	43.02
Age	2015 minus the year of occupation permit (number of years)	-	12.13	4.81
Local environment	Environment quality of residential complexes the property, rated on a 5-point Likert item from “very bad” (1) to “very good” (5)	+	3.08	0.93
School	Dummy variable, 1 if the property is *xuequfang*, 0 otherwise	+	0.13	0.33
Kindergarten	Dummy variable, 1 if there are at least one kindergarten within 500 meters, 0 otherwise	+	0.83	0.37
Middle school	Dummy variable, 1 if there are at least one middle school within 1000 meters, 0 otherwise	+	0.82	0.38
Xiamen University	Dummy variable, 1 if Xiamen University is within 1000 meters, 0 otherwise	+	0.02	0.13
BRT	Dummy variable, 1 if there are at least one BRT (Bus Rapid Transit) station within 800 meters, 0 otherwise	+	0.23	0.42
Distance to hospital	Euclidean distance to the nearest Class 2A or 3A hospital (km)	?	0.81	0.77
Distance to cultural/sports center	Euclidean distance to the nearest cultural/sports center (km)	-	1.11	0.66
Distance to city center	Euclidean distance to Zhongshan Road, the city center of Xiamen Island (km)	-	6.84	2.57
Distance to lake	Euclidean distance to the nearest lake (km)	-	1.08	0.68

Note: [a] + and − represent increasing and decreasing impacts on housing prices respectively; ? indicates a *priori* undetermined sign.

4. RESULTS

4.1 Initial hedonic price regression

EVIEWS 9 is used to build a semi-log and a double-log model using the ordinary least squares (OLS) method. The dependent variable is modified by a natural log transformation in both models whereas independent variables are modified by a natural log transformation only in the double-log model. We do not transform five dummy variables as they are not definitely greater than 0. Table 2 provides the modeling results. The goodness-of-fit values of both models (0.801, 0.850) are higher than that based on the same data source in Yang et al. (2015) (0.789). This indicates that the two models were able to predict higher proportions of variability in their outcomes compared to the model in Yang et al. (2015). Moreover, with a higher model fit, the double-log model outperforms the semi-log model, which indicates that it captures more variations in housing prices. All but two variables are significant at the 5% level in both models. Kindergarten and Middle school are not significant at the 5% level, which implies that they are not associated with housing prices.

Table 2. Regression results of semi-log and double-log models

Variable	Semi-log model		Double-log model	
	coefficient	t-value	coefficient	t-value
Constant	4.579[a]	88.67	1.091[a]	13.89
Area	0.010[a]	59.16	1.008[a]	70.70
Age	-0.011[a]	-7.65	-0.153[a]	-11.26
Local environment	0.068[a]	8.36	0.177[a]	7.94
School	**0.089[a]**	**4.00**	**0.108[a]**	**5.45**
Kindergarten	0.009[c]	0.47	-0.011[c]	-0.68
Middle school	-0.001[c]	-0.06	0.032[c]	1.91
Xiamen University	0.206[a]	3.45	0.144[a]	3.04
BRT	0.077[a]	4.72	0.100[a]	6.85
Distance to hospital	0.047[a]	4.41	0.018[b]	2.13
Distance to cultural/sports center	-0.057[a]	-5.04	-0.049[a]	-5.25
Distance to city center	-0.021[a]	-6.04	-0.077[a]	-6.36
Distance to lake	-0.072[a]	-6.06	-0.051[a]	-5.95
Performance statistics				
Adjusted R^2	0.801		0.850	
Log-likelihood	66.00		238.69	
AIC	-0.09		-0.37	

Note: [a] significant at the 1% level. [b] significant at the 5% level. [c] not significant at the 5% level.

With no exception, the signs of all variables' coefficients agree with *a priori* expectation. The coefficients associated with Area, Local environment, School, Xiamen University, BRT are positive. This implies that properties with larger size, having better local environment and BRT access, within attendance zone of a high-quality school and closer to Xiamen University, exhibit higher values. The coefficients of Age, Distance to cultural/sports center, Distance to city center, Distance to lake, have the hypothesized negative signs. It indicates that houses at the younger age, with better accessibility to the city center, culture/sports center and lake, are more expensive, all else being fixed.

The coefficient associated with Distance to hospital is positive, which indicates that proximity to Class 2A and 3A hospitals negatively affects housing prices. This indicates the nuisance effect of being located near hospitals, which seems somewhat surprising, but consistent with the findings in Li et al. (2013) and Peng, B. et al. (2015). There are two possible explanations. Firstly, different age cohorts have differing needs and preferences of services, for example health care services (Wong et al., 2018). Normally, young adults seldom go to hospital, so they may not consider proximity to hospitals when making residential location decisions, even tend to live far away from hospitals. Notwithstanding, the elderly are in general more likely to go to hospital (Yang, 2016b; Szeto et al., 2017; Wong et al., 2017) and may tend to live close to hospitals for better access due to higher visiting frequency (Li et al., 2013). In addition, it is crowded around high-level comprehensive hospitals generally. There are a huge number of people and vehicles within these regions, generating noises and air pollution, thereby reducing nearby residents' quality of life (Peng, B. et al., 2015).

The coefficients of the double-log regression function correspond to average attribute elasticities. Gross floor area is found to be the dominating elemental attribute, which has the greatest influence on housing prices as hypothesized. In addition, being located in the attendant zone of a high-quality school has nearly the same positive impact on housing prices as access to BRT (0.108 vs 0.100). Furthermore, among four location variables, Distance to city center exhibits the largest impact on housing prices, which is consistent with the bid-rent theory proposed by Alonso (1964).

4.2 Box-Cox transformation

For further checking the robustness of variables, four Box-Cox functions are estimated. All functional forms represent relatively simple applications of the Box-Cox transformation: the simple left-hand-side Box-Cox model; the simple right-hand-side Box-Cox model; the simple both-side Box-Cox model; the separate both-side Box-Cox model. It should be noted that we do not transform five dummy independent variables as they are not definitely positive.

Table 3 shows the results and reveals that the most flexible form, the separate both-side Box-Cox model, outperforms other three Box-Cox models. It has the lowest AIC (Akaike information criterion) value and the greatest adjusted R^2 and Log-likelihood.

The levels of statistical significance of all twelve independent variables are consistent in all six model specifications (two pre-specified and four Box-Cox transformed models). Kindergarten and Middle school are not associated with housing prices while other variables significantly affect housing prices (significant at the 5% level). This implies that our hedonic price models (both pre-specified and Box-Cox transformed) can explain price variations well and the variables included do affect housing prices. In addition, the signs of all coefficients are in line with expected.

Table 3. Results of four Box-Cox transformed functional forms

Variables	Simple LHS Box-Cox model:	Simple RHS Box-Cox model:	Simple both-side Box-Cox model:	Separate both-side Box-Cox model:

	coefficient (t-value)	coefficient (t-value)	coefficient (t-value)	coefficient (t-value)
Constant	9.784 (34.54)[a]	58.907 (5.20)[a]	1.137 (12.87)[a]	1.618 (19.41)[a]
Area	0.055 (63.53)[a]	1.429 (59.11)[a]	1.035 (70.56)[a]	0.833 (70.52)[a]
Age	-0.074 (-9.30)[a]	-3.044 (-10.17)[a]	-0.169 (-11.32)[a]	-0.151 (-11.20)[a]
Local environment	0.434 (9.36)[a]	16.629 (8.05)[a]	0.203 (8.00)[a]	0.195 (8.01)[a]
School	0.616 (5.14)[a]	36.359 (5.90)[a]	0.128 (5.48)[c]	0.129 (5.46)[c]
Kindergarten	-0.005 (-0.05)[c]	-4.621 (-0.88)[c]	-0.013 (-0.70)[c]	-0.013 (-0.67)[c]
Middle school	0.029[a] (0.28)[c]	4.011 (0.76)[c]	0.036 (1.84)[a]	0.033 (1.70)[a]
Xiamen University	0.990 (3.09)[b]	42.604 (2.53)[b]	0.170 (3.04)[a]	0.172 (3.03)[a]
BRT	0.429 (4.93)[a]	19.596 (4.38)[a]	0.117 (6.81)[a]	0.116 (6.72)[a]
Distance to hospital	0.252 (4.47)[a]	11.195 (4.06)[a]	0.022 (2.16)[b]	0.023 (2.21)[b]
Distance to cultural/sports center	-0.294 (-4.71)[a]	-12.988 (-4.16)[a]	-0.059 (-5.31)[a]	-0.062 (-5.39)[a]
Distance to city center	-0.134 (-7.26)[a]	-5.477 (-7.12)[a]	-0.088 (-6.37)[a]	-0.084 (-6.28)[a]
Distance to lake	-0.345 (-5.42)[a]	-10.734 (-3.32)[a]	-0.061 (-5.99)[a]	-0.063 (-5.99)[a]
Left-hand side parameter	0.317 (11.41)[a]	-	-	0.032 (1.02)[c]
Right-hand side parameter	-	1.128 (19.03)[a]	-	0.080 (1.45)[c]
Both-hand side parameter	-	-	0.030 (0.95)[c]	-
Performance statistics·				
Adjusted R^2	0.826	0.806	0.851	0.851
Log-likelihood	-1999.85	-6864.68	39.83	26.60
AIC	3.26	11.15	-0.04	-0.02

Note: [a] significant at the 1% level. [b] significant at the 5% level. [c] not significant at the 5% level.

4.3 Propensity score matching

The “MatchIt” package in R constructs (Ho et al., 2011), is used for treatment effects estimation. The model employed to estimate propensity score, defined as the probability of receiving treatment, conditional on the covariates, is a binary logistic regression model. The explanatory variables used for logistics regression are the same as those used for the hedonic price function estimates. There are 158 treatment and 1092 control observations in our data set. The matching method we use is “optimal” matching, which seeks out the matched observations with the smallest total absolute distance within matched units. This method (i.e., “optimal” matching) is, in nature, strikingly different from “greedy” matching, which starts with some treated units and matches the closest control unit that has not yet been matched, without trying to minimize a global distance measure, so it efficiently avoids a problem of “greedy” matching, *variant to the order in which units are matched* (Ho et al., 2007).

After matching, we compare the difference between the means for each explanatory variable in full samples and matched samples and find that matching does greatly enhance the balance of covariates. The estimation of the treatment effect reveals that the residential properties being located within high-quality school attendance zones (*xuequfang*) are 12.1% higher than the properties located outside of these areas (non-*xuequfang*), all else keeping fixed.

4.4 High-quality school value premiums

The following interpretation of the value premiums offered by high-quality schools is based on the semi- and double-log hedonic price models developed and propensity score matching. The coefficient of School in the semi- and double-log model is 0.089 and 0.108, respectively. This indicates that residential properties being located within high-quality school attendance zones (*xuequfang*) exhibit values that are between 9.3% (=$e^{0.089}$-1) and 11.4% (=$e^{0.108}$-1) higher than the properties located outside of these areas (non-*xuequfang*), *ceteris paribus*. The value premium estimation provided by propensity score matching (12.1%) is very consistent with the hedonic price regression results.

The magnitude of the price premium offered by high-quality school of Xiamen Island is a little higher than that estimated in Beijing (8.1%) (Hu, Zheng, & Wang, 2014) and Shanghai (8.7%, 9.7%) (Shi & Wang, 2014; Peng, B. et al., 2015), but lower than that in Tianjin (l4.7%) (Wang, Z., Mei, & Wang, 2014) and Hong Kong (39.4%, 27.3%) (Jayantha & Lam, 2015).

5. DISCUSSIONS

According to the pedagogy theory, four factors - genetics, environment, school and subjective initiative - can affect the physical and mental development of people. Among them, only environment and school are space-relevant. The former involves loads of factors, with family environment accounting for a major proportion, while school is a very important factor which parents can do something for the physical and mental development of their children.

The demarcation of school attendance zones is based on many factors such as school distribution, population distribution and natural boundary. It is, originally, to ensure the accessibility and security of school-age children. However, since elementary schools show exceptional heterogeneity (obvious disparities, tremendous diversity) in some aspects such as test performance and entering-school rate, parents' expectation would deviate from the reality in terms of school choices. That is, assuming that a child with local *hukou* registered in the attendance zone of school A wants to attend school B, it is very difficult, if not impossible, according to strict policy of entrance from attendance zones alone, however. So, in most cases, parents need to buy a residence in the attendance zone of school B. As a result, the imbalance of inadequate supply and growing demand leads to the higher prices of *xuequfang*. For example, in Nanjing, the supply-demand ratio of *xuequfang* reaches 10 (Chen & Tang, 2009). Obviously, the advent of the *xuequfang* phenomenon is in stark contrast to original goals of school attendance zone demarcation.

According to Chen and Tang (2009), there are a series of negative effects of the *xuequfang* phenomenon: (1) unfair educational resource allocation. Coupled with the advancement of the nation, education is no longer regarded as a privilege. Good educational resources are expected to be unfairly allocated and driven by the market mechanism. The introduction of territorial-based school admission policy which links educational resources with residential properties, distorts the market. As a result, the better the nearby educational resources are, the higher value the housing exhibits. This turns out that the rich can still obtain high-quality educational resources with their economic advantages, while the poor have few chances to get access to a prestigious school. Therefore, socio-economic polarization would be reinforced and then fixed in place (Wu, Q., Zhang, & Waley, 2016). (2) formulating spatial barriers and separating different income groups. The school attendance zone demarcation and the dramatic housing price gap have gradually exerted influence on urban form and led to the isolation of communities. Like some invisible barriers, the poor quarter and the wealthy neighborhood may be imperceptibly partitioned by different school attendance zones. This may hamper the communication and interaction among different income groups, thereby ruining social harmony and stability. This results in the Matthew effect of the rich and poor. (3) extruding consumer market. People have stable disposable income, but spend a great amount on *xuequfang*. This decreases household expenses in other areas, such as food, clothes, tour, which would affect the development of other industries and consumer market. With family wealth rising and living conditions improving constantly, people have a higher requirement for living space and housing. Yet, real estate market grows in an unhealthy way due to the *xuequfang* phenomenon.

Based on the aforementioned analysis, a few countermeasures can be discussed: (1) reforming household registration system (HRS) gradually. Although HRS is a major tool of social control adopted by the state and has historical contributions (e.g., economic development, social stability) (Cheng & Selden, 1994; Chan & Zhang, 1999), it is associated with the discriminative provision of social welfare (including education). Its potential reform has drawn the extensive attention of scholars and policy makers. The reform should not be achieved in a short period of time, but proceed in a gradual manner (Zhao, 2003; Yang & Hong, 2013). Directly deregulating or eliminating the limitation of population migration may not be appropriate. Removing the social welfare provision functions of HRS, transforming it from a (discriminative) status-checking system to one that basically registers people's residency statuses and linking social welfare to common citizenship (instead of discriminative *hukou*) is thereby suggested (Peng, X., Zhao, & Guo, 2009). (2) optimizing the resource distribution to balance the quality of education. The scarcity and unequal distribution of good educational resources give rise to the *xuequfang* phenomenon, constituting the biggest hindrance to the development of education. As people rush to purchase a *xuequfang*, education and real estate industry grow abnormally. Accordingly, homogenizing educational resources and flattening school gap become rather imperative. To achieve educational equity and balance resource allocation, appropriately boosting education investment is essential and feasible as it helps optimize facilities and improves teaching environment. (3) highlighting family education and children's all-round development. Obviously, not all excellent students graduated from prestigious schools. Indeed, school is an essential external factor that shapes a child. Many internal factors such as family education and subjective initiative, are also important to the success of a child. Even in the ancient time characterized by material deprivation, poor environments brought up a batch of extraordinary people as well. Therefore, conducting family education, focusing more on character and moral advancement, teaching children in accordance with their aptitude and activate their self-consciousness of success become necessary. Blindly following talent-cultivating objectives by purchasing a *xuequefang* are not be acceptable.

6. CONCLUDING REMARKS

In China, due to the scarcity of high-quality schools, the household registration system and the territorial-based school admission policy, a feasible way for parents to offer high-quality education to the next generation is to buy a *xuequfang*. The supply-demand imbalance leads to the *xuequfang* phenomenon. Higher prices of *xuequfang* contain parents' investment in children's future.

Using Xiamen Island as a case study, this study empirically appraises the value that parents place on school quality by estimating how much residents are willing to pay for a *xuequfang* based on a set of hedonic price models, more specifically, two pre-specified and four Box-Cox transformed models, and the propensity score matching technique. The results indicate that these two approaches play complementary roles in data analysis. Our study adds an empirical study in the Chinese context about the quantitative valuation of high-quality school attendance zones to previous sparse literature, and demonstrates that *xuequfang* exhibit values that are 9.3% to 12.1% higher than non-*xuequfang*, all else keeping constant. High-quality school does generate a premium that is reflected in property prices, and homebuyers' willingness-to-pay for high-quality school can be clearly identified. Overall, our models are satisfactory: the signs of all parameters are consistent with *a priori* expectation, and their levels of statistical significance are consistent in all six models. They have been proved to have a very significant and consistent explanatory power. The value premium estimation provided by propensity score matching (12.1%) is very consistent with the hedonic price regression results. The issues pertinent to the *xuequfang* phenomenon has been discussed including school attendance zone demarcation, its negative influences, and countermeasures.

This study has several limitations which deserve further research. Firstly, our study failed to account for the obvious spatial effect (spatial autocorrelation) in data. The spatial regression can be used to take account of this. Secondly, due to the absence of rich data, some potentially contributory factors (e.g., floor area ratio, property management fee, population density), were not included in our models. Thirdly, due to data limitation, we used Euclidean distance (shortest distance, straight-line distance) to measure the accessibility of geographical elements instead of network distance (real-life distance). Last but not least, to reflect travel frictions, geographical distances (instead of travel times) are used. Actually, for residents, the perception of travel time might be more important than travel distance in determining mode choice. Cervero (2005) notes that accessibility is a product of mobility and proximity. In this regard, our study simply considered proximity, but ignored mobility. It is a weakness of most of existing literature. Calculating travel time by differing transport modes (e.g., walking, cycling, public transportation, automobile) under different conditions (at least, during the peak and non-peak hours) to reflect accessibility and incorporating these metrics into hedonic price models may yield more detailed results.

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Prospective living arrangement of China's urban elderly and development of an Agent-based Simulation (ABS) model for elderly care needs

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Abstract: As China is characterized by a large ageing population, and its rapid speed of ageing, urbanization, and socio-economic transformation, the senior service issue is both typical and urgent. To support the urban planning and decision-making of relevant policies for senior services, which is significantly challenging, this research employs the multi-agent simulation (MAS) approach to simulate the complicated process of Chinese senior service provision. The approach defines the elderly, day-care centers, and residential aged care facilities (RACF) as the kernel agents, determines the behavior rules of different agents, and confirms the interaction between agents, individual agents and urban environments. Altogether nine simulation modules were designed and integrated. This study focuses on the diversifying elderly population, complexity of the senior services system, and the uncertainty of the developing background. Seniors' socio-economic attributes such as income, family structure, education and hukou status, day-care center, and RACF agents' characteristics, such as price, location, service standard, public /private status, were emphasized at a microscopic scale. Using a bottom-up approach, neighborhood differentiation was considered the main determinant of senior service needs. Through the design of different policy-scenarios, critical parameters were determined to have the most important influence on senior service needs and their provision. The regulation of these crucial indicators will be a great scientific support to the planning of provisions for senior service facilities and to the decision-making of environmental improvement policies in different urban neighborhoods. The MAS approach is recognized as a modelling paradigm for capturing the dynamics of complex systems. This research is especially useful for supporting the provision of elderly service facilities and the environmental improvement of livable urban neighborhoods through future urban planning.

1. INTRODUCTION

Due to the global ageing trend, senior service provision is gradually becoming a critical issue worldwide. Senior service is a complicated, dynamic, systematic social problem, significantly subject to population growth, the provision of socio-economic institutions, economy, regional infrastructure, culture and value, and service management. The senior service system is composed of a large number of autonomous stakeholders (service suppliers, elderly persons, policy makers, etc.) who play fundamental roles within the system, and interact with each other in a dynamic urban environment.

The sixth census in China, conducted in 2010, demonstrated that the population above 60 years old had reached 178 million, accounting for 13.3% of the total population. It was predicted that by 2030, this figure will double (CPC Central Committee and State Council, 2011). Due to its reduced fertility rate and increasing life expectancies over the last few decades, China is experiencing rapid demographic changes. Since ageing overlays with industrialization, urbanization, and socio-economic transformation (Peng, 2011), the elderly service issue in China is relatively more typical and presents more challenges, such as with the difficulty of prematurely ageing before acquiring sufficient retirement funds, or with problems due to the large population of disabled seniors, “empty-nest” seniors, and the traditional role of families decreasing. At present, the most acute and fundamental contradiction in senior service is structural imbalance between the demand and provision.

To resolve this problem, three important factors must be adequately addressed, which are demographic transitions, diversification of seniors, and policy reform. The one-child policy has played a key role in the demographic transition by greatly reducing the number of children available to support ageing parents. A common concern for urban seniors is the hesitation over whether to enter a care facility, which presents a departure from tradition, or to rely on the care of a single child. After the policy of reform, socio-economic differentiation (e.g. income, hukou status) has emerged in China, which has affected senior service demand between elderly people with different characteristics. The utility levels of senior care services vary with socio-economic diversification. Health care reform, social security system reform, and introduction of a household registration system have been undertaken recently, and a series of policies related to senior service will be formulated in the near future. All of the policies will have important implications for the viability of future senior service strategies.

Most of the existing studies on senior service needs are multi-disciplinary, because it is difficult to clarify this problem using the analysis methods of any one discipline. According to the behavioral model in gerontology and sociology, three sets of variables can account for differences in health service use among the elderly, which are predisposing variables (e.g. age, sex, and education), enabling variables (e.g. family income, financial capacity of the elderly and their accessibility to services), and need variables (e.g. symptoms of health and illness, functional health problems, and perceived need for health care) (Andersen, 1995). From sociology and psychology, the health belief model focuses on the role of the individual’s perceptions in seeking the health services, not on the role of demographic and social conditions (Hooyman & Kiyak, 1988). It suggests that seniors’ beliefs about health problems, perceived benefits of action and barriers to action and self-efficacy are triggers for health service utilization (Janz & Becker, 1984). The P-E fit model, presented by environmental gerontologists, shows how the integration of the elderly with their physical and social environments hugely impacts health service demand (Lawton & Simon, 1968; Longino Jr, Perzynski, & Stoller, 2002; Rowles & Bernard, 2013). Studies on public health show that China has experienced an epidemiologic transition in its leading causes of death, from infectious disease and acute illness to chronic disease and degenerative illness (Gong et al., 2012). The changes lead to an ageing society with changing health and disease patterns, and different health service expenditures (Levit et al., 2003).

To address the mismatch between the demand and supply of elderly care services, research shows the importance of different factors, such as status and way of life, the relationship between the elderly and their urban living environment, access to facilities(e.g. location, care service), and the effect of policy (Barnes, 2002; Gao, X. L., 2013; Gao, X., Yan, & Ji, 2012; Golant, 1979; Moos & Lemke, 1979; Shapiro & Tate, 1985; Yan & Gao, 2014). Nevertheless, the statistical method, social approach, and traditional spatial analyses are too macroscopic, aggregate, and static to solve this problem. They are unable to respond to an elder individual's behavior and an individual facility's operation in a diversifying society, and to understand the concrete challenges in this comprehensive, systematic, and integrated problem.

A Multi-Agent System (MAS) has an advantage in its ability to simulate complex, dynamic systems (e.g. urban land use and urban transportation changes), by modelling the interacting, autonomous agents in a dynamic environment (Batty, 2011; Ligtenberg et al., 2004; Shen et al., 2011; Suryanarayanan, Theodoropoulos, & Lees, 2013). Agents have behaviors, often described by simple rules, and interact with other agents, which in turn influence their behaviors and the whole system (Macal & North, 2010). In an urban development simulation, the most important things to consider are the selection of agents, definition of behavior rules, expression of interactions between agents, and the extraction and importation of environment variables (Chen, Gao, & Shen, 2012). Not all of the stakeholders should be considered as agents. The confirmation of an agent's behavior is prior knowledge – based on and impacted by the research target, involving an interdisciplinary study, in which all of the theoretical conflicts must be resolved. Circular interactions among the agents are simultaneous and difficult to model. The inter-face of the urban environment contains the social, economic, environmental, cultural and policy related variables which are the essential inputs of the simulation and needs to be quantified.

Therefore, an MAS is used to construct the Elderly Caring Service Supply (ECSS) Model in order to reasonably provision elderly care services dynamically, and to expand the application of MAS to model the urban complex system.

Based on the gerontology, sociology, urban geography, etc., the essential agents are selected (e.g. the elderly, facility), the agent evolution laws and the behavior rules are confirmed, and the agent behavior modules designed. According to the interaction between various agents, the agents' behavior are integrated, framing the affecting mechanism of different agents' modules, simulating the urban elderly care services demand-supply system at the micro scale, and identifying the macro evolution law. Consequently, based on the forecast outcomes of micro behaviors of elder individuals and facilities, the macro laws of the whole demand-supply system of elderly care services can be concluded upon. According to this, intellectual support can be provided more reasonably and predictably in a manner that addresses the planning and provision of elderly care services. Moreover, in the complex environment, the micro-level simulation and scenario analysis will bring a new perspective to regional and urban planning, and significantly influence the distribution and allocation planning of infrastructure and public service facilities.

2. FRAMEWORK AND AGENT-BASED SIMULATION

2.1 General framework of the simulation

The ECSS Model aims at developing, testing, and applying a new type of integrated urban elderly services supply model that simulates the interaction between the elderly and their environment (Figure 1) in a whole system, under the conditions of a rapid ageing and urbanization process.

Firstly, the characteristics of elderly people in the urban region are defined, such as age, health status, income, education, etc. Then, demands for spatial interaction are created, such as shopping, leisure travel, participation in activities, receiving care, etc. There are also elderly who need more care for their declining health and loss of independence. The daily activities, health care, and specific treatments of the elderly occur in different areas with different levels of accessibility and service convenience, which consequently triggers their reactions (e.g. their morale, mood, well-being, life satisfaction). Secondly, the adjustment of living arrangements as a deliberate behavior of seniors significantly influences the senior care services demand. Urban senior service systems will provide services accordingly and improve the life quality of the elderly. In the whole process, there is a remarkable need to consider the different aspects of the environment such as personal space, buildings, neighborhoods, facilities, etc. Their locational and physical attributes should be taken into account in the interaction between the physical environment and the elderly population.

There are two important feedbacks in this system model: 1) Subjective feedback: Based on the existing senior services and urban living environment, elderly people will conduct an evaluation of their wellbeing which will influence their future decisions regarding their living arrangements; 2) Objective feedback: The allocation of elderly care service facilities will impact the modes of urban living arrangements for seniors where the provision of urban senior service systems is significantly restricted by a government policy.

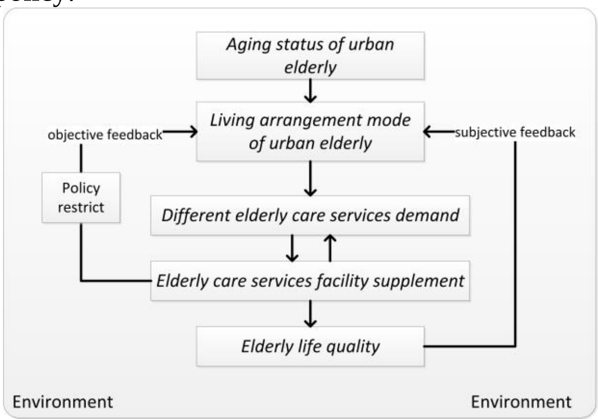

Figure 1. ECSS Model framework

This theoretical framework recognizes elderly diversity, complexity of the senior service system and the uncertainty of the developing characteristics. It can be used for predicting the growth of the elderly population and the demand for senior services in future, and assessing to what extent these urban environments can effectively meet the needs of elderly people for senior services, evaluating the efficiency and impact of potential social policies that support senior service systems.

2.2 Selection of agent and module relationship

According to the multi-agent system, the essential agents are first selected, and then their behavior rules confirmed and the interactions between agents, and between agents and their environments, constructed through various simulation modules.

The ECSS Model is microscopic, and includes three types of agents, 1) elderly agents, 2) residential aged care facility agents, and 3) day care center agents. For elderly agents, which are the kernel agents in this simulation, all health and economic status, social support changes, livelihoods, modes of living arrangements, and elderly care facility selections will be modelled using multi-agent based simulation. For residential aged care facility agents and day care center agents, the profit or non-profit, location, capacity for visitors, content of services, and cycles of business operation (business cycles) can be simulated per individual facility. The interactions between elderly care service demand (e.g. home-based services, community-based services and care services from aged care facilities) and facility supply (e.g. residential aged care facility, day care center, and hospitals) are modelled at the level of individuals. Within the simulation environment, urban policies, such as senior service facility plans, will be input into the simulation environment. In addition, an urban governor/policy framework will be simulated to manage, restrict, and supervise the provision of the elderly service system, and also to select the urban development strategy, and regulate the urban environment construction (e.g. hospital, leisure space, transport facility, etc.). The urban ageing process, urbanization, and the developing macro-level background of this model are also essential factors in the simulation, impacting upon the behavior of different related agents, and should be represented and input as well.

According to the characteristics of different types of agents, the elementary behavior and decision-making processes are encoded as basic computer program codes, each running a different module. The ECSS Model consists of nine modules. There are five modules conducted by elderly agents, which are the life cycle module, care pattern shift module, living arrangement and care pattern choice module, relocation module, and facility choice module, and four modules executed by the day care center, or residential aged care facility (RACF) agents, which are the day care center business cycle module, day care center's location module, RACF business cycle module, and the RACF's location module. The simulation modules of the ECSS Model interact in various ways with each other. Interactions between the modules, and between agents and the environments, are operated by a coordinating program. Existing research models and empirical findings are the foundation of simulation modules which perform the essential mechanisms of the agents' behavior rules and their interrelationships with other agents or environments. Proceeding is therefore an introduction of the related studies and findings.

3. BEHAVIOR RULES OF THE ELDERLY

3.1 Elderly lifecycle module

Ageing is the central topic of study in gerontology. One's life course is determined by their life trajectory, important life events, and role/status transitions (Riley, Johnson, & Foner, 1972). Elder (1975) found that there are key times and places that encapsulate experiences over a lifetime, which shape the life course of individuals. Life events generally refer to things such as schooling, marriage or divorce, retirement, death of a spouse and so on (Li, Deng, & Xiao, 1999). The role/status changes of the elderly mainly include the biological, social, and psychological aspects, such as the transition of sensory function, cognitive abilities, lifestyles, social contribution, intergenerational relationships, values, and well-being (Hooyman & Kiyak, 1988; Moen, Dempster-McClain, & Williams Jr, 1992; Riley, 1987).

The different dimensions of a life course are defined according to the study by Morgan and Kunkel (2011) and are shown in Table 1. Age related life course events in later life include children leaving home, retirement, death of a spouse, declines in health, and reductions in income, which significantly impact the later life of the individual.

Table 1. Various dimensions of life course

Age	…-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Life course	…	Young adult	Adult	Middle age		Later maturity		Old age	
Job/ retirement	…	Job experiment	Job advancement		Retirement planning	Retirement occurs		Retirement	
household	…	Marriage/parents	parents		spouses			Widowhood?	
Intergenera-tional relationship	…	Kids under 6	Kids 6-12	Kids 12-18	Adult-adult	Empty nest		Dependent on child?	

According to their age, the elderly can be subdivided into pre-elderly (55—64 years old), young-elderly (65—75 years old), middle-elderly (75—85 years old), and old-elderly (85+ years old) (Atchley, 2000; Bures, 1997; Carr & Komp, 2011; Longino Jr, Perzynski, & Stoller, 2002). Carr and Komp (2011) propose a different conception of life course using functional distinctions between ages. According to their concept, the third age of the elderly is described as the period of life that occurs after retirement but prior to the onset of disability, a period in which individuals have the capacity to remain actively engaged in society. The third age is brought to an end by the fourth age, characterized by declining health and loss of independence. The third age emphasizes the role of health status in the life course, and is a response to the concept of productive ageing in gerontology, which focuses on seniors' productive participation (e.g. whether they are engaged in work, taking care of grandchildren, caring for sick friends, or taking part in educational training) (Morgan & Kunkel, 2011).

Although transitions in the life cycle influence the decision-making process of elder individuals, they tend to plan well within their particular limitations (Clausen, 1993; Elder, 1975). Therefore, as rational actors, the living arrangements, health care, social care, and facility selections of later life have already been considered within elderly decision-making scopes, and abide by the principle of maximum utility of the elderly within their current life courses (Wu, C. P. & Jiang, 2006).

3.2 Care pattern shift module

From the life course modules of the elderly, different life courses within the physical, psychological and social ageing process are examined. Living environments, including the physical environment, social environment and senior care services, are closely linked with seniors' lives. So, how does the urban environment impact elderly citizens in different life courses, and influence their lives? Answering this question is the essential task of this module.

Elderly people are more sensitive to their environment than young people (Hooyman & Kiyak, 1988). Golant (1979) argued that elder people's geographic experience in their neighborhoods involves a complex set of experiential categories, including action, orientation, feeling, and fantasy that together provide a holistic expression of the individual's adjustment (such as a move to an institution, locomotion within the proximate environment, and movement during long-distance vacations) within their physical and psychological capabilities and unique life history. Lawton (1982) developed a predictive model for the behavior of senior citizens, based on the relationship between the senior and their living environment. After Lawton's ecological theory, the relationship between the elderly and the environment has been studied further. Evans (2009) provided research on the social well-being of elderly people living in "housing with care" (for example, retirement villages and extra care housing). A sense of community is critically important for elderly people's quality of life. The influencing factors include social networks, inclusive activities, diversity, and the built environment. Phillips et al. (2005) categorized these dwelling conditions as the interior environment (for example, indoor lighting, crowdedness, temperature, security devices, lifts/escalators, etc.) and the exterior environment (lighting in public spaces, green areas/parks, recreational or sitting and rest areas, passages, flyovers/subways, air pollution in the estate/community, etc.), and demonstrated the greater impact of the interior environment on residential satisfaction than the exterior environment. Yan and Gao (2014) revealed that in different neighborhoods (for example, traditional courtyard housing blocks, low-income rental housing neighborhoods, commercial housing neighborhoods, etc.), residential environments play a significantly different role in the ageing process for the diversity of seniors who are ageing in an RACF in China.

Therefore, based on the fitness of the elderly person, and their well-being or satisfaction, their adjustments or behavior can be predicted (for example, the changing of living arrangements). The elderly care pattern changing-desire module is simply the process to assess the relationship between the elderly and their living environment, and the probability of certain behaviors.

3.3 Living arrangement and care pattern choice module

The relationship between the elderly and their environment influences their mental status (for example, depression), quality of life, and individual behavior. The adjustment of living arrangements and residential locations can be viewed as a manifestation of the ways in which elderly people have adjusted to the social, behavioral, and environmental factors.

Generally, living arrangements include independent living (living alone or with a spouse), co-residence (living with at least one child or other kin), and living in an institution. The particular arrangement has many implications for the current well-being of an elderly person, and is selected dynamically and should be responsive to changes in individual circumstances and to changing expectations about the future (Phillips et al., 2005). Functional losses and lower life quality, for example, due to diseases such as Alzheimer's disease, require an increase in informal or formal care services and more supportive dwelling environments. Therefore, lower life quality functions as a predictor of the higher probability of movement into a skilled nursing facility (Kaplan,

D. B. & Andersen, 2013). In addition, different values, cultural specificity, and the assimilation of elder people are essential factors in the decision-making of living arrangements. Foreign-born, Asian elderly in Canada/America were usually living under the auspices of family reunification, and so the percentage living with family instead of living alone or with a nonrelative is highest, and their socioeconomic status correlates with this pattern (Boyd, 1991; Kamo & Zhou, 1994; Phua, Kaufman, & Park, 2001). Although in China the traditional preference of the elderly has been to live with their children, recently, due to the influence of acculturation, economic feasibility, and demographic availability, there is an increasing preference for elderly people to live independently or to enter an institution (Gao, X., Yan, & Ji, 2012).

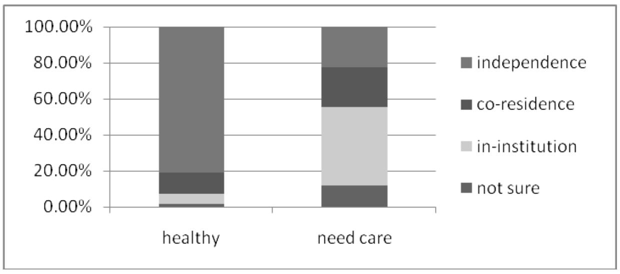

Figure 2. Chinese elderly's living arrangement based on Beijing survery (Gao, X., Yan, & Ji, 2012)

The selection of living arrangement in the elderly population is associated with their functional losses and changes in the level of received care and assistance (Dostie & Léger, 2005). Based on current living arrangements, as an individual's physical energy, mobility, and health status changes, they need more services, including Activities of Daily Living (ADL) care, and Instrumental ADL (IADL) care. These services belong to different care patterns which are supplied by various care providers (See Table 2).

Table 2. Relationships between living arrangement and urban long-term care system

Living arrangement	**Care pattern**	**Care provider**	**Long-term care (ADL care, IADL care)**			
			Emergency/ acute treatment	Technical recovery health care	Recovery health care (non-technical)	Supportive real-time health care
In- institution	Residential care	Hospital	Δ			
		Residential care facility		Δ	Δ	Δ
Co-residence/ independence	Community care	Community-based facility /Day care center				Δ
	In home care	At-Home Care Company		Δ	Δ	Δ
		Community elderly center				Δ
		Relatives/ Friends: Informal care service				Δ

Policy concern over elderly living arrangements arises from the large effect of living arrangement choices on elderly care and welfare, especially for those suffering from physical limitations or health problems. This concern may be especially cogent in rapidly developing countries, such as China, where the percentage of elderly living independently (alone or with their spouse) has increased substantially. However, public senior social services remain relatively defective. For example, most of the elderly who are living in public nursing homes are retired, rather than disabled old-elderly; there is thus a shortage of care facilities. Some studies on this have already been conducted; for example, Dostie and Léger (2005) suggested that policies may be more effective at reducing institutionalization if, among the elderly living independently, policies are targeted at married females with fewer children and at encouraging seniors to return to community care or in-home care if they are living in a nursing home.

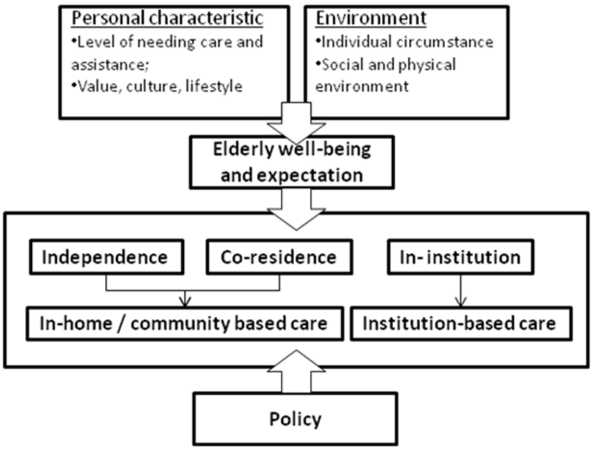

Figure 3. Elderly living arrangement and care pattern selection

Consequently, the elderly living arrangement and care pattern selection module is designed to clarify the relationships between individual elderly, the living circumstance, and related policies. This module will illustrate, and to what extent, the relationship and related policy will impact the well-being or expectation of the elderly and induce them to choose a certain kind of living arrangement and corresponding senior care (See Figure 3).

3.4 Residential moving of the elderly

As a result of limited mobility, frailty or other physical/mental health problems, many elderly require long-term care, including in-home care, community-based care, and institution-based care, as well as a more supportive living environment (See Table 2). Therefore, according to the different demands of the physical/social environment and senior services available, large numbers of elderly choose to relocate.

Borup (1983) identified four types of elderly relocation: type 1) inter-institutional (for example, from hospitals to nursing facilities, and continuing care retirement communities); type 2) residential (moving from one residence to another); type 3) residential or institutional (such as from home to a residential aged care facility); and type 4) intra-institutional (for example, movement within the facility). Wiseman and Roseman (1979) categorized local movement into six types: suburbanization, inner city relocation, apartmentalization, communalization, homes of kin, institutionalization. The simulation of seniors' migration is complicated as it refers to long-term decisions, impacted by several factors, especially, aspects of the individual's life course and the perceived benefit of alternatives. Based on the study of different relocations by Borup (1983) and Wiseman and Roseman (1979), it is suggested that when a senior decides to move, the alternative places are limited to other local communities (for example, nearby communities and relatives' homes), and residential care facilities.

3.4.1 Relocation module

The majority of elderly people prefer to age in their own home or in a relative's home. The aim of this module is to simulate the senior's migration to other communities. Because elderly people are usually long-term in-home residents, there is an importance placed on the provision within communities of senior's physical/social environment (for example, outdoor areas, transportation, dwelling conditions, social participation, social inclusion, etc.) and daily social services (for example, the service provided by a seniors' center, meal delivery service, information and referral service, home care and health care, protective services, etc.).

The classic migration decision models (for example, the push-pull model, stress-threshold model, spatial equilibrium model, and human capital/cost-benefit models, behavioral model, location-specific amenities model, etc.) tend to clarify the complicated process of decision-making (Gregory et al., 2009; Northcott & Petruik, 2011). Wiseman (1980) made use of the concepts of "push" (for example, physical decline or death of a spouse, and environmental pressure) and "pull" (for example, the therapeutic landscape in a community, relocated relatives), which were defined as "triggering mechanisms" impacted by a seniors' endogenous factors (for example, personal attributes, neighborhood ties) and exogenous factors (for example, cost of care and housing). In the spatial equilibrium model and cost-benefit model, the elderly migrate through seeking housing locations with a maximizing utility (Rudzitis, 1979) or the largest least-cost benefit. The behavior model emphasizes the individual's belief, attitude, and perception, which influences the evaluation of their dwelling and neighborhood. Their ability to obtain access to health and social welfare services (such as the socio-economic stratification, health status, and housing status) is a strong indicator of migration (Golant, 1979; Fokkema & Van Wissen, 1997). De Jong (1999) argues that the decision-making should be based on the balance of five parts: demographic factors, social networks, values and expectations, residential satisfactions, and behavioral restrictions, which underpin intentions of migration. The location-specific approach argues that relocation is a result of a change in demand for location-specific amenities, which can only be satisfied by moving to elderly desirable sites or places (Rudzitis, 1979).

Some studies conclude that besides ageing in specific places, seniors rather prefer to age near those places by moving, for example, to other nearby communities within the same city/town/village (Northcott & Petruik, 2011). Focusing on the different levels of desirability of suburbs and central cities, the order of preference for elderly movers was first to the suburbs, followed by nonmetropolitan areas, with the central city as a distant third (Golant, 1979). However, a minority of elderly people were attracted to the central city due to the convenience of public transportation and ease of access to a wide range of urban facilities that addressed the needs of the elderly, as well as the availability of smaller-sized, less expensive rental accommodations and a relatively low cost of travel, and more attractive social situation (Golant, 1979).

In other studies, the proximity of elderly people to relatives (Chai, 2010; Fokkema & Van Wissen, 1997; Longino Jr, Perzynski, & Stoller, 2002; Warnes, 1993), and the therapeutic landscapes in their living environment were specifically emphasized (Andrews & Phillips, 2005). Cuba (1991) found that individuals may repeatedly spend their vacations at the locations that eventually become their retirement places.

According to a review of research on elderly relocation, the most important process in this module is observing how an individual senior will find the location that maximizes utility having comprehensively considered other factors, such as the various attributes of seniors, the advantages of alternative locations, the impact of relatives, and so on, as well as by comparing the original location and new location - specifically the extent to which the new location offers an improvement.

3.4.2 RACF choice module

When the elderly become disabled, they usually need to make an environmental modification to preserve their independence (Litwak & Longino Jr, 1987; Longino Jr et al., 1991). Although ageing in place is always the preferred pattern, daily activities are an insurmountable barrier to this for the disabled elderly due to narrow doorways, stairs, etc. Alternatively, they may opt for relatively expensive meal deliveries and in-home nursing care. Not all elderly voluntarily age in place, where some may prefer to move, but lack the requisite resources, and can be viewed in this respect as "blocked movers" (Moore & McGuinness, 1997).

Therefore, this module focuses on the elderly who decide to migrate to an RACF, and simulates which or what kind of facility is selected from options such as nursing homes and continuing care retirement communities. Because of the different life histories, family structures, income, education, and hukou (in China), socio-economic and cultural diversity are the essential distinguishing features of the individual seniors, and will impact significantly upon the perception, evaluation, preference, and selection of RACF (Shapiro & Tate, 1985).

Firstly, according to the service contents, location, business size (large or small), profit or non-profit, and type (public, voluntary, private) of the RACF, residential care, such as assisted living, nursing home, or continuing care retirement, is a discrete category. This makes the individual's selection of an RACF a complicated choice.

Cheng et al. (2012) analyze the accessibility of residential care facilities seniors to. They suggest that geographical access, information access, economic access, socio-cultural access, and the socio-managerial environment are the primary factors influencing elderly people and their family members' decision-making process for the selection of RACF. The study on the preference of urban elderly for care facilities, conducted by Gao, X. L. (2013) on Beijing, China, points out that about 40% of elderly people prefer public facilities, and 70% prefer facilities of which the monthly expenditure is no more than 2000 RMB. As Barnes (2002) suggests, there are two types of assessment tools that can be applied to assist elderly to select their preferred facility. The first type is the multiphasic environmental assessment procedure (MEAP), which focuses on physical and architectural features of a physical facility (for example, community accessibility, physical amenities, social and recreational services, and safety), staff characteristics, and the social environment (Barnes, 2002; Moos & Lemke, 1979); the second type is the assessment tool specifically for dementia care settings, such as the professional environmental assessment protocol (PEAP) and therapeutic environment screening survey (TESS-NH) (Barnes, 2002). Focusing on MEAP, the Sheffield Care Environment Assessment Matrix (SCEAM) was provided, which emphasizes several architectural elements, such as location, outdoor space, building form, bathrooms and toilets, and private rooms, (Parker et al., 2004).

There are also other concepts related to RACFs that are developed within the field of environmental gerontology, which are "place", "home", and "being at home". These are presented as other important factors for the selection of RACF. Places are more than environmental contexts to be modified when the elderly become frail; they are holistic, dynamic, and meaningful entities with histories and evolutionary trajectories with which seniors have intimate relationships and on which they depend. Therefore, in assisted living environments, the relationship between the new RACF and home is highlighted and referred to as "connectedness" (Cutchin, 2013; O'Shea & Walsh, 2013).

Therefore, the precondition for successful elderly relocation to an RACF is the match between individual preference and the specific facility. The selection of RACF is related to the service levels, staff, and the physical environment of the facilities (for example, the natural landscapes, building design, and amenities), and is influenced by the health status and socio-economic attributes of seniors. Based upon the overwhelming evidence from the existing studies, this module will emphasize the elderly preference first, and then will use one MEAP to simulate the RACF selection decision-making process.

4. BEHAVIOR OF FACILITY AGENTS

The living environment refers to the physical/social environment and senior services, and it includes two kinds of essential facilities, the day care center and RACF, which are closely related to their health care services. Therefore, the day care center and RACF are selected as the agents in this simulation. They will be simulated through four modules, the day care center business cycle module, the day care center location module, the RACF business cycle module, and the RACF's location module. Given the scope limitations of this paper, we take the RACF as an example to introduce the simulation of the business cycle and RACF location.

4.1 RACF's business cycle module

The business of RACFs refers to the provision of services and the revenues generated by the provision of services to target customers. Meanwhile, there is the cost of business, such as the costs of materials, labor, and equipment. Therefore, based on the profit, the business will continue to operate or become bankrupt. As for not-for-profit RACFs, the continuation of their business depends on whether the revenue that covers their expenses is acquired through the government or through donations. This module will simulate the RACF business cycle (see Figure 4), which influences the system of urban senior services provision.

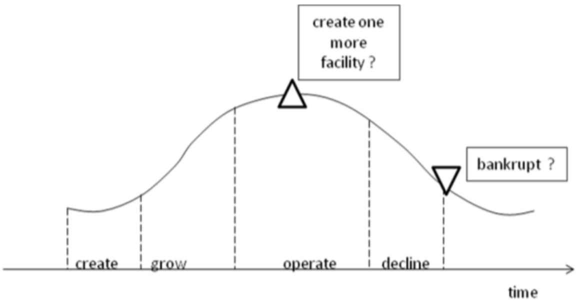

Figure 4. The business cycle of RACF

In most countries, there are acts, codes, and standards on senior services implemented by local authorities. In the United Kingdom, *Home Life: a code of practice for residential care* (UK Centre for Policy on Ageing, 1984), was the first code of practice which concentrated on care standards, residents' rights, privacy and financial affairs, facility administration, physical features, and staffing. After that there were policies such as *A Better Home Life: a code of good practice for residential and nursing home care* (UK Centre for Policy on Ageing, 1996), and *Fit for the Future? National Required Standards for Residential and Nursing Homes for Older People* (UK Department of Health, 1999), which mainly focused on health and personal care, daily life and social activities, accessibility, evaluation of care and cost, complaints procedures and protection, environmental standards, staffing requirements and standards, and management and administration standards (Andrews & Phillips, 2005). Therefore, policies for protecting the older residents significantly emphasized the regulation of quality, accessibility and cost of care.

Research on RACF businesses following the legislation of the above documents indicated that some RACFs have recently had to close due to their inability to meet the new standards (Andrews & Phillips, 2005). Many private facilities will have to reduce their capacity and may face financial difficulties to meet the new standards. It showed that poor financial and quality performance prior to the implementation of the new standards increased the risk of failure, while a larger size decreased the likelihood of performance failure (Andrews & Phillips, 2005).

The business cycle of an RACF is related to the demands of the elderly on the number of care places. For example, in Beijing, policies on the development of social senior services suggest the social senior services system is characterized as "90/6/4", which indicates that 90% of old people will rely on in-home care, 6% on community care, and 4% on residential care by 2015 (Beijing Municipal Bureau of Civil Affairs, Beijing Municipal Commission of Development and Reform, & Beijing Municipal Commission of Urban Planning, 2008). This means the demand for the number of RACFs will increase to between 140,000 and 160,000 by 2015. In Australia, there is a national target level of 113 care places per 1000 persons aged 70 years and over, which includes targets to meet the needs and preferences of care recipients. In the allocation of RACFs under the aged care policy, prospective RACFs are required to make places operational within two years, failing which the applying facility must apply for an extension (Australian Institute of Health and Welfare, 2012; Department of Health and Ageing, 2006). The RACF allocation approach was therefore put into practice through the projection of the older population and the allocation processes being well-controlled by certain policies.

This shows that the important factors within the business operation of an RACF include its health care, place, cost, and accessibility. The influence of policy on RACFs will be emphasized in this module. The main simulation process should include two parts, such as service positions, business size increase or decrease, and finally the decision over whether or not to create the new facility or close the RACF.

4.2 RACF's location module

This module is conducted to simulate how the RACF agents choose a location, and which factors are essential indicators for the decision of the

RACF. These will influence the availability of RACFs to seniors, and the selection of RACFs.

The location of an RACF is impacted by several factors. Public or private facilities have distinct distributions. Early research identified that historical influences and the varying policies of local governments are primary factors for the spatial variation of public facility provision (Andrews & Phillips, 2005). The existing studies on private RACFs suggest that funding changes, management decisions, and local planning influence the location of private RACFs (Phillips & Vincent, 1988). Demographic and socio-economic differentiations across areas influence the distribution of residential aged care facilities. The concentration and affluence of the local aged population are reliable predictors of location of both public and private RACFs. According to an interview conducted by an urban planner in Shenzhen, China, the expected distribution of RACFs is significantly related to green space, medical services, suburbs, and residential land (Shenzhen Urban Planning and Land Resources Committee, 2013).

Location selection of RACFs involves urban land use planning. The *Code for Planning of City and Town Facilities for the Aged in China* specifies the basic principles of location selection. RACFs should be adjacent to areas with high densities of elderly, hospitals, and parks, and located in natural and sunny environments. The land should be flat and well-ventilated. Infrastructure and transportation should be convenient, and removed from the highway, heavy traffic intersections, pollution sources, and dangerous goods (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2007).

The location selection process of the RACF is relevant to senior services planning, which confirms the target level of RACF places (for example, four places per 100 persons in Beijing) to ensure an adequate supply of care places and to achieve equitable access to services between the city center, and suburban and rural areas. Then, according to the number of places planned in different regions, the government or private investors make the decisions about operating the RACF and choosing its location. Land can be acquired in three different ways, as land from previously bankrupted RACFs, land that can be repurposed from its original use (for example, industry land, commercial land, or land used for infrastructure), and new land, which is allocated according to the principles of RACF location selection, such as under the *Code for Planning of City and Town Facilities for the Aged in China*.

5. ENVIRONMENTS AND THEIR INTERACTION WITH THE AGENTS

As mentioned above, the living environment is linked significantly with seniors' lives. The World Health Organization (WHO) uses the concept of the age-friendly city, which provides a detailed description of age-friendly environments (World Health Organisation (WHO), 2007). Age-friendly cities are defined in eight parts which overlap and interact with each other (See Figure. 5).

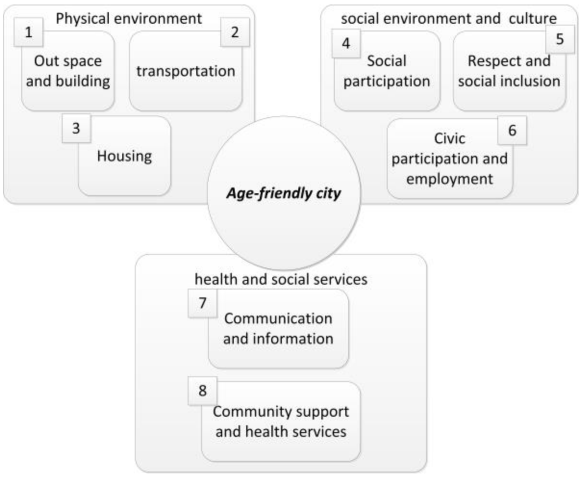

Figure 5. Age-friendly city framework of WHO

Outdoor spaces and buildings, transportation, and housing are key features of a city's physical environment. The social environment affects the mental well-being of seniors. Health and social services are offered for the promotion, maintenance and restoration of health (World Health Organisation (WHO), 2007). Therefore, the living environment plays a fundamental role in the daily lives of the elderly, especially for seniors who are ageing at RACFs. Many social geographers, urban planners and architects have done further studies on specific enabling environments, such as barrier-free environments, parks, and recreational settings for the elderly (Carp & Christensen, 1986; Kaplan, R., 1985; Phillips et al., 2005; Rosenberg, 1998). In addition, different types of neighborhoods are characterized by location, environmental quality, access to services and facilities, and residential density. Seniors living in different neighborhoods have significantly different socio-economic attributes and behaviors (Knox & Pinch, 2000; Chai, 2010; Wu, F. L., 1992). They will also make discriminating assessments on different dimensions of seniors' living environments (Cunningham & Michael, 2004; State Advisory Council on Aging, 2007). Therefore, the enabling environments in different neighborhoods should be diverse.

In this simulation, the input of the environment should primarily include the physical environment, social environment, health services, and the urban distribution of different types of neighborhoods. According to the environment parameters (for example, the number of bus stations, size of outdoor spaces, etc.), and the agent evaluation indicators (such as an elderly person's accessibility or satisfaction), the interactions between agents and environments are built. The statistical report of these factors provides a method to support the systematic allocation of infrastructure or facilities and the urban planning of age-friendly cities. The urban policy is an essential aspect of the environment as well. It includes direct policies, such as the social senior service policies, and indirect policies, such as social security system policies and household registration policies. The critical contents of these policies will be selected and translated into the parameters that are important for the rules governing agents or the interactions between agents or between agents and environments.

6. INTEGRATED SIMULATION AND DISCUSSION

The ECSS Model includes three simulation parts: 1) several simulation modules, 2) the section of the database and data input, and 3) the definition of output reports. The simulation modules are related to elderly population, urban environment, and external factors. The integration of the micro simulation modules of the ECSS Model is shown in Figure 6. Through inputting the data of individual elderly, day-care centers, RACFs, and other environmental facilities in simulation modules, changes and transitions of different agents are processed according to their behavior rules as this paper has introduced above.

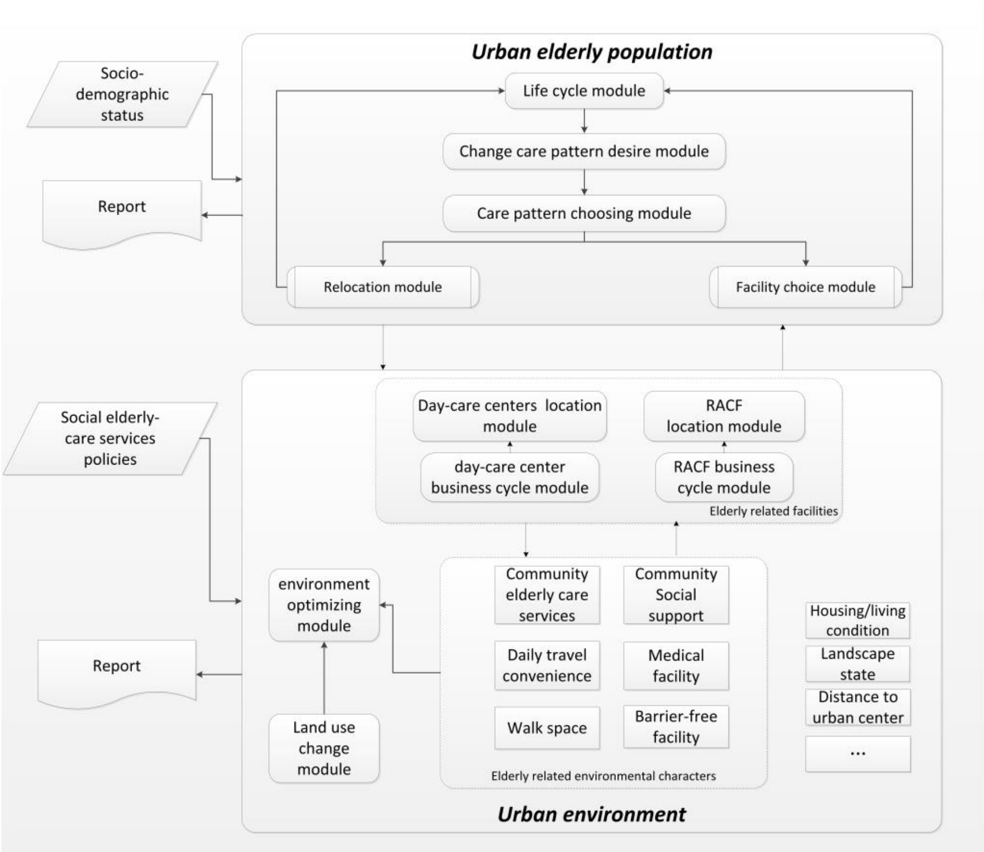

Figure 6. Urban elderly population and environment change processes and micro simulation modules

With the agent-based modelling (ABM) approach, there are several platforms that can be used to integrate the agents, modules, and interactions, and to simulate the complicated processes. The platforms now widely used are MASON, NetLogo, Repast, and the Java and Objective-C versions of Swarm. NetLogo is the highest-level platform of these, providing a simple but powerful programming language, with built-in graphical interfaces and comprehensive documentation.

The expected results include two parts, which are the prediction of senior services and the improvement of senior service provision. Regarding the prediction of senior services, the behavior of the elderly within their life cycle courses, the living environment evaluation, the probability of living arrangement changes, and the decision-making process for relocations are imported into the corresponding modules in each simulation cycle. Consequently, the aged population and service needs will be forecast. Based on this, RACFs and their places are provided, and the adjustments to the age-friendly environment in different spaces are conducted. These changes will then impact on the business cycle of facilities and the whole social care system, which will be further regulated by the governance factors. Therefore, by focusing on the individual behavior, micro-space and the dynamic change of agents, the prediction accuracy of this study will improve upon previous research.

In view of the uncertainty of various policies, different policy-scenarios are designed, which are entirely differentiated from the traditional approach known as survey-analyze-plan or SAP. The provision of social senior services will be simulated accordingly, and the suitable long-term provision plan will be determined.

This study is one of the first studies to design a simulation framework that models the demand-supply of senior services with MAS. The findings will be a great support to the provision of elderly service facilities and environmental improvement in urban neighborhoods. The reasonable provision of aged services will be extremely important to the rapidly ageing society and developing countries as capital and resources are limited. The approach of this study (simulation, scenario analysis) is especially useful for urban planning; however, it has limitations in terms of the selection of agents: in actuality, for example, the relatives or children of the elderly play an important role in seniors' lives, even though the impacts do reduce gradually. The programming of children as agents was not possible due to the lack of available data. Due to the nature of cross-disciplinary studies, the diversity of urban policies, and the complicated external environment, the rules and interaction of agents, and the quantitative set of the external impacting factors, are difficult to consider comprehensively, which may be a source of potential errors. In the future, these areas should be further studied and the methods refined.

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