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Conference Paper

Does built form matter in a moving urban fringe? Evidence from a Land Use-Transport Interaction (LUTI) model

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Does built form matter in a moving urban fringe? Evidence from a Land Use-Transport Interaction (LUTI) model

Keywords

land use-transport interaction model, built form, urban growth, urban fringe, greenbelt, green wedges

Abstract

The urban population in 2014 accounted for 54% of the total global population, up from 34% in 1960. This unprecedented growth trend will continue in most developing countries. With massive urbanisation, land at the urban fringe becomes the most popular for development and therefore the urban fringe is moving outwards continuously. As one of many emerging cities, Beijing has undergone rapid urbanisation from 1950-2010. The main built-up area expanded concentrically from 100 to 1210 km², some placed haphazardly. The government concentrated efforts in “stopping pancake-like fringe expansion”. However, the effects remain unclear.

The land use-transport interaction model is widely used to assess the effects of planning policies at entire city scale, and generate the whole metropolitan area’s spatial pattern. However, it is somehow insensitive to built form change. Because LUTI model works on the aggregate level and difference in the built form will be omitted when being aggregated and passed to the LUTI model. However, in reality, different built forms will lead to different policy performances. Most LUTI models, to the best of our knowledge, are incapable of measuring this difference. Therefore, this paper augments existing LUTI models with a LUTI framework compliant built form component, allowing investigations into the impact of built form on whole city function.

In our newly assembled model, we first quantify the effects of built form change on access link change. Then, this change is passed to the macro-level MEPLAN transport model (Echenique, 2004, 2011). Finally, we input the MEPLAN results, including generalised travel cost, distance and time, into a LUTI framework (Jin, Echenique, & Hargreaves, 2013) to simulate population distribution, changes on price level and spatial costs. We then apply this model to Beijing in order to: validate the micro built form component in the general LUTI framework; predict the impacts of alternative built forms in reshaping the city’s fringe; gain insights into how built form at the urban fringe shapes the bigger scale spatial structure.

We calibrate a 211-zone Greater Beijing Region spatial equilibrium model using observed data in 2010. Alternative built forms at the urban fringe for 2030 that share the same floorspace provision are tested. These scenarios include sparse greenbelt and densely built around metro stations (green wedges). The model results will show each area’s spatial cost.

The analyses suggest that under rapid transformative urban change, the built form has an indirect but significant impact on the economic performance of the entire city, through travel behaviour change. In green wedges scenario, access trip length decreases, as does the spatial cost. More people opt to use public transport. In the sparse greenbelt scenario, spatial costs increase and more people use private cars. These results allow understanding of the impact to whole city economic performance from built form change at the neighbourhood scale. They also provide insights into designing better built forms, as such design on neighbourhood and district scale are more feasible in practical implementation – not only for cities in emerging economies but also fast-growing cities in the developed economies that are revisiting the design.

1. Introduction

The urban population in 2014 accounted for 54% of the total global population, up from 30% in 1950, and continues to grow (Department of Economic and Social Affairs United Nation, 2014). This unprecedented growth trend will continue in most developing countries. Growing urban population demands massive land for urban constructions. Urban expansion has been witnessed in many developed countries (US, Canada, UK, France) as low density constructions sprawling into the suburbs, and also in many developing countries (China, India, Mexico) as an outward expansion from the urban core to the periphery in a concentric ring structure.

Such expansion cause many problems. Brueckner (2001) notes three types of market failure which lead to the excessive spatial growth of cities: 1 a failure to take into account the social value of open space; 2 a failure on the part of social costs of congestion; 3 a failure to take into account the public infrastructure costs. The market failures explain the economic loss of urban expansion, associated with social and environmental problems, which have been witnessed in empirical studies as too much travel, pollution, congestion and vanishing urban open spaces (Anas & Pines, 2008).

In the moving urban fringe, the problems tend to be severer. Urban fringe is a place where the new bulk of development happens and various constructions and regulations conflict each other. It therefore plays a crucial role in shaping the city. There have been many attempts to control the development of the urban fringe for a variety of policy objectives. For example, in the UK greenbelt policies have existed for more than 60 years to control the ribbon development and sprawl of London and many other cities (Hall, 1973); urban growth boundary policies have a long tradition in the United States (Jun, 2004; Staley, Edgens, & Mildner, 1999). Apart from the macro level urban containment policies, there are also policies on design level to address the problems caused by urban expansion. For example, the Uxcester Garden City research (Rudlin & Falk, 2014) suggested a “snowflake” pattern at the urban fringe. So that new constructions are well linked to existing city and the sizes are confined to a certain radius. The Beijing government intended to densify roads, increase neighbourhood density and improve public transport in the urban fringe, so that the accessibility will be improved. However, the effects of such policies remain unclear, especially in emerging economies with rapid change, where the urban population are expected to double in the coming decades.

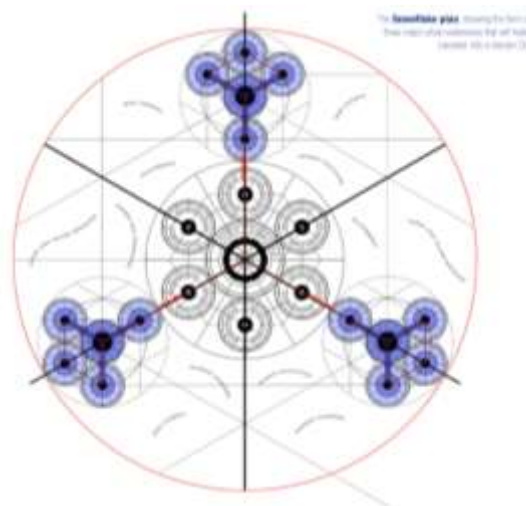


Figure 1 snowflake plan of Uxcester garden city. Source: (Rudlin & Falk, 2014)

On the macro scale, there are many well established models that examine a certain effect of urban growth restrictions, for example the effects on housing price, location choice, travel time, etc. They have identified both land and house price differentials (Ball, Cigdem, Taylor, & Wood, 2014; Knaap,

1985; Nelson, 1986, 1988) due to supply constraint and amenity values (Correll, Lillydahl, & Singell, 1978; Lee & Fujita, 1997; Lee & Linneman, 1998; Lee, 1999) as probable consequences from growth controls such as greenbelts and urban growth boundaries. The impacts of growth restriction on transport costs can be seen from the re-distribution of jobs and population (Jun & Bae, 2000; Jun & Hur, 2001).

Apart from modelling a certain effects of growth restriction, land use transport interaction (LUTI) models are applied to reveal interactions amongst markets and generate an “instant metropolis” at a point in time in the future (Wegener, 2014). Pioneering efforts of LUTI model stemmed from von Thuenen’s model of agricultural land use and developed by Alonso-Muth-Mills into a monocentric city model, concerning trade-offs between location (transport) and plot size (land use). Lowry’s Model of Metropolis (Lowry, 1964) was the first operational land use-transport model. Following these efforts, a wide range of different land-use transport models applications, including MEPLAN(Echenique, 2011), DELTA(Simmonds, 1999), RELU-TRAN (Anas & Liu, 2007) and so on. Such models are able to examine the effects of growth control on the entire city, including on the transport pattern, population and job distribution, travel mode changes, price related indices and so on.

The other strand is the micro scale modelling, which allows us to see how the bottom-up power has shaped the urban fringe. For example, Cellular Automata (Caruso, Peeters, Cavailhès, & Rounsevell, 2007)(Caruso, Peeters, Cavailhès, & Rounsevell, 2009) (Long, Shen, Mao, & Dang, 2010) (Long, Shen, & Mao, 2011) and Agent Based Model (Brown, Page, Riolo, & Rand, 2004) (Irwin, Bell, & Geoghegan, 2003) simulate the urban fringe land change on a finer granularity. These models are hard to calibrate, but the finer scale is helpful in policy design process when making decisions on each piece of plot.

However, neither the macro nor the micro models analysed the impacts of micro level design on macro level land use-transport change. That is to say, the LUTI model is able to assess the effects of planning policies at entire city scale, but it is insensitive to micro-level (neighbourhood or district) built form change. For example, assume there are two policy scenarios with the same floorspace supply quantity as inputs into LUTI model. One case is that all houses concentrate around road nodes; the other that houses distribute sparsely. Because the LUTI model works on the aggregate level, the difference in built form is omitted when aggregating floorspace. Given equal floorspace provisions, regardless of built form, the LUTI model will output the same spatial patterns. However, in reality, different built forms will lead to different policy performances. Most LUTI models, to the best of our knowledge, are incapable of measuring this difference. Therefore, this paper augments existing LUTI models with a built form component, allowing investigations into the impact of built forms on whole city function.

2. Methodology

2.1. Land use-transport model framework

The land use-transport interaction model focuses on the macro level simulation and explores interactions between urban activities, transport demand, land supply and infrastructure supply. On the demand side, urban activities generate transport demand so that people and goods can move within and between different zones, which also affect urban activities. On the supply side, land supply incorporates with transport and infrastructure supply. There are interactions linking supply side and demand side until an equilibrium reaches. Traffic flows generated by land pattern will be substituted into the transport model, while transport model will generate updated travel time, cost and distance which will be feedbacks for land use model. In this way, a feedback loop is formed.

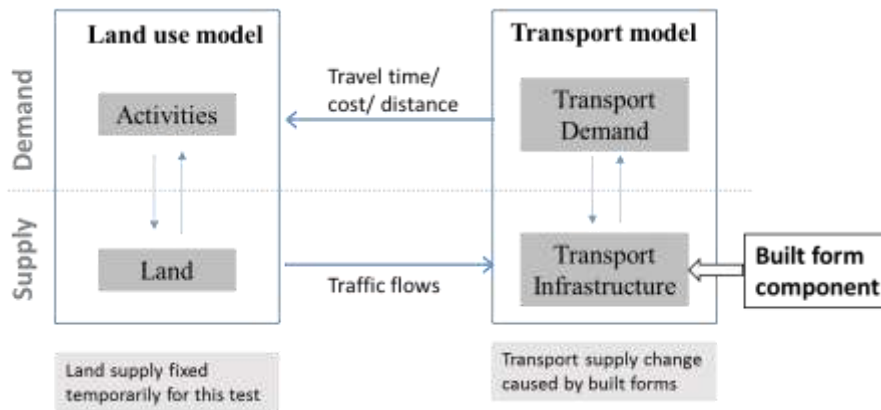


Figure 2 model structure. Source: drawn by the author

In this model version, we fix the land use side of the model and only take the transport infrastructure supply as variable. The variables are passed from a micro built form component to macro transport model because different built forms affect the access road length in transport supply. The transport model will generate travel costs and these will be used for land use model in future tests.

2.2. Strategic transport model

The strategic urban transport model is one of the most effective tools to support the policy makers and planners through predicting the effects of alternative policies. The model area is divided into zones, complying with the land use model, and can output travel demand between zones (inter-zonal trips) and within zones (intra-zonal trips) in different travel modes on each link, given a certain network supply. The supply of transport infrastructure in the study area is represented in the model by a network, comprising a set of nodes and a set of links.

The basic structure is a four-stage transport model (Williams, 1994). 1 trip generation; 2 trip distribution; 3 modal split; 4 link assignment. The first two stages are carried out in the land use module to generate travel demand and convert trips into flows. The transport model then carry out stage 3 and 4 so that we can see the travel mode split and congestion level under alternative policies.

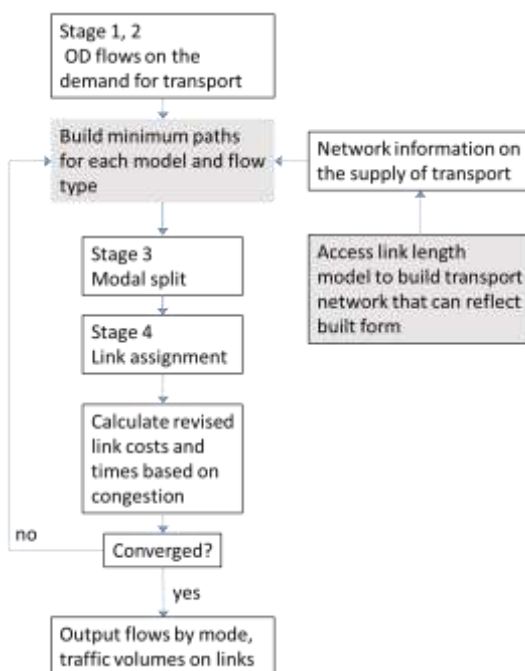


Figure 3 transport model structure. Source: drawn by the author

The modal split step is a logit based hierarchical discrete choice model of the basic form as equation below:

$$F_{ijh}^k = F_{ij}^k \frac{e^{-\lambda^k(\phi^k c_{ijh}^k + t_{ijh}^k + p_{jh}^k + \Omega_h^k)}}{\sum_h e^{-\lambda^k(\phi^k c_{ijh}^k + t_{ijh}^k + p_{jh}^k + \Omega_h^k)}}$$

where F_{ijh}^k is the trips of type k from zone i to zone j on mode h . The modal disutility function consists of four elements: out-of-pocket travel cost c_{ijh}^k converted into time units through the marginal utility of money ϕ^k , travel time t_{ijh}^k , destination disutility (such as parking fee) p_{jh}^k , and mode specific constant Ω_h^k (Jin, Williams, & Shahkarami, 2002). The network assignment also applies a logit-based, stochastic user equilibrium algorithm.

2.3. Built form component and access link length

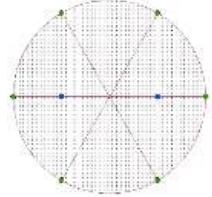

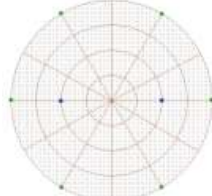

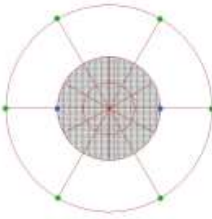

In the transport model, we work with spatially aggregated data on zonal level. That is to say activities are assumed to be generated from the zonal centroid. In inter-zonal travel, journey starts from a centroid and ends in another centroid. We are able to measure the travel cost and distance on each link, but unable to accurately measure the cost between the centroid and the road access node from which people begin to use the road. This is because the aggregate centroid does not accurately reflect the disaggregated locations of activities (Miller & Shaw, 2001, p. 212). This problem especially stands out in the urban fringe zones, because in such zones activities are dispersed and the zonal sizes are larger. Additionally, the aggregate centroid cannot reflect different built forms in the zone. That is to say access link network is not well represented in the transport supply side of LUTI model.

For example, when building the Beijing model, we are not able to measure built up patches one by one. Also the population data is on an aggregated zonal level. So we cannot find an accurate centroid to represent activities, and consequently the access link length is not well represented. The basic solution is to relate the access links length to the geometric features of the zone, namely the radius, in order to estimate the length change due to built form change. In such way, although the land use information is inadequate, we can still obtain a reasonable gauge of the access link length to reflect built forms. In this light we establish a built form component that can estimate access link length based on the zonal built form.

There are 3 typical built form in the urban fringe: 1 Greenfield. 2 Towns (ubiquitously built up). 3 Transit Oriented Development (TOD) new towns. Type 1 zone is mainly greenfield, which means roads and built up areas are sparse. Type 2 zone is the commonly seen in concentric pancake-like urban expansion, which means roads and constructions spread ubiquitously and homogeneously without policy intervention. In Type 3 zone, construction is allowed in the designated areas, like a built-up wedge, concentrating around transport nodes densely. The rest part is still maintained as greenfield.

For each type of built form, a ratio is assigned to represent the relations between the zonal radius and access link length. Detailed calculation and validation method can be found in the next section.

Table 1 built forms and access link length estimation

Type	Generic type	Example	Road access link length	Station access link length
1			100% R	114% R
2			93%R	86%R
3			96%R	58%R

2.4. Built form component calculation and validation

2.4.1. Calculation of access link length in the built form component

In the aggregate transport model, if travelling by car, traffic will be passed from centroid to the nearest road access nodes, and through these nodes to links. Then the model will compute the optimized paths to another zone. This method is widely used. It works well in the city zones with ubiquitous urban activities and ubiquitous roads. However, in the most urban fringe zones, road density is not as high as the city and built up patches do not distribute homogeneously. Then the access link length comprises a large proportion of distance of “not-on-link” travel. In that case, the common method of using the nearest road nodes should be improved.

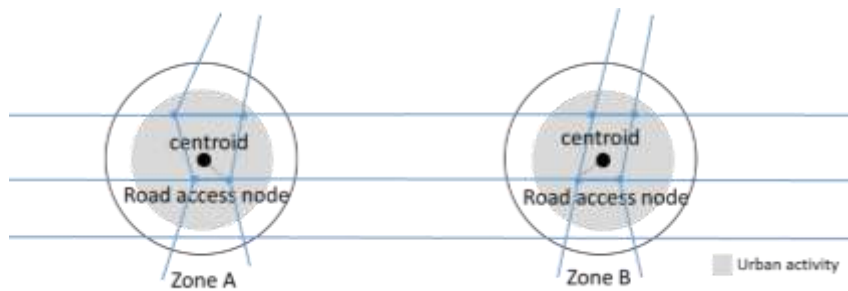


Figure 4 diagram of building access link in homogeneous urban area with ubiquitous roads

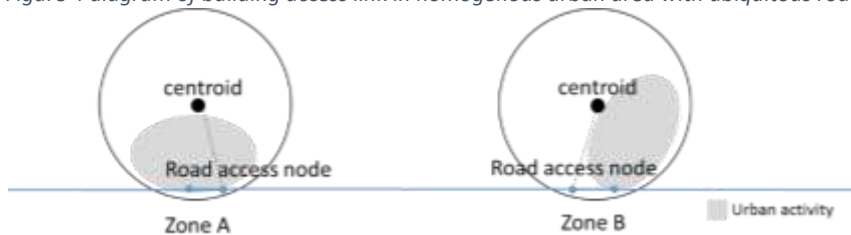


Figure 5 diagram of building access link in heterogeneous urban area with sparse roads

If travelling by metro, traffic will be passed from centroid to a certain station that can minimise the distance to the destination zones. For example, if travelling from Zone A to B, the station in the east of zone A will be used. And the access distance is the straight line distance from centroid to stations. In the urban fringe zones the algorithm stays the same but the distance to the station will be longer because of less road provision.

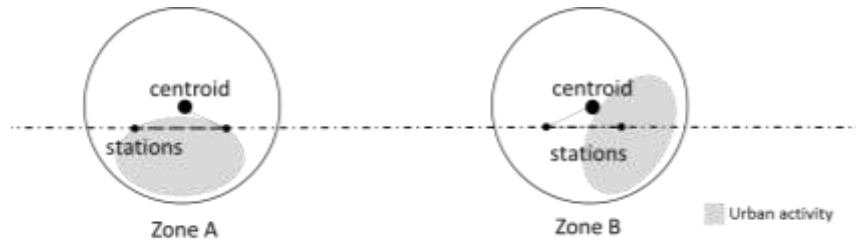


Figure 6 diagram of building access link for stations

a. Archetypes and assumptions

In order to find the distance from where urban activities generate to the road access nodes, a round city zone with a radius of 4 km is built. The size of the zone is determined based on the approximate average size of the urban fringe zones in Beijing. There are 5088 dots (on a 100m*100m grid) distributing homogenously in the circle, each of which represents an urban activity, namely the origin of a trip. Green dots are the road access nodes while the blue dots are the stations. g The 3 generic types follow the classification in last section.

Table 2 archetypes of zones

Type 1 greenfield	Type 2 towns	Type 3 TOD new towns

Urban activities will be either sorted or unsorted according to their trip destination. Sorted urban activities means that activities choose to locate around the node which is near the destination zone for inter-zonal travel. For example, if a man lives in a zone and works in another zone to the west of this zone, he will choose the left part of this zone to reside, because the very left node is the one he uses to travel to the west. Unsorted urban activities is the opposite. Even if someone is travelling to the west to another zone, he might live in the east of the zone and still choose the access node in the left half. When calculating the distance, we will use the average of sorted and unsorted length.

b. Calculation

The length to nearest node consists two parts. The first part is to get the average distance from any starting point onto the nearest link, namely the green line. The second part is to get the distance on the link to the nearest node, either road access node or station, namely the blue line.

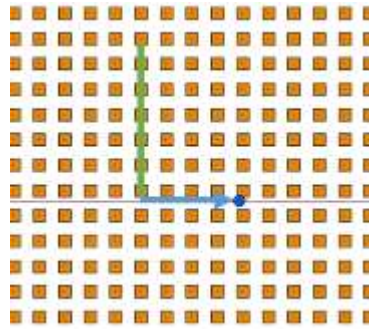


Figure 7 diagram of length composition

We use Monte Carlo method to simulate Part 1 and Dijkstra's algorithm to simulate Part 2. Then the two parts are added to find the total average distance from urban activities to access node.

c. Results

Table 3 results to road access nodes (at the border)

	Part 1 door to road			Part 2 on road to road access node						total		
	Type1	Type2	Type3	type1		Type2		Type3		Type1	Type2	Type3
Distance to road access nodes as a percentage of radius	11.3%	4.5%	3.1%	88.8%		88.3%		93.1%		100.1%	92.8%	96.2%
				sorted	unsorted	sorted	unsorted	sorted	unsorted			
				41.9%	135.7%	54.8%	121.8%	73.4%	112.8%			

As the results show, the average distance that people travel to their nearest road access nodes (at the border) to another zone is about the radius of the zone. If ubiquitous road system is built, the distance should be slightly shorter because there are more roads to choose and short cut may exist.

Table 4 results to stations

	Part 1 door to road			Part 2 on road to station						total		
	Type1	Type2	Type3	type1		Type2		Type3		Type1	Type2	Type3
Distance to stations as a percentage of radius	11.3%	4.5%	3.1%	102.7%		81.9%		55.2%		114.0%	86.4%	58.3%
				sorted	unsorted	sorted	unsorted	sorted	unsorted			
				93.4%	112.0%	65.8%	98.0%	46.3%	64.0%			

The difference of distance change is caused by the provision of roads to the stations and also by the density of population around the stations. TOD is a type of built form that high density urban activities concentrate around stations. As a result, travel distance to stations are shortened.

2.4.2. Validation of access link length in the built form component

a. Data

We measure several zones access distances in the urban fringe area of Beijing and use the empirical data to validate the ratios we obtained in the theoretical model. Radius of zones are defined as the arithmetic average distances from centroid to all vertices.

Land use data

We selected zone 23, 86, and 89 as our case study area. The study area contains Yizhuang town centre and its surrounding hinterland. It is between the 5th and 6th ring road and also locates in the greenbelt. Zone 86 is a type 2 zone with ubiquitous roads. Zone 23 and 89 are type 1 zones with sparse roads. Land cover data is mapped by the author, based on google earth historic maps, 2005-2010-2015. Land cover was classified into 7 types according to planning code (Ministry of Housing and Urban-Rural Development, 2011):

Table 5 land use type classification

	Land use types	Estimated FAR	FAR Source
Village	H12,H13,H14,	0.8	estimated from map
Low density housing	R1	1.5	
Medium-high density housing	R2	2.5	Estimated from Yizhuang regulatory plan
Industry+warehouse	M,W	1.5	
Commercial+service	A,B,U	3.5	
Road	S1,S2	\	\
Open space	The rest land use types	\	\



Figure 8 land overage, 2005 (top left) 2010 (top right) 2015 (bottom)

Based on the census and mini census, the zonal employed residents and employed workers are calculated as follow:

Table 6 data employed residents and workers

	Zone 86		Zone89		Zone23	
	Employed resident	Employed worker	Employed resident	Employed worker	Employed resident	Employed worker
2005	52,465	153,660	41,500	44,877	37,383	22,519
2010	84,074	221,250	60,526	57,139	57,282	29,657
2015	101,931	275,223	78,728	67,922	67,970	34,909

Population will be distributed according to the plot area, land use type and FAR of each patches. For different land use type, we use the FAR defined in Table 5 and then allocate employed residents to land use type H12,H13,H14, R1 and R2; allocate employed workers to land use type M,W,A,B and U. In that case, travel demand are generated.

Transport data

Transport network is done by Deng (2015).

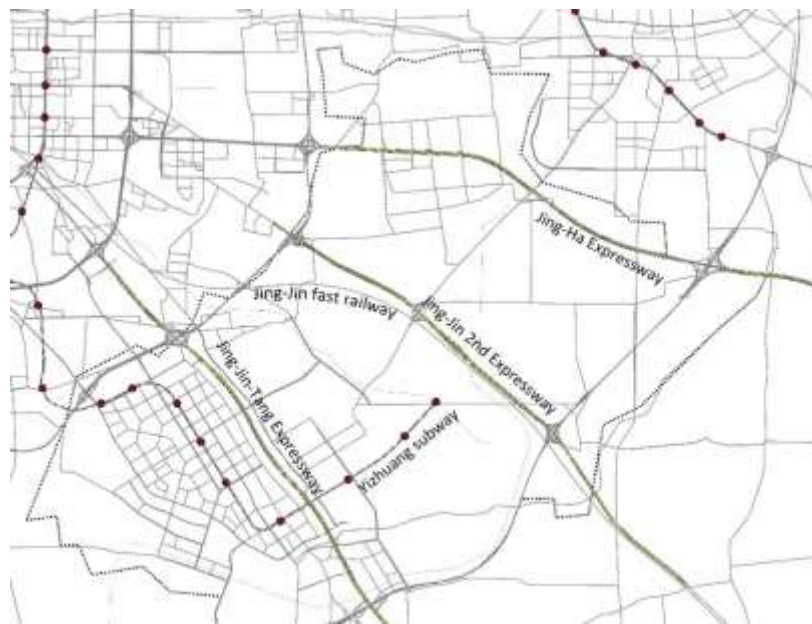


Figure 9 transport network

b. Analysis

The following steps are used in access link length calculation

1. Find patch centroids to represent patches in 2005, 2010, 2015, as origins of trips. Each origin has got an assigned number of road users, due to the allocation of employed workers and residents.
2. Select road access nodes at the border; normally one road access node to one zone. Select stations as access nodes; normally one station leads to one direction.
3. Generate the length from all patches to nearest road access node under perfect sorted assumption; from all patches to a certain road access node under unsorted assumption, using ArcGIS software.
4. Find the weighted average trip length from each patch.

$$L = \frac{\sum(\text{access link length} * \text{number of road users})}{\sum \text{number of road users}}$$

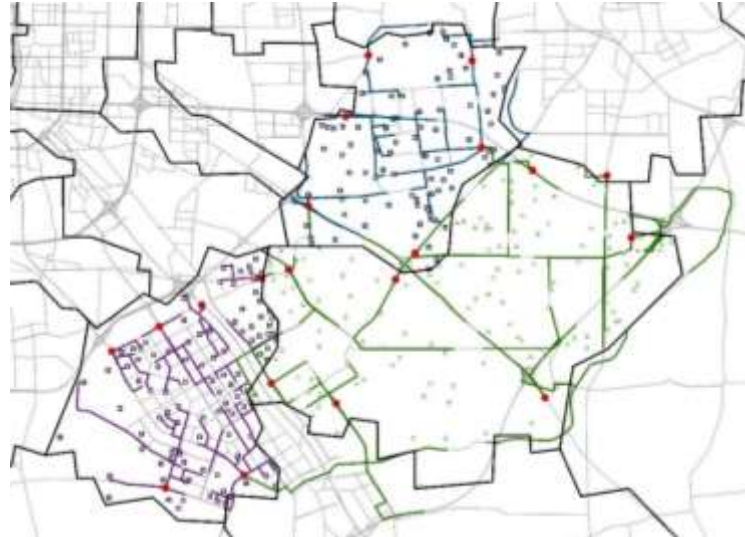


Figure 10 diagram of finding shortest path using ArcGIS

Table 7 comparison of empirical number against theoretical number for road access link length

	23 type1 greenfield			86 type2 towns			89 type1 greenfield		
radius	3519			3724			5152		
	unsorted	sorted	ave	unsorted	sorted	ave	unsorted	sorted	ave
2005	6124	1784	3954	5337	2104	3720	7401	2474	6175
2010	5784	1829	3807	5676	1793	3734	7202	2935	6536
2015	5459	1918	3689	5875	1782	3828	7173	2726	6313
Distance to road access nodes as a percentage of radius	104%-112%			99%-102%			96%-98%		
Ratio from theoretical model	100%			93%			100%		

Table 8 comparison of empirical number against theoretical number for station access link length

	86 type2 towns			89 type1 greenfield		
radius	3724			5152		
	unsorted	sorted	ave	unsorted	sorted	ave
2010	4326	2525	3426	7554	4279	5917
2015	4357	2515	3436	8165	3795	5980
Distance to stations as a percentage of radius	91%-92%			115%-116%		
Ratio from theoretical model	86%			114%		

The empirical numbers prove that the ratios from theoretical model are close enough to reality. We did not measure the type 3 zones for its access link length. It is a future ideal built form that promoted by the government. It is reasonable to assume that the access link length to stations reduces when people live in a compact form. Therefore, we use these ratios to build Beijing transport model.

2.5. Modelling results assessments

The land use model outputs will show the average economic productivity and household utility under different greenspace configurations and these economic indices can also be presented in quantities in zones, including total productions, product price, wages, rents, household utility and economic mass.

The transport model outputs will show the travel time, distance and costs under different greenspace configurations by social economic groups and by different travel modes.

At this stage, we only run the transport model, and the results from land use model and their interaction will come in future.

3. Modelling the moving urban fringe of Beijing

3.1. Background

Beijing has undergone rapid urbanisation from 1950 to 2010: the main built-up area expanded concentrically from 100 to 1210 km². Its population grew from 4 to 20 million, implying an annual growth rate of 2.5%. By comparison, London grew by 0.88% per year under its rapid growth period 1891-1941.

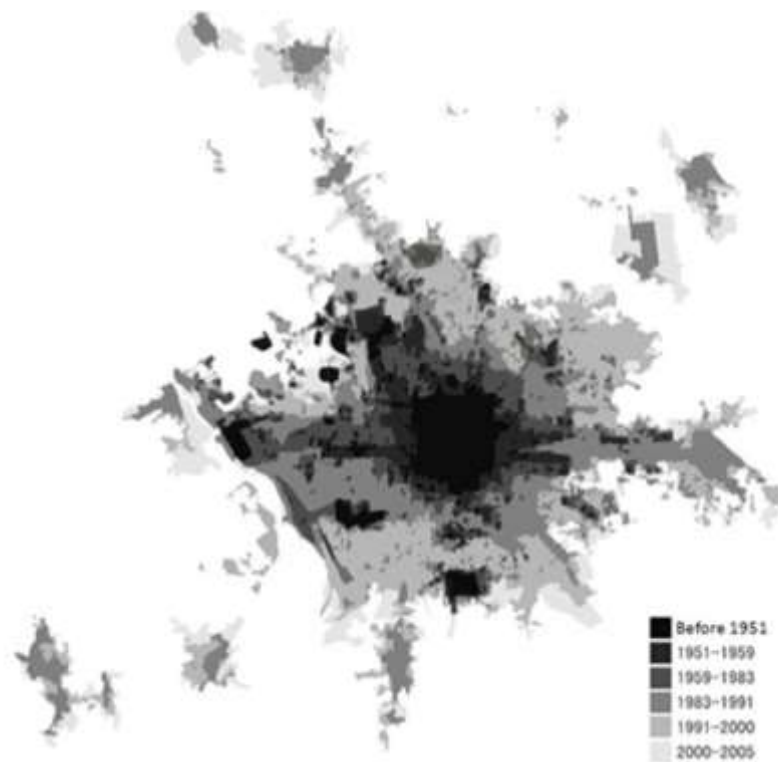


Figure 11 Beijing's urban expansion 1950-2005

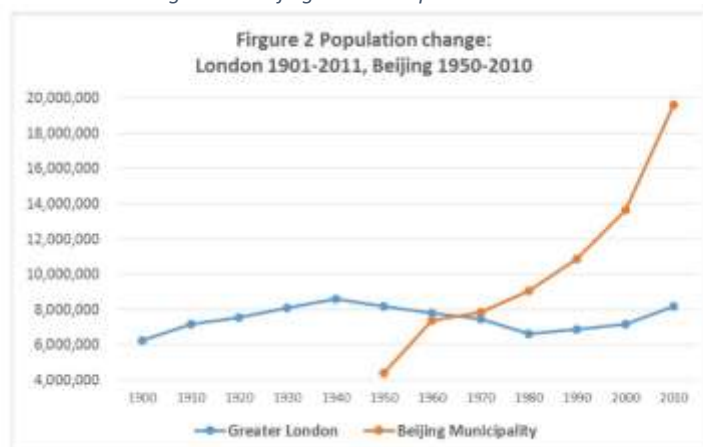


Figure 12 comparison of population change

The government followed the practice in the UK and introduced its First Greenbelt policy in 1994 to mitigate the problems at the urban fringe, including bad sanitary conditions, haphazard constructions and losing green spaces. 240 km² of green areas around the fourth ring-road of Beijing were designated as the First Greenbelt. The long-term goal was that by the end of 20th century, 40% of the total area of Beijing would be greened. Recreational facilities were allowed to be built in greenbelt but the only 2-3% land could be used for constructions. However, the urban expansion in the mid to late 1990s spread across this designated greenbelt land. The total built-up area within the designated First Greenbelt increased from 33.3% in 1993 to 49% in 2005, with a corresponding decrease in the green area from 66.7% to 44.3% (Han & Long, 2010).

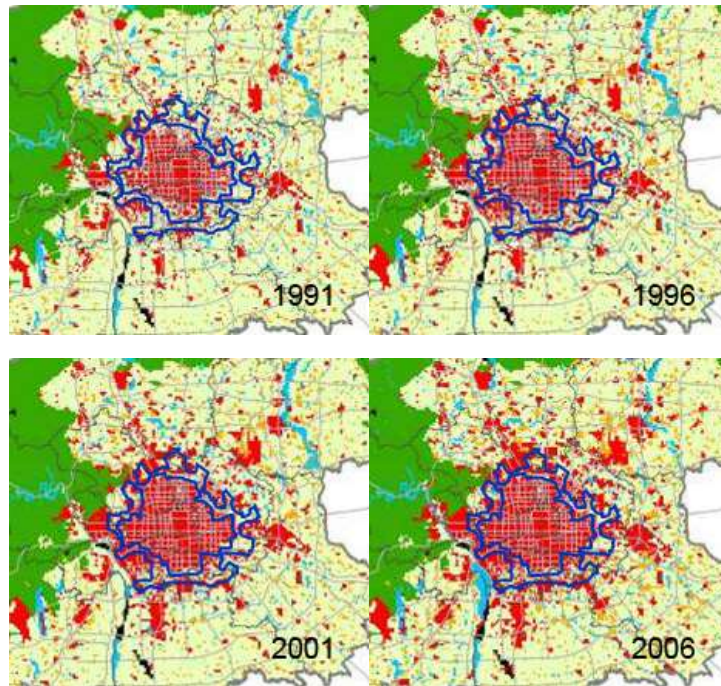


Figure 13 Urban land use change before and after 1st Greenbelt policy Source: (Long, Gu, & Han, 2012)

The Second Greenbelt was introduced in 2003 and emphasised in Master Plan 2004-2020, with a designation of 1556 km² of green areas between the fifth and sixth ring-roads. It widens the First Greenbelt and connects the first with the outer suburb area of Beijing. The long-term aim is that in 2020, 50% of this area will be covered by vegetation. This policy had some effects as the total green area increased from 366 km² to 566 km² from 2001 to 2008 (Gan, 2012). However, this number is still lower than the original total green area in 1990s which was 757 km² and is far from the policy aim.

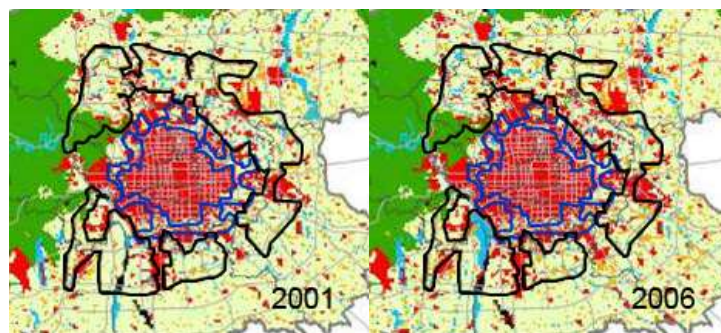


Figure 14 Urban land use change before and after 2nd Greenbelt policy Source: (Long et al., 2012)

Population in Greater Beijing is expected to reach 40 million before 2050. As economic, environmental and social conflicts at the urban fringe have intensified, “stop pancake-like expansion” policy has been re-emphasised in recent Mayor’s statements. Greenbelt still stays in the latest revision of Beijing

Master Plan although there are arguments about releasing it. Meanwhile, some planners proposed to build on some areas in the greenbelt with high density, in order to mitigate the housing shortage and improve the local farmers' living condition.

But there is no conclusive policy scenario to elaborate what will happen in Beijing's urban fringe in the coming decades. The strengths and weaknesses of different proposed built form should be analysed quantitatively and rigorously. Therefore, we establish this model to test and compare the densely built wedge form (green wedges) to the sparse greenbelt built form as a solution for Beijing's sustainable growth.

3.2. Model set up

3.2.1. Geographical extent and zoning system

This model covers the whole Beijing Municipality, Tianjin Municipality and the major regional hubs in Hebei province. The whole model consists 211 zones according to the existing administrative boundaries and transport links. Beijing Municipality is divided into 130 zones with detailed road network.

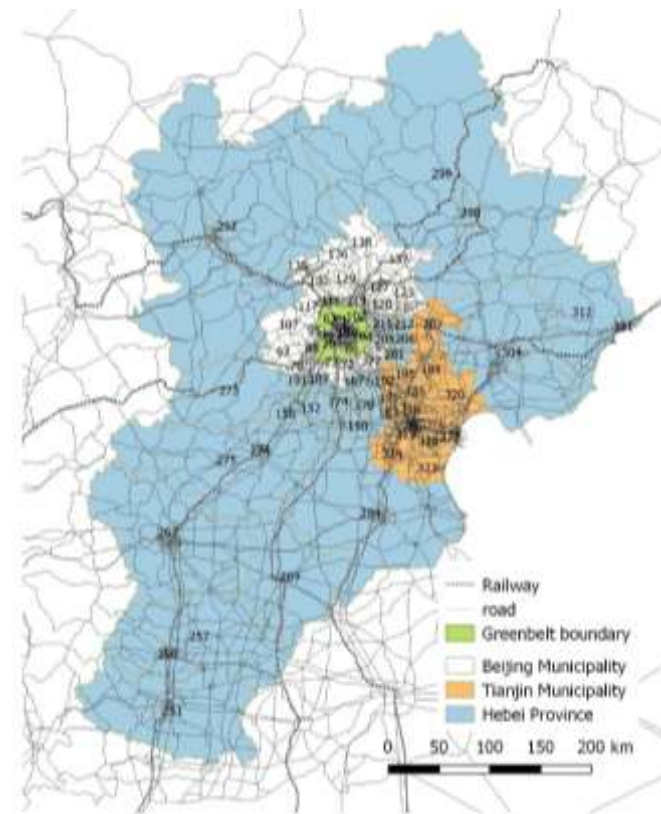


Figure 15 zoning system with railways and greenbelt

We then extract 28 zones as urban fringe zones based on the 2nd greenbelt policy. Boundaries of the 28 zones do not 100% comply with the Second Greenbelt policy, because zones are defined by transport and administrative boundaries, not by greenbelt policies. But this zoning is good enough to show the ring effects.

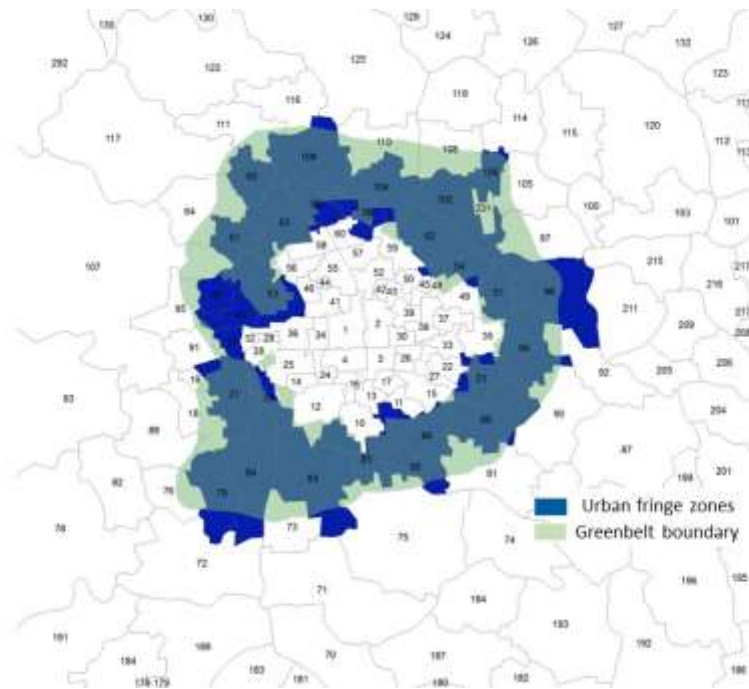


Figure 16 selection of 28 urban fringe zones

The 28 urban fringe zones are then divided into 3 types according to the built form component classification in section 2.3. Green zones are Type 1 greenfield. Red zones are Type 2 towns. Orange zones are Type 3 TOD new towns, namely wedges.

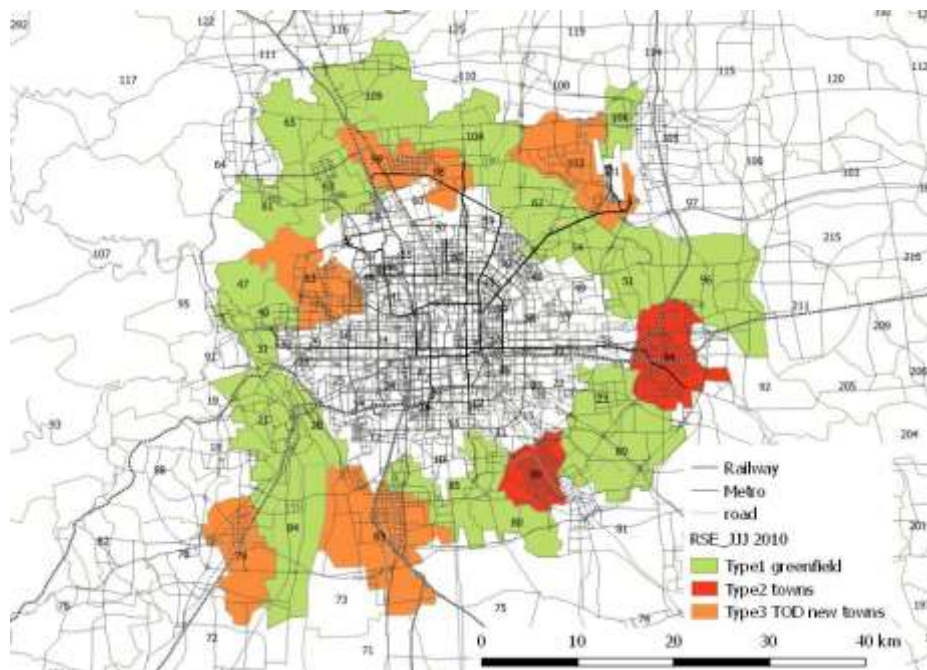


Figure 17 built form classification of urban fringe zones in 2010

3.2.2. Modelling years and transport network updates

We will take 2010 as base year and predict the future 2020 and 2030 land use-transport pattern of Beijing under different policy scenarios, namely trend growth, sparse greenbelt and densely built wedges. The base year 2010 network is built by Deng (2015) based on open street map. Networks are classified into road, metro and rail. For each type of networks there are different types to represent

speed and capacity. In future model years 2020 and 2030, according to the transport development plan of Beijing, new metro lines are added.

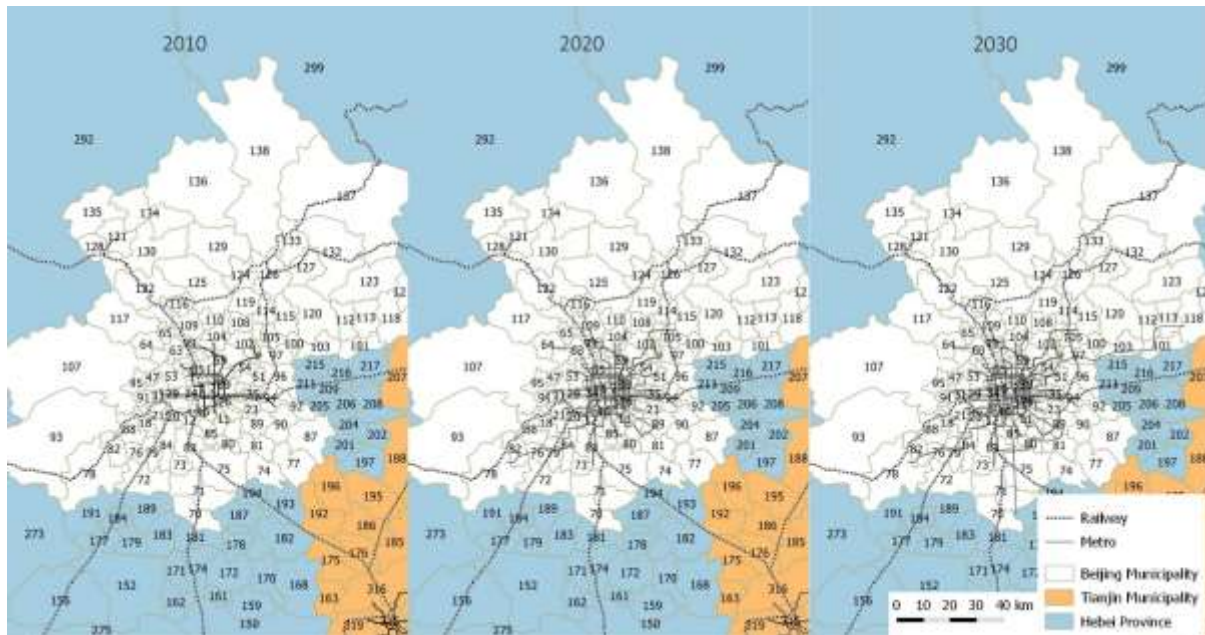


Figure 18 Metro lines and main railway connections development

3.3. Scenarios

The scenarios in the same year have the same demographic settings: the same number of households and jobs, and the same family size and income. In order to show the effects of built form change clearly, we fix the zonal floorspace supply in different scenarios in the land use model. This is to say the only variable – built form at urban fringe - is represented in the transport model, not the land use model.

Each fringe zone will be designed to evolve into another built form type or remain the original built form type from 2010. As built form changes, access link lengths to stations and to road junctions also change according to the ratio in section 2.3. Transport model will reach new equilibrium given new inputs of access link. Then the updated zonal travel time, cost and distance will be fed into the land use model 2020 and 2030 for scenario tests.

Table 9 description of scenarios

Scenarios	Description	Variable: access link length
Trend growth	The pancake like expansion of Beijing shown in Figure 11 will continue. All the greenfield will be filled with constructions.	Base case
Sparse greenbelt	The greenbelt policy will be reinforced. Most zones at the urban fringe will be kept or turned back into greenfield.	Generally speaking, the access link length to stations will increase and to road nodes will remain similar, compared to the base case.
Green wedges	Development is allowed in most zones at the urban fringe, but confined within a certain area around stations.	Generally speaking, the access link length to stations will be short and to road nodes will remain similar to the base case.

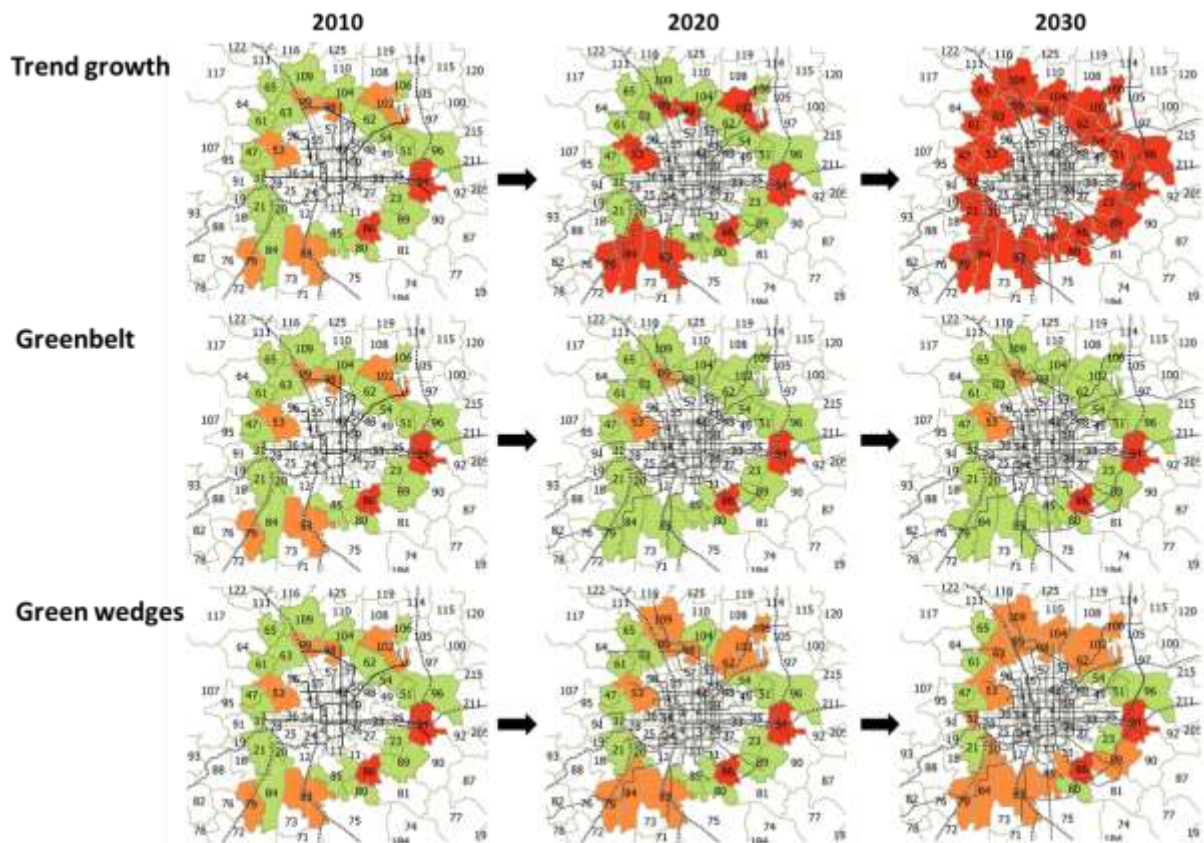


Figure 19 zone type changes in scenarios through time

The access node codes and the link codes, as shown in Figure 20, remain unchanged through years across scenarios. The only change is their lengths, based on the built form types they are assigned in the scenario. The length is defined according to Table 1. For example, if a zone is a type 1 zone (green) in 2010, the distance to station node is $114\%R$. Under the densely built wedges policy, it turns into a type 3 zone (orange) in 2030, the length of the same link to the station will reduce to $58\%R$.

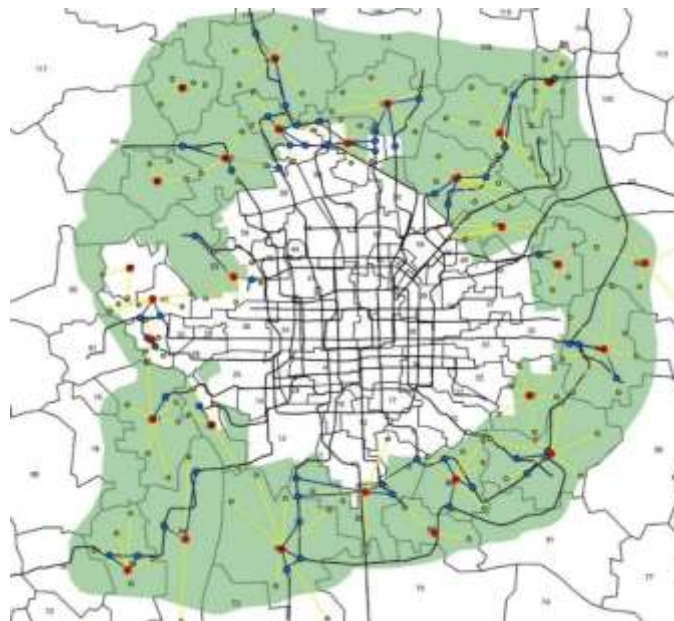


Figure 20 access nodes (yellow for road access nodes, blue for station access nodes)

3.4. Model runs

We first calibrate the 2010 base year model. It is a full LUTI loop until the model reach equilibrium. The land use information will be passed to 2020.

For 2020, we run the land use model first. The land use information will be passed directly to 2030. As we get the job and resident distribution, a travel demand will be generated and travel flows will be input into the transport model. The transport model will calculate travel cost and mode share according to different scenarios. However at this stage, we have not input the calculation results from transport model back into land use model yet. But we assume that if the travel cost is input back to the land use model to form the loop, the land use pattern will be reinforced.

For 2030, we repeat the 2020 simulation sequence. At this stage, the model jumps from 2010 directly to 2030, and model year 2020 is skipped in the recursive simulation, but will be added soon.

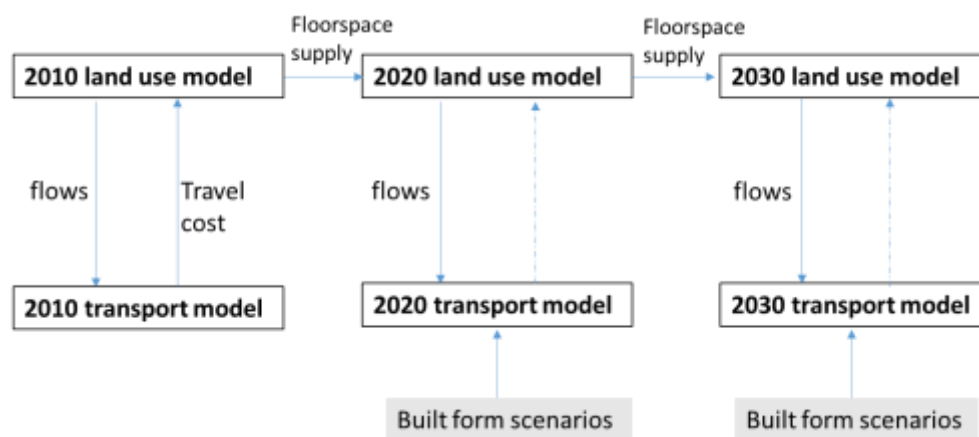


Figure 21 interaction of land use-transport model through time

3.5. Results

3.5.1. Land use modelling results

Results will come in future.

3.5.2. Transport modelling results

The model gives the travel mode share and average travel costs under 3 policy scenarios. Table 10 mode share is the percentage of total trips using a certain mode. The trip purposes include commuting, education, business and all the other trips.

Table 10 overall mode share within 6th ringroad

	2010 base	2030 trend growth	2030 sparse greenbelt	2030 green wedges
Mode share car	29%	40.0%	41.1%	37.0%
Mode share bus	26%	24.3%	24.2%	24.1%
Mode share walk	24%	14.1%	14.1%	14.1%
Mode share cycle	9 %	4.7%	4.7%	4.7%
Mode share metro	11%	17.0%	15.9%	20.1%

Table 11 shows the overall commuting distance and time in morning peak hours in Beijing within 6th ringroad.

Table 11 average commuting time and distance

	2010base	2030 trend growth	2030 sparse greenbelt	2030 green wedges
Average commuting time (min)	39.7	40.0	39.7	38.1
Average commuting distance (km)	7.8	8.5	8.6	8.7

Table 12 zooms into the urban fringe and shows how the people who live at the fringe commute.

Table 12 mode share of commuting trips from urban fringe to zones within the 6th ringroad

	2030 trend growth	2030 greenbelt sparse	2030 green wedges
Mode share car	43.8%	46.7%	36.0%
Mode share walk	24.2%	24.1%	23.7%
Mode share cycle	8.5%	8.5%	8.5%
Mode share bus	3.6%	3.6%	3.6%
Mode share metro	19.9%	17.1%	28.3%



Figure 22 commuting mode share from urban fringe to the city centre

4. Discussions and conclusions

In 2010, motor vehicles are the dominant travel method, as car and bus take 55% of the total travel mode share. Metro, as an eco-friendly travel mode, comprises 11%. In 2030, motor vehicles are still the most popular travel method, but more people begin to use metro, as the percentage goes up to about 20%. Less people walk and cycle. The average commuting time stays relatively stable from 2010 to 2030, but people travel further within the same time. That is to say, the overall speed is improved, by adding more metro lines and shifting to faster travel modes.

In green wedges 2030 scenario, people can reach further distance within a shorter time, compared to trend growth and greenbelt. The transport supply in the 3 scenarios are the same. That is to say, the improvement is from the built form change and the popularity of using metros.

Comparing to 2030 trend growth scenario, greenbelt encourages the use of cars and discourages the use of metros to 17%. Green wedges is a pro-metro scenario as the mode share of metro is the highest (28%). If people live sparsely and the distance to metro station increases, as tested in the greenbelt scenario, more people adopt to car. If people live nearby the metro station in a higher density and the accessibility to the station is improved, as tested in the green wedges scenario, more people adopt to metro. For long distance commuting, most people adapt to metros.

This model helps to assess the pros and cons of different configurations and offers alternatives. It assists the planners and policy makers to make the decision of whether or not to break the greenbelt

and build in it, and what urban form should be established in the moving urban fringe. The model suggests that instead of preserved as greenbelt, land at the urban fringe should be built on, but only in certain areas where the transport conditions are good. Meanwhile the footprint of buildings should be confined within a distance to the metro stations with relatively high density. In that case, the total area of floorspace will stay the same, the total area of greenfield will increase, and the total spatial cost will reduce.

The current model has not reach the full land use-transport equilibrium, because the land use model has been fully established and calibrated. Therefore the model only tested the built form impact on transport side. We believe that the overall patterns of travel and spatial cost will only reinforce themselves under different scenarios in the land use model. Therefore it is reasonable to conclude that in the full LUTI test, densely built wedges will probably still be the low cost and eco-friendly policy scenario while a restrictive greenbelt will probably be the high cost and car oriented policy scenario.

The Beijing case study model is calibrated using data collected for 2010, and used to predict 2020 and 2030, which is the first time that a dynamic spatial equilibrium model is empirically established for a city in an emerging economy. The built form component allows the micro level land use change being connected to the macro level transport impacts. However, results from this paper are from preliminary tests. They should be rigorously calibrated on a finer scale through empirical work.

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