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# Influences of Different Transport Routes and Road Nodes on Industrial Land Conversion: A Case Study of Changchun City of Jilin Province, China

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**Abstract:** Nowadays, urban transit system has become one of the major forces underlying urban pace transformation via changing accessibility of related land parcels, which leads to the changes of land value and land use structure. This paper studied the interaction between land use changes and related transport routes, particular about how different transport routes and road nodes influence the conversion of industrial lands to residential and commercial uses respectively. Taking Changchun, an old industrial city in the rust belt of China as a case of study, we explored and compared the influences of different transport routes and road nodes on industrial land conversion. We found that surrounding the studied transport routes, more industrial lands were replaced by residential lands than by commercial lands. Also, apparent differences exist in the corridor effects of different transport routes (i.e., light rail, expressway and trunk road) and road nodes (i.e., expressway nodes and trunk road nodes) while the industrial lands convert to residential and commercial uses. Our research findings help us to illuminate the interactive relationships between transportation and industrial land conversion in old industrial cities which are undergoing social, economic and the related urban transition in Northeast China.

**Keywords:** urban transport routes; road node; industrial land conversion; corridor effect; spatial effect; old industrial city; China

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## 1 Introduction

Since 1978, urban China has been experiencing rapid spatial, social and economic development, which leads to fundamental urban changes. Two parallel processes, i.e., the expansion at the urban fringe and land use redevelopment at inner city part, have become one of the most apparent changes in urban China. Transportation system is one of the major driving forces of urban spatial and land use changes (Cervero and Landis, 1997; Pan and Zhang, 2008; Cervero and Kang, 2011; Calvo et al., 2013). With the progression of urbanization, urban spatial expansion is often coupled with the construction of diverse transit systems to improve the accessibility of land parcels at different locations (Hawbaker et al., 2005). The relationship between transportation and urban land use remains a classic topic in academia to explore the driving forces of urban land use and the related development of certain urban structures. Classic urban theories such as location theory (Weber, 1929), concentric model theory (Burgess, 2008), multiple nuclei theory (Harris and Ullman, 1945) and bid rent theory (Alonso, 1964) all suggested the significance of locations on urban land use development. These theories

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also paid great attention to the role of transit system in urban land use development. Based on the rent gap theories elaborated by Alonso (1964), land rent near the transit system changes is in parallel with the changes of location. Specifically, the closer a region is to the transport routes, the more convenient it is and the higher the land rent is. Different land use types and the related social-economic activities therefore need to compete with each other for the location near the transport routes. Generally, the higher the payment capacity, the closer the land use type is to the transport routes. The payment capacities of different land use types and their sensibility related to the distance and commuting time determine their spatial distribution pattern and therefore boost the changes and development of urban spatial structure.

A wealth of studies have documented the interaction between transportation and land use with regard to land use structure, intensity and property value (Boyce et al., 1972; Gamble et al., 1974; Baerwald, 1982; Cervero and Landis, 1997; Bowes and Ihlanfeldt, 2001; Perk and Catalá, 2009; Roukouni et al., 2012; Zhang et al., 2013; Lin et al., 2018; Cordera et al., 2019; Zhao and Shen, 2019). Knight and Trygg (1977) studied the extent of the impact of the transportation system on land use. They found that with the acceleration of urbanization, the construction of rapid transit routes can improve the location, i.e., the accessibility of land along the routes, which lead to the diversification of land uses along the routes (Hawbaker et al., 2005). In urban suburbs, increasing the capacity of highway corridors can significantly stimulate the development of land use along the routes (Cervero and Hansen, 2000; 2002; Cervero, 2003). Meinel et al. (2007) found that the closer a region is to a highway, the higher the intensity of land development in the region. Mason (1974) found that commercial development is most heavily concentrated in a 2–4 mile area from the interchange. In a study of the Minneapolis Metro Blue line, Hurst and West (2014) found that after the metro goes into operation, land located closer to metro stations shows a much higher probability of undergoing land-use changes than land located farther away. Bhattacharjee and Goetz (2016) analyzed the changes of the amount of different land use types. They found a noticeable amount of land use change, and especially the growth of commercial and multi-family land use in areas closer to the rail transit system is significantly higher than that in areas far away from the system. Zhang and Wang (2013) examined three newly built suburban transit lines in Beijing and concluded that mass transit system has significant and positive impacts on land development. Also, the improvement of transportation can promote conversion between different land use types. Through exploring the land use changes associated with rail transit in Shanghai, Pan and Zhang (2008) found that higher intensity and more capital intensive development occurred in the areas near stations, and more commercial and office uses of lands replaced residential uses of lands in areas closer to the stations. Tang et al. (2016) analyzed the changes of land use surrounding the expressway. Their study revealed a frequent shift in land use in the areas surrounding the expressway. Areas located far away from the expressway show a much lower intensity of land use change than areas closer to the expressway. A recent study showed that arterial roads seem to play a stronger role in promoting more capital intensive land uses such as commercial and retail uses than metro systems in Beijing. In the core impact areas of metro stations, there are more land parcels transferred for commercial development than for residential development (Zhao et al., 2018).

Some researchers defined the spatial influences of transit system (routes, roads, *etc*.) on land use structure, land use change, land value and so on as 'corridor effect' (Taaffe et al., 1992 ). Baerwald (1982) reported that suburban functional areas tend to be seen in corridors along highways, in clusters, or as corridor-cluster combinations. Sutton (1999) studying land use development in Denver's I-225 beltway corridor, classified it into three stages: residential penetration, residential proliferation and commercial penetration, and commercial proliferation and reorientation of land use. It is also shown that urban trunk road has obvious attracting and excluding effects on land use (Mao and Yan, 2004). Ma et al. (2018) used corridor effect theory to study the influence of diverse transport routes on three land use types. They found statistically significant differences in the corridor effects of different transport routes. Based on these studies, first, many studies have confirmed that the intracity corridor effect is objective. This means that newly constructed transport routes trigger quantitative and distributed adjustment of urban industrial land use in the corridor regions, and industrial land adjustment in regions closer to the transport routes are more intensive than those in regions farther away from the transport routes. More specifically, the intracity corridor effect can be divided into attracting and disturbing effects. The attracting effect refers to that a transport route accelerates the replacement of a particular land use type with another land use type within its corridor region. This attracting effect strengthens with decreasing distance to the transport route, which motivates the replacement of such land use type along the route. The disturbing effect refers to that a transport route disturbs the replacement of a particular land use type with another land use type within its corridor region. This disturbing effect strengthens with decreasing distance to the transport route. Second, we assume that road nodes also have effects, similar to corridor effects, on land use change. More specifically, the spatial effects of road nodes can also be divided into attracting and disturbing effects. This paper thus focuses on the spatial effects of transport routes and road nodes on the existing urban industrial land conversion. Currently, geographic information systems (GIS) and analytical software play a fundamental role in understanding spatial patterns and relationships in a variety of diverse topics. Among these tools, density analysis and buffer analysis provide technical support for in-depth study of relationship between transportation and industrial land conversion connection.

The above research mainly studied land use changes from the perspective of intensity and value, which reflects the spatial restructuring of different socio-economic activities in the changing macro, meso and micro contexts. However, these studies overlook the contents and processes of land use changes. In fact, land use changes in urban areas do not perform in a piece of vacant land or be like drawing figures on a piece of white paper. Rather, they have always been the replacement of an existing land use type with another land use type: between different socio-economic sectors, and from land use type with lower productivity to higher ones. Moreover, when traditional theory is used to explain the influence of transportation on land use, the traffic network is often considered homogeneous and the role of road nodes is ignored. Also, researchers roughly analyze the spatial distribution of urban land uses. There is a lack of consideration of the heterogeneity of transportation system. This paper thus not only studied the influences of different transport routes on industrial land conversion, but also took into account the influences of urban road nodes, which provides a new perspective for the study of the relationship between transportation and land use. In addition, most existing empirical studies on transportation and land use are mainly about developed countries or cities in developed coastal areas in China, while little attention is paid to other less developed cities which have been experiencing relatively slow urban development and economic growth. This paper therefore also fills this gap by taking Changchun, an old industrial city in the famous and typical rust belt of Northeast China, as an example. This study should be of both theoretical and empirical significance.

## 2 Materials and Methods

### 2.1 Study area

Changchun is the capital city of Jilin Province of China, with a total population of 7.49 million in 2017 (National Bureau of Statistics of China, 2018) and a total area of 7557 km$^2$. The city has seven administrative districts, including Chaoyang, Nanguan, Kuancheng, Luyuan, Erdao, Shuangyang, and Jiutai. In this research, we focus on the central urban area of Changchun with an area of 612.08 km$^2$. The lands in this region are mainly used for industrial, commercial, residential and transportation purposes (Fig. 1).

Changchun is a typical old industrial city in Northeast China which is also known as 'Oriental Detroit' and industrial land has been an important land use type in urban Changchun. Since the establishment of People's Republic of China, it has owned one of the most important automotive production companies in China, the First Automotive Works Group Co., Ltd. (FAW). Changchun is also one of the most important transportation hub in Northeast China, with multiple transport routes and high speed trains connecting regional cities. Currently, Changchun is experiencing drastic urban spatial changes at the city level, featured by intensive interaction between industrial land replacement and transportation development. For instance, the total length of various transport routes including light rails (LRs), expressways (EWs), trunk roads (TRs), secondary trunk roads (STRs) and branch roads (BRs) increased by 75.48% from 1537.01 km in 2007 to 2697.09 km in 2017. Among these transport routes, the lengths

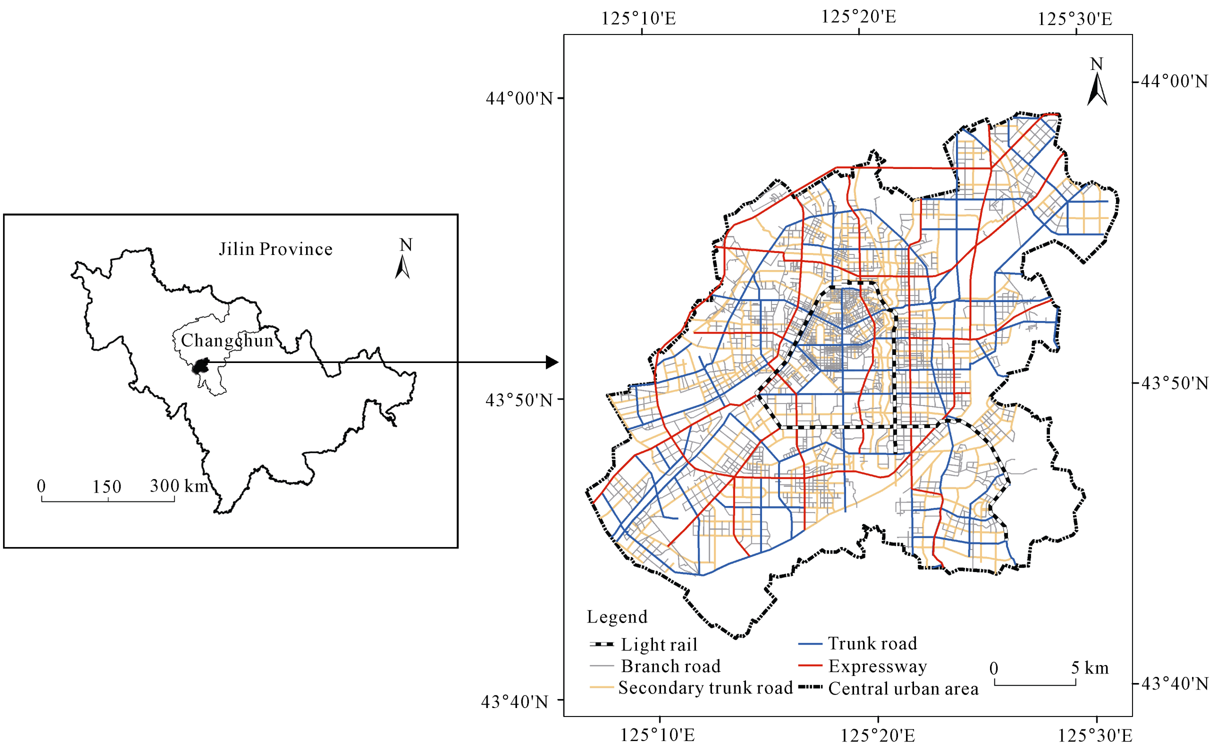


**Fig. 1** Changchun's central urban area

of EWs, TRs, STRs, BRs and LRs have increased by 61.64%, 71.73%, 73.50%, 82.02% and 41.80%, respectively. In parallel with the rapid development of transit system, large-scale industrial land replacement near the transport routes has been occurring. From 2007 to 2017, 71.19 $km^2$ of industrial lands had been converted to other land use types in Changchun's central urban area. Among them, 11.67 $km^2$ of industrial lands were converted to residential uses and 3.21 $km^2$ were converted to commercial uses. The above urban spatial changes and the rapid transportation development in Changchun make the city an ideal example for studying the influences of different transport routes and road nodes on urban industrial land conversion.

## 2.2 Data acquisition and processing

The data used here mainly include two categories. The first category is about the urban land use maps of Changchun municipality, which were extracted from the very-fine-resolution color aerial photographs taken in June of 2007 and 2017 at a scale of 1 : 5000. We corrected the urban land use map based on the related fieldwork. This research mainly focuses on three urban land use types: industrial land (IL), residential land (RL) and commercial land (CL) (Table 1), which are classified according to the 'Code for Classification of Urban Land Use and Planning Standards of Development Land' (GB 50137-2011 (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2012a)).

The second category of data is about the urban transportation system, obtained from the urban master planning of Changchun in 1996 and 2010. Urban rail transit is based on urban traffic route network. There is great similarity in the layout of direction and transfer joints of urban rail transit network and urban traffic route network (Wang, 2017). Therefore, the urban transport route studied here is a comprehensive concept. Urban rail transit system and road system are included in the urban transportation system, which is conducive to a comprehensive and systematic study on the effects of urban transport routes on the layout of industrial lands (Mao and Yan, 2002). A classification system (Table 2) was established for urban transport routes with reference to the 'Code for the Design of Urban Road Engineering' (CJJ37-2012 (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2012b)) revised by the Ministry of Housing and Urban-

**Table 1** Urban land uses studied in Changchun City

| Land use type | Description |
|---|---|
| Industrial land | Factory, warehouse, and affiliated facilities |
| Commercial land | Commercial, business, and recreational facilities, not including service facilities on residential land |
| Residential land | Housing and corresponding service facilities |

**Table 2** Classification of the five types of urban transport routes studied

| Route | Designed speed (km/h) | Road width (m) | Motor vehicle lanes |
|---|---|---|---|
| Expressway | 60–100 | 40–45 | 6–8 |
| Trunk road | 40–60 | 45–55 | 6–8 |
| Secondary trunk road | 30–50 | 40–50 | 4–6 |
| Branch road | 20–40 | 15–30 | 2–3 |
| Light rail | 20–35 | – | – |

Rural Development of the People's Republic of China in 2016. Furthermore, the urban road nodes studied in this paper refer to intersection and connection points between urban roads.

The aforementioned maps and digital photographs were imported into ArcGIS 10.1, and all maps were geometrically intermatched. Then land use types, land area, all types of transport routes and road nodes in 2007 and 2017 were extracted from urban land use maps and urban transportation system maps. We processed the industrial land in 2007 and the residential and commercial land in 2017 respectively through 'Analysis tool'-'Overlay'-'Intersect' in Arcgis software, then we obtained residential land and commercial land converted by industrial land from 2007 to 2017. Finally, a database of urban land use and transportation systems was established with the above information. Using this database, we can identify the relationship between a particular transport route and industrial land conversion, and the relationship between a particular road node and industrial land conversion, as well as visualize the influences of different transport routes and road nodes.

## 2.3 Methods

### *2.3.1 Kernel Density Estimation*

Kernel Density Estimation (KDE) Method was used here to measure the intensity of the conversion of industrial lands to residential and commercial uses during 2007–2017. KDE can be calculated as follows (Green et al., 1988):

$$F(x) = \frac{1}{nh^d}\sum_{i=1}^{n} K\left(\frac{x-x_i}{h}\right) \quad (1)$$

where $F(x)$ is the kernel density function; $h$ is the threshold; $n$ is the number of points in the search circle; $(x-x_i)$ means the distance from the mean center $x$ to point $x_i$; and $d$ is the data dimensions.

In this paper, data management tools were used to convert the polygons of residential land and commercial land converted by industrial land into points. Following this, the density of residential lands and commercial lands were calculated by weighting the corresponding land areas using spatial analysis tools.

Finally, five areas were classified according to the values of KDEs and using Jenks Natural Break Methods: high-density area, secondary high-density area, medium-density area, secondary low-density area, and low-density area (Fig. 2). Fig. 2 depicts the change of the intensity of conversion of industrial land to residential and commercial uses during 2007–2017. The change in intensity from low to high levels reflects more and more industrial lands are converted to residential and commercial uses.

### *2.3.2 Logarithmic Attenuation Function*

The transport route is considered as an artificial corridor and the area that surrounds the corridor is called corridor area. The spatial influence of the corridor on surrounding area attenuates as the distance of the area to the corridor increases. This is called corridor effect. Similarly, spatial effect caused by road node also exists. Theoretically, the spatial intensity of the corridor effects of transport routes and the spatial effects of road nodes can be measured by logarithmic attenuation function (Zong, 1998; 1999):

$$D = f(e) = a\ln\left(\frac{a \pm \sqrt{(a^2 - e^2)}}{e}\right) \mp \sqrt{(a^2 - e^2)} \quad (2)$$

where $e$ is the intensity of the corridor or spatial effects; $D$ means the distance to the route or node; and $a$ is peak intensity of the corridor or spatial effects, determined by the grade of the urban corridor and node.

In this paper, buffer analysis technology was used to study spatial changes of land use types caused by transportation development. In light of Equation (2), four buffer polygons were created at 200-m intervals as a series of spatial fields surrounding every transport route

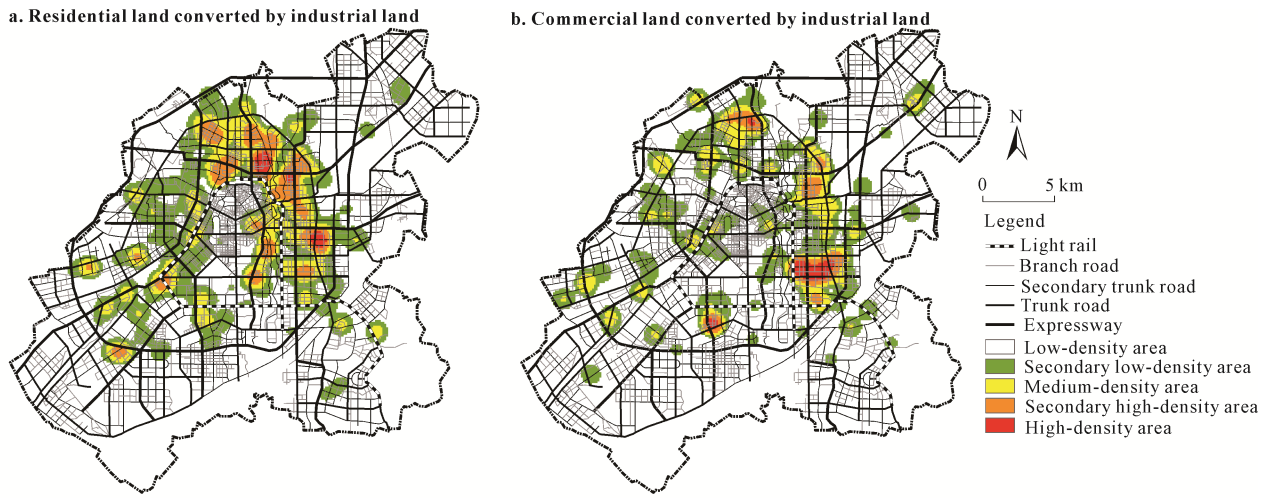


**Fig. 2** Spatial distribution pattern of residential land and commercial land converted by industrial lands in Changchun City from 2007 to 2017

(light rail, expressway and trunk road) and every road node (expressway node and trunk road node) in Changchun's central urban area (Fig. 3). The four buffer intervals surrounding every transport route were 200-m zone (Zone I), 200–400-m zone (Zone II), 400–600-m zone (Zone III), and 600–800-m zone (Zone IV). The four buffer intervals surrounding every road node were 200–400-m zone (Zone A), 400–600-m zone (Zone B), 600–800-m zone (Zone C), and 800–1000-m zone (Zone D). We calculated the proportion that the area of land converted from industrial to other land use types in each zone account for of the total area of that in the region along transport routes as well as the proportion that the area of land converted from industrial to other land use types in each zone account for of the area of each zone surrounding road nodes from 2007 to 2017. Then we applied Equation (2) to fit the logarithmic attenuation function of the distribution curve of the proportion of the area of land converted from industrial to other land use types surrounding light rail, expressway, trunk road, as well as expressway node, trunk road node from 2007 to 2017 respectively.

The ability of transportation systems to shape land use development could vary depending upon the specific locations of transport route (Wang et al., 2019). In this paper, we selected three particular transport routes in Changchun's central urban area, including Light Rail Line 3, the North Expressway and the East Ring Road, which are at appropriate distances to the city center and do not interfere with each other in space (Fig. 3a). The principles of selecting these three urban transport routes and four road nodes are as follows. First, urban transport route and road node should be at appropriate distances to the city center in order to avoid that the corridor effect and spatial effect are obscured by the circle effect of the city center (Mao and Yan, 2004; Chen and Qiu, 2014). Second, the intensities of corridor effects of light rail, expressway and trunk road, as well as spatial effects of expressway node and trunk road node should be comparable. It is necessary to choose transport route and road node whose radiation intensities received from the city center are similar. Therefore, we choose the abovementioned three transport routes. Among them, the lengths of Line 3, North Expressway and East Ring Road are 31.93 km, 9.00 km and 10.94 km, respectively. The types of road nodes are determined by the functions of different transport routes. The expressway nodes include the North-East Expressway Node and Jilin Road-Yangpu Street Node (Fig. 3b). The trunk road nodes include the Nanhu Road-Diantai Street Node and Ziyou Road-East Ring Road Node (Fig. 3b).

## 3 Results

### 3.1 Spatial distribution pattern of conversion of industrial lands to residential land and commercial land

Fig. 2a shows the spatial distribution pattern of IL-to-RL (industrial land-to-residential land) conversion in Changchun's central urban area from 2007 to 2017. Transportation

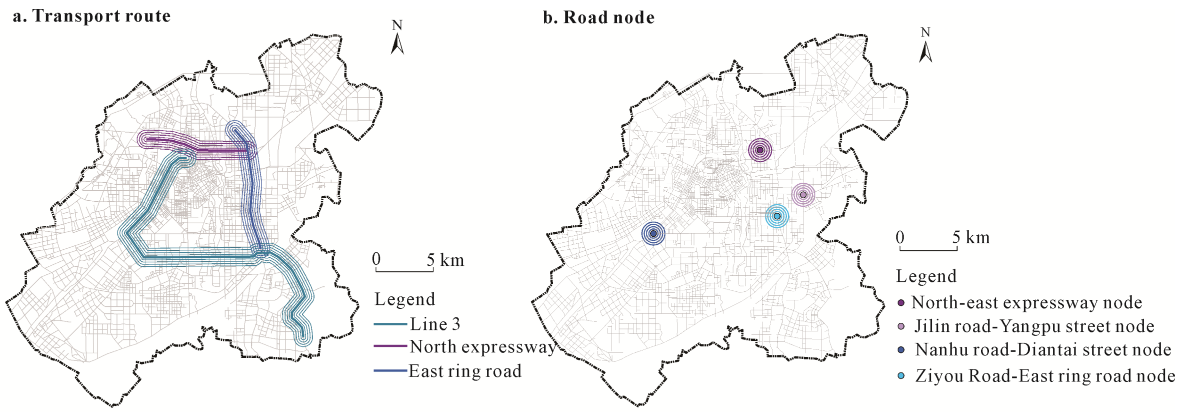


**Fig. 3** Transport routes, road nodes and their buffer division in Changchun City

affects IL-to-RL conversion mainly in two aspects: land value and traffic accessibility. In the context of rapid transit development, the industrial land in Changchun's central urban area is challenged by the increasing demand for land use efficiency and the rise of land price. The improvement of traffic accessibility has greatly increased the land value, which forced the renewals and the changes of the nature of industrial land use, and promoted IL-to-RL conversion. As shown in Fig. 2a, the IL-to-RL conversion phenomenon is mainly concentrated around the outer ring of Line 3 and Line 4 and there exist two major cluster areas. One is around the North Expressway and Yatai Street, and the other is around the East Ring Road and Jilin Road. The influences of different transport routes on the types of IL-to-RL conversion are different. Industrial lands along light rail are mostly converted to regular commodity housing uses, while industrial lands along expressway and trunk road are mostly converted to villa and high-end residential quarter uses.

According to the land rent theory, land that is of higher value is preferred in areas near the transport hub. Various commercial centers are often formed in the area near the transport hub which promotes the IL-to-CL (industrial land-to-commercial land) conversion. As shown in Fig 2b, unlike the spatial distribution pattern of IL-to-RL conversion, the spatial distribution pattern of IL-to-CL conversion displays a more scattered pattern in Changchun's central urban area from 2007 to 2017. The IL-to-CL conversion is mainly concentrated in the area around Nanhu Road and Linhe Street. Newly constructed expressway has advanced the out-movement of industries and warehouse from city center to urban fringe. The vacated land has then been replaced and occupied by the high-end services uses, which promotes the conversion of industrial lands to commercial uses in Changchun's central urban area.

## 3.2 Corridor effects of different transport routes on industrial land conversion

### *3.2.1 Light rail*

From 2007 to 2017, the area of land converted from industrial to residential uses in the corridor area surrounding Line 3 was 1.16 km$^2$, accounting for 42.17% of the total area of land converted from industrial to other uses in this corridor area. Light Rail has an attracting effect on IL-to-RL conversion along it. Fig. 4 illustrates that the areas of lands converted from industrial to residential uses in Zones I–IV accounted for about 31.58%, 33.41%, 18.04% and 16.98%, respectively, of the total area of land converted from industrial to residential uses in the corridor area. The corridor effect of the light rail on IL-to-RL conversion shows a decreasing trend from Zone I to IV. Zone I and II were found to have the most intensive IL-to-RL conversion in the corridor area surrounding Line 3.

From 2007 to 2017, the area of land converted from industrial to commercial uses in the corridor area surrounding Line 3 was 0.28 km$^2$, accounting for 10.27% of the total area of land converted from industrial to other uses in this corridor area. Light Rail has a disturbing effect on IL-to-CL conversion along it. Fig. 4 illustrates that the areas of lands converted from industrial to commercial uses in Zones I–IV accounted for about 26.83%, 9.52%, 8.68% and 54.97%, respectively, of the total area of land converted from industrial to commercial

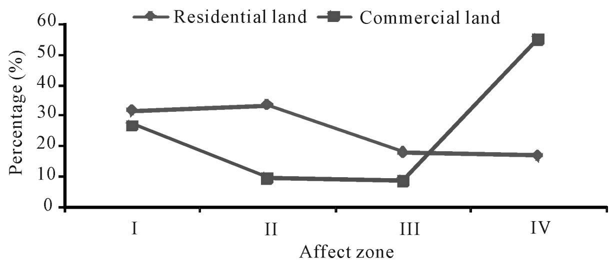


**Fig. 4** The proportion that the area of land converted from industrial to residential or commercial lands in zones I–IV surrounding Line 3 in Changchun City from 2007 to 2017

uses in the corridor area. The corridor effects of light rail on IL-to-CL conversion decreases from Zone I to III and then increases from Zone III to Zone IV. This may be related to the fact that the most important road node in Changchun is located near Zone IV, featured by large population and good accessibility, which are conducive to the development of commercial activities.

### *3.2.2 Expressway*

From 2007 to 2017, the area of land converted from industrial to residential uses in the corridor area surrounding the North Expressway was 0.89 km$^2$, accounting for 40.13% of the total area of land converted from industrial to other uses in this corridor area. The expressway has an attracting effect on IL-to-RL conversion along it. Fig. 5 displays that the areas of lands converted from industrial to residential uses in Zones I–IV accounted for about 25.96%, 29.40%, 28.17% and 16.46%, respectively, of the total area of land converted from industrial to residential uses in the corridor area. The corridor effect of expressway on IL-to-RL conversion shows a decreasing trend from Zone I to IV. Zones II and III were found to have the most intensive IL-to-RL conversion in the corridor area surrounding the North Expressway.

From 2007 to 2017, the area of land converted from industrial to commercial uses in the corridor area surrounding the North Expressway was 0.16 km$^2$, accounting for 7.02% of the total area of land converted from industrial to other uses in this corridor area. The expressway has a disturbing effect on IL-to-CL conversion along it. Commercial space is a space where traffic system is developed and a large volume of people gathered. The expressway is characterized by high capacity and high speed, and plays a strong promoting role in the conversion of industrial land to commercial uses along the transportation line, especially at the intersection between the expressway and road. Fig. 5 shows that IL-to-CL conversion decreased from Zone I to Zone II, and then increased sharply from Zone II to Zone III. It has been found that many wholesale markets are located within 200-m buffer area surrounding expressway since large-scale trades depend heavily on expressway rather than other types of transport routes. As the distance to the expressway increases (Zone III and IV), many large commercial complexes or business centers emerge due to the large volume of people.

### *3.2.3 Trunk Road*

From 2007 to 2017, the area of land converted from industrial to residential uses in the corridor area surrounding the East Ring Road was 1.53 km$^2$, accounting for 33.71% of the total area of land converted from industrial to other uses in this corridor area. The trunk road has a disturbing effect on IL-to-RL conversion along it. As shown in Fig. 6, the areas of lands converted from industrial to residential uses in Zones I–IV accounted for about 20.71%, 26.83%, 28.00% and 24.46%, respectively, of the total area of land converted from industrial to residential uses in the corridor area. Zone III was found to have the most intensive IL-to-RL conversion, while Zone I was found to have the least intensive IL-to-RL conversion. This disturbing effect of trunk road on IL-to-RL conversion in its surrounding corridor area differs from the corridor effect of expressway.

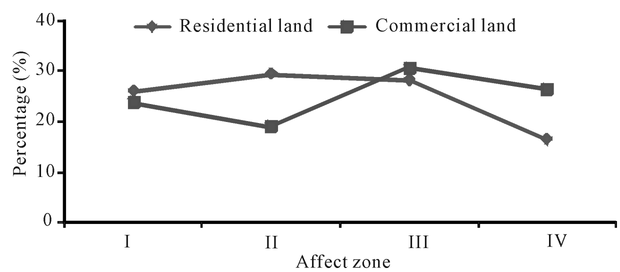


**Fig. 5** The proportion that the area of land converted from industrial to residential or commercial lands in zones I–IV surrounding the North Expressway in Changchun City from 2007 to 2017

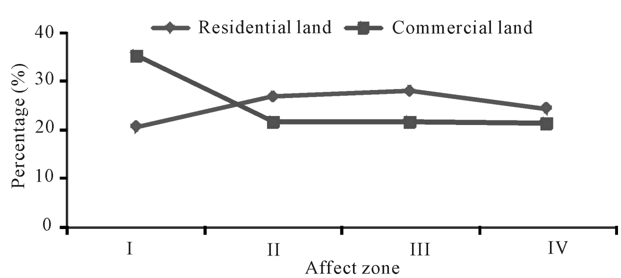


**Fig. 6** The proportion that the area of land converted from industrial to residential or commercial lands in zones I–IV surrounding the East Ring Road in Changchun City from 2007 to 2017

From 2007 to 2017, the area of land converted from industrial to commercial uses in the corridor area surrounding the East Ring Road was 0.95 $km^2$, accounting for 20.96% of the total area of land converted from industrial to other uses in this corridor area. The trunk road has an attracting effect on IL-to-CL conversion along it. Figure 6 shows the areas of lands converted from industrial to commercial uses in Zones I–IV accounted for about 35.21%, 21.73%, 21.70% and 21.36%, respectively, of the total area of land converted from industrial to commercial uses in the corridor area. The corridor effect of trunk road on IL-to-CL conversion shows a decreasing trend from Zone I to IV.

### 3.3 Comparison of differences in corridor effects of transport routes

As Table 3 shows, light rail and expressway attract the conversion of industrial lands to residential uses along them, and the attracting role of light rail is stronger than that of expressway. In comparison, trunk road disturbs the conversion of industrial land to residential land along it. Compared with the other two types of transport routes, rail transit is more convenient and environment friendly for people to use (Liu, 2005), which promotes the housing demands along its transportation line and further promotes the land use changes from industrial to residential uses. In our case, the areas with the good accessibility surrounding urban light rail Line 3 make them ideal place for people to live, which causes the conversion of nearby industrial land to residential uses (there are residential quarters such as Dikuang Huayuan, Lingxiu Chaoyang and Shangyuan). Similar land use changes also took place in the corridor area surrounding expressway, which is convenient for people who work in the city center but live in the urban fringe. This further boosts the housing needs surrounding expressway and results in the conversion of industrial land to residential uses. For instance, several large-scale residential communities are emerging and developing near Jilin Road-East Expressway node, which in the past was occupied by industrial land use. Also note that the attracting role of light rail is stronger than that of expressway. This is possibly due to governmental strategies that encourage the transit-oriented development in the areas surrounding transit nodes. Since trunk road is characterized by lower capacity and serious congestion, the commuting efficiency of residents living surrounding trunk road is low. Consequently, trunk road disturbs the conversion of industrial land to residential uses along it.

Table 3 also reveals that light rail and expressway disturb the conversion of industrial lands to commercial uses along them, and the disturbing role of light rail is stronger than that of expressway. In comparison, trunk road attracts the conversion of industrial land to commercial uses along it. It should be noted that the role of the light rail and expressway in the conversion of industrial lands to commercial uses change from an attracting role to a disturbing role from Zone I to IV. In IL-to-CL conversion, the commercial land along light rail is mainly used for constructing commercial complexes and business centers, whereas that along expressway is mainly used for constructing large wholesale markets. Rail transit is characterized by high speed, high efficiency and high capacity, and can promote the flow of population, goods and information, trigger urban renewal in surrounding areas, and promote developing of commercial complexes and business centers. For example, in IL-to-CL conversion the commercial land along Line 3 in Chaoyang district was used for constructing Happy City Plaza, which is a large-scale commercial complex and also a business center in the central region of southwestern Changchun. The expressway, characterized by high speed and high capacity, meets the needs of development of wholesale markets. Therefore, the area surrounding the entrance and exit of expressway is often where large wholesale markets are located. For example, in IL-to-CL conversion the commercial land surrounding the North-East Expressway entrance and exit were used for constructing wholesale market such as Macalline Market and stainless steel processing plant. Trunk road can attract a lot of goods, population and capital to surrounding areas and promote the economic development in these areas.

**Table 3** The functions for the conversion of industrial lands to residential or commercial uses along the transport routes in Changchun City from 2007 to 2017

| Route | Residential or commercial use | Function |
|---|---|---|
| Light rail | Residential use | $y = -0.119\ln(x) + 0.3448$ |
| | Commercial use | $y = 0.1189\ln(x) + 0.1555$ |
| Expressway | Residential use | $y = -0.049\ln(x) + 0.2888$ |
| | Commercial use | $y = 0.0381\ln(x) + 0.2197$ |
| Trunk road | Residential use | $y = 0.0352\ln(x) + 0.2221$ |
| | Commercial use | $y = -0.101\ln(x) + 0.3302$ |

For example, the industrial lands along the East Ring Road were mostly converted to commercial uses such as vehicle repair plant and automobile sales company.

## 3.4 Spatial effects of different road nodes on industrial land conversion

### *3.4.1 Expressway node*

From 2007 to 2017, the area of land converted from industrial to residential uses in the region surrounding the North-East expressway node was 0.20 $km^2$, accounting for 44.20% of the total area of land converted from industrial to other uses in this region. The expressway node has an attracting effect on IL-to-RL conversion surrounding it. From Zone A to D, the proportion that the area of land converted from industrial to residential uses in each zone accounted for of the area of each zone decreased from 10.03% to 4.56% (Fig. 7), with Zone A having the most intensive IL-to-RL conversion.

From 2007 to 2017, the area of land converted from industrial to commercial uses in the region surrounding Jilin Road-Yangpu Street node was 0.14 $km^2$, accounting for 25.17% of the total area of land converted from industrial to other uses in this region. The expressway node has an attracting effect on IL-to-CL conversion surrounding it. From Zone A to D, the proportion that the area of land converted from industrial to commercial uses in each zone accounted for of the area of each zone decreased from 9.41% to 1.07% (Fig. 7). This indicates that the attracting effect of expressway node on IL-to-CL conversion decreases with increasing distance to the expressway node.

### *3.4.2 Trunk road node*

From 2007 to 2017, the area of land converted from industrial to residential uses in the region surrounding Nanhu Road-Diantai Street node was 0.19 $km^2$, accounting for 55.62% of the total area of land converted from industrial to other uses in this region. The trunk road node has an attracting effect on IL-to-RL conversion surrounding it. From Zone A to D, the proportion that the area of land converted from industrial to residential uses in each zone accounted for of the area of each zone decreased from 18.26% to 1.57% (Fig. 8), with Zone A having the most intensive IL-to-RL conversion.

From 2007 to 2017, the area of land converted from industrial to commercial uses in the region surrounding Ziyou Road-East Ring Road node was 0.48 $km^2$, accounting for 36.53% of the total area of land converted from industrial to other uses in this region. The trunk road node has a disturbing effect on IL-to-CL conversion surrounding it. From Zone A to D, the proportion that the area of land converted from industrial to commercial uses in each zone accounted for of the area of each zone increased from 2.58% to 20.74% and then decreased to 17.07% (Fig. 8), with Zone C having the most intensive IL-to-CL conversion.

## 3.5 Comparison of differences in spatial effects of road nodes

As Table 4 shows, expressway node and trunk road node can attract the conversion of industrial lands to residential uses surrounding them, and the attracting role of trunk road node is stronger than that of expressway node. Trunk roads constitute the skeleton of urban transportation network and connect the major urban areas with a moderate-speed among the transit system. Compared with the expressway node, the trunk road node is characterized by appropriate walking distance and high safety, and thus becomes an appealing location for housing development. For instance, in IL-to-RL conversion the residential land surrounding Nanhu Road-Diantai Street node was used for constructing residential quarters such as Jin Zuobiao and Tiansheng Mingdu. The comparative lack of interests in residential

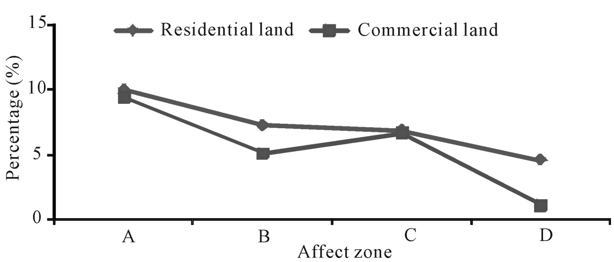


**Fig. 7** The proportion that the area of land converted from industrial to residential or commercial lands in zones A–D surrounding the expressway node in Changchun City from 2007 to 2017

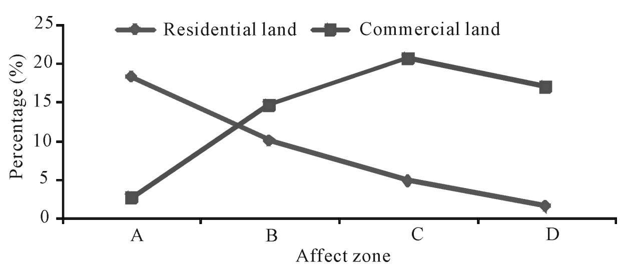


**Fig. 8** The proportion that the area of land converted from industrial to residential or commercial lands in zones A–D surrounding the trunk road node in Changchun City from 2007 to 2017

development surrounding the expressway node is highly related to the heavy noise and air pollution caused by automobiles, which negatively affect the quality of life in surrounding residential areas. Consequently, the attracting role of expressway node in IL-to-RL conversion is weaker than that of trunk road node. For example, in IL-to-RL conversion the residential land surrounding the North-East Expressway node was used for constructing residential quarters such as Wansheng Yushuiwan and Dongyi Meijun.

Table 4 also reveals that expressway node can attract the conversion of industrial land to commercial uses surrounding it, while trunk road node disturbs such conversion process. The expressway with high speed and high capacity reduces the traffic burden from trunk road, secondary trunk road and branch road and improves the efficiency of urban transportation system as a whole. Consequently, expressway node has become the most significant driving force of the conversion of industrial land to commercial uses. In comparison, the intensified social and economic activities caused by the massive flow of goods, population and information has aggravated the congestion in the areas surrounding trunk road node. This phenomenon has been driving many commercial activities away from the areas surrounding trunk road node to avoid traffic congestion. For example, in IL-to-CL conversion the commercial land surrounding Ziyou Road-East Ring Road node was used for constructing commercial space such as Jinyuan supermarket.

**Table 4** The functions for the conversion of industrial lands to residential or commercial uses in the regions surrounding road nodes in China from 2007 to 2017

| Road node | Residential or commercial use | Function |
|---|---|---|
| Expressway node | Residential use | $y = -0.036\ln(x) + 0.1004$ |
| | Commercial use | $y = -0.049\ln(x) + 0.0946$ |
| Trunk road node | Residential use | $y = -0.121\ln(x) + 0.1828$ |
| | Commercial use | $y = 0.1187\ln(x) + 0.0433$ |

## 4 Discussion and Conclusions

The paper studied the spatial effects of different transport routes and road nodes on industrial land conversion by exploring how industrial lands converted to residential and commercial uses surrounding the transport routes and road nodes, taking an old industrial city, Changchun of Jilin Province of China, as an example. It was found that more industrial lands were converted to residential uses than to commercial uses along the studied transport routes. Notably, different transport routes and road nodes have different effects on industrial land conversion. In terms of distribution, the conversion of industrial lands to residential uses tends to occur along light rail and expressway, as well as surrounding expressway node and trunk road node. While the conversion of industrial land to commercial uses tends to occur along the trunk road and surrounding the expressway node. In terms of influence, the attracting role of conversion of industrial lands to residential uses along light rail is stronger than that along expressway and the disturbing role of conversion of industrial lands to commercial uses along light rail is stronger than that along expressway. The attracting role of conversion of industrial lands to residential uses surrounding trunk road node is stronger than that surrounding expressway node. The characteristics of the transit systems determine their influences on nearby industrial land conversion. Light rail, characterized by no traffic congestion, is mainly used for transporting people. Expressways with fewer traffic lights for automobiles are more convenient than trunk roads often with traffic congestion. Therefore, areas surrounding light rail or expressway become popular locations for the conversion of industrial lands which are used for housing developments.

In fact, we found that more industrial lands were converted to residential uses than to commercial uses along the studied transport routes. One of the reasons for that is urban growth in China's cities is also called 'property-led growth'. In inner Changchun, from 2007 to 2017, the area of industrial land decreased from 68.55 $km^2$ to 62.58 $km^2$. Changchun has gradually shifted from an old industrial city featured by 'production first and life second' to a more livable city (Zhao, 2014), especially for residential development. This is related to the progression of regional urbanization. Studies reveal that the population of Northeast China has been declining, accompanied by economic recession, especially in the industrial sector which can not provide enough job opportunities (Fu et al., 2019). However, the regional central cities especially capital cities in Northeast China such as Changchun, Shenyang and so on are attracting more migrants from rural areas to settle down. For instance, from 2007 to 2017 the population in Changchun increased from 3.58 million to 4.38 million in city (National Bureau of Statistics of China, 2018). The influences of population increase on different industries and land use types are different. The agglomeration of population contributes to urban expansion mainly featured by rapid residential development rather than other types of land use development (Liu et al., 2018). In Changchun, from 2007 to 2017, the residential area increased from 77.56 $km^2$ to 112.06 $km^2$, while the commercial land area merely increased from13.05 $km^2$ to 22.84 $km^2$. Capital related to regional population urbanization flows into commodity housing markets rather than commercial markets. Meanwhile, the slow economic development and even recession in recent decades in Changchun have led to limited increase in the income and consumption ability of residents. Therefore, the transition experience of Changchun, from an old industrial city featured by strongly planned socialist economy to a more livable regional city, has implications for the development path of the regional central cities in the rust belt of China.

By studying the influence of transportation on industrial land conversion, we can better understand the relationship between transportation and industrial land. To achieve more integrated transportation and land use development, cities need to pay more attention to the influence of special nodes such as expressway entrances and exits, rail transit stations and road three-dimensional intersections on surrounding land use conversion when redeveloping inventory land. These nodes are windows for the interaction of transportation and land, which deeply influence the land use changes in the surrounding areas. In China large and medium-sized cities are at the peak of urban infrastructure construction, and urban renewal has become an important task of high-quality development (Zhang et al., 2018; Hu et al., 2019). Therefore, clarifying the mechanism and characteristics of the influence of different urban transport routes and road nodes on industrial land conversion is of great practical significance for optimizing the layout of urban functional spaces and constructing a three-dimensional integrated transportation system.

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