林思齊東西學術交流研究所
David C. Lam Institute for East-West Studies (LEWI)
Working Paper Series 研究報告系列

Paper Number: 110
April 2011

Transport Infrastructure Development and Changing Spatial Accessibility in the Greater Pearl River Delta, China, 1990-2020

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Abstract

This paper analyses the accessibility implications of the development of limited-access expressways and inter-city railways in the Greater Pearl River Delta (GPRD) over the period 1990-2020. Average travel time was firstly reduced by expressway development; and it will be reduced further by the introduction of the inter-city rail system in 2011. The unevenness in regional accessibility remained relatively high during the initial stage of expressway development, but later expansion brought more balanced accessibility landscapes. The first stage (2010-2020) of inter-city railway development will raise the accessibility inequality. Its later effects, however, remain to be seen. Convenience in transport connections is associated with the spatial pattern of industrialization. In addition, accessibility improvement is tied to the direction of city-region development, as exemplified by Guangzhou's choice of Nansha, the city's outer port, as development focus.

Keywords: Limited-access expressways, inter-city rail system, accessibility, intra-regional disparity, Greater Pearl River Delta

1. Introduction

China has experienced rapid transport infrastructure development in recent years. The total length of limited-access expressways, for example, more than tripled from 191,000 km in 2001 to 651,000 km in 2009 (MoT, 2010). The development has been especially rapid in the mega city-regions of the country, more specifically, the Beijing-Tianjin-Tangshan region, the Yangtze River Delta and the Pearl River Delta (PRD). A good example is the 36-km Hangzhou Bay Bridge, which has been the longest bridge in the world since its opening in May 2008. More aggressive plans including national high-speed railway networks have been proposed; many are under construction.

The development of transport infrastructure has direct implications for spatial accessibility at both national and regional scales. In China such an issue has been addressed by various researchers. Li and Shum (2001) examined the national trunk highway project launched since the late 1990s and its impacts on the accessibility of individual provinces. Similarly, Jin and Wang (2004) and Wang *et al*. (2009) analysed the development of national railway networks in the 20^{th} century. At the regional scale, Cao and Yan (2003) examined road and railway network evolutions and the changing accessibility in Dongguan, Guangdong Province, over the period 1980-2000, and Luo *et al*. (2004) studied the impact of high-speed railways on the accessibility landscape in the Shanghai-Nanjing corridor. Zhang and Lu (2006) adopted a more comprehensive view by taking into account both rail and road transport in the evaluation of regional accessibility in the Yangtze River Delta.

A major concern is the spatial distribution of accessibility improvement. The question is whether new transport infrastructure will bring forth more equal regional accessibility or induce more uneven development. Regarding high-speed railways, most research findings show that their construction will increase the imbalances between major cities and their hinterlands (e.g. Murayama, 1994; Gutiérrez *et al.*, 1996; Jiang *et al.*, 2010). For example, after the introduction of Shinkansen, the high-speed rail in Japan, cities connected to this system immediately gained location advantages, while non-Shinkansen cities were marginalized (Murayama, 1994).

With respect to highways, however, the findings are less conclusive. At the national scale, it has been reported that development of trunk highways would initially aggravate regional accessibility inequality, but further expansion of the network would bring about more balanced development. In other words, the development lends support to Williamson's (1965) inverted-U hypothesis of regional development (Li and Shum, 2001). At the metropolitan level, a study of the Madrid M-40 orbital motorway found that the resulted accessibility improvement varies according to individual locality's relative location within the metropolitan area. The further away from the city centre, the greater equality of accessibility the orbital motorway will bring (Gutiérrez and Gómez, 1999). In summary, the equalization of accessibility brought by highway development is both time- and location-specific.

The present study purports to analyse the accessibility implications of the development of limited-access expressways and inter-city railways in the Greater Pearl River Delta (GPRD) between 1990 and 2020. The GPRD refers to the Pearl River Delta Economic Region (PRDER) [1] plus the two Special Administrative

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1 The PRDER was formed by Guangdong Provincial Government in 1994. In 2000, it contains 9

Regions (SARs) of Hong Kong and Macau. The years following the latter's handover to China in 1997 and 1999, respectively, have been critical for the two SARs and the GPRD. Major transport facilities including the Hong Kong-Shenzhen West Corridor have been completed. Projects under construction include the Hong Kong–Zhuhai–Macau Bridge and the Guangzhou-Shenzhen-Hong Kong High-Speed Railway. With increasing ease of transport, the housing and labour markets as well as the recreation activity space of neighbouring cities have become increasingly integrated. A vivid example was the case of cross-city viewing of the movie *Avatar*. There were no cinemas to show the iMax version of the movie in Shenzhen. For this, many Shenzhen residents went to Hong Kong to see the movie.

In the rest of the paper, we first provide an overview of the expressway and railway systems in the GPRD. After introducing the methodology and data, we analyse the changes in accessibility resulting from the developments, both implemented and planned. Special attention is given to the issue of accessibility unevenness. Unlike the other two mega-urban regions where the respective dominance of Beijing and Shanghai is indisputable, in the GPRD Hong Kong, Guangzhou and to a lesser extent also Shenzhen all try to claim primacy. Accessibility is a useful indicator to assess primacy (Hou and Li, 2011). Meanwhile, Guangdong Province and the Hong Kong and Macau Special Administrative Regions (SARs) purport to promote coordinated and sustainable development for the entire GPRD and reduce intra-regional disparity (GDHKMC, 2009, p.72). The present paper addresses this issue of inter-locality competition amidst the pledge for coordination from the accessibility perspective.

2. Development of Limited-Access Expressways and Inter-City railways[2]

2.1 Expressway development and key bridges

2.1.1 Expressways

prefecture-level cities, covering a total area of 42,188 km^2. A series of administration adjustments has been made since 2000. For example, Panyu District in Guangzhou was split into new Panyu and Nansha Districts. To make consistent comparisons through time, necessary adjustments have to be made. For instance, Panyu and Nansha Districts are combined into one spatial unit, Panyu, for the 2010 and 2020 datasets in order to allow for temporal comparison.

2 For transport development in the PRD before 1995, see Loo (1999). This section basically serves as an update of the Loo (1999) study, with an emphasis on expressway and inter-city rail development.

The development of limited-access expressways in China started in the late 1980s. The first expressway in the country, Shanghai-Jiading Expressway, was opened to traffic in 1988. The 15.7 km long Guangzhou-Foshan Expressway, the first in Guangdong Province, was completed one year later. Expressway development in China has accelerated since the mid 1990s, in part due to the aggressive fiscal policies to stimulate the economy in response to the 1997-1998 Asian Financial Crisis (Wang and Wang, 2008). In the PRD the total length of expressways reached 1301 km in 2000, and the density of the network stood at 31.21 km per 1000 km^2. The corresponding figures further increased to 3508 km and 84.12 km per 1000 km^2 by the end of 2009. The coming decade will witness similarly impressive growth. According to the recent plan of infrastructure development in the PRD, the total length will reach 6145 km by 2020 (Table 1).

Table 1. Total length and density of limited-access expressways in the PRD and comparison with provincial and national levels

a. Total length (km) and density (km/’000 km^2) of limited-access expressways in the PRD and comparison with provincial and national levels

Year	PRD		Guangdong Province		China	
	Length	Density	Length	Density	Length	Density
1990	16	0.38	23	0.13	500	0.05
2000	1301	31.21	1,186	6.60	16,300	1.70
2010	3508	84.12	4,035 [a]	22.44	65,100 [a]	6.78
2020	6145	147.36	7300 [b]	40.60	85,000 [c]	8.85

b. Total length (km) and density (km/’000 km^2) of limited-access expressways in the PRD

Year	Eastern PRD		Central PRD		Western PRD		PRD	
	Length	Density	Length	Density	Length	Density	Length	Density
1990	0	0.00	16	2.11	0	0.00	16	0.38
2000	449	32.70	358	48.11	495	24.09	1301	31.21
2010	1371	99.95	856	115.09	1281	62.34	3508	84.12
2020	2024	147.55	1364	183.50	2756	134.15	6145	147.36

Source: Guangdong province data (1990 and 2000) are from NBSC (2010a), and Guangdong’s 2010 data and China’s data since 1990 to 2010 are from NBSC (2010b).

Note:

a: Data at the end of 2009.
b: Data from GDTD (2008).
c: Data from MoT (2005)

The spatial unevenness in expressway development is evident from Table 1. Expressway density in Guangdong Province was and will continue to be three to four times the national average. Likewise, within the province, expressway density in the PRD was and will continue to be three to four times the provincial average. Moreover, within the PRD, the central part of the region (Central PRD) has maintained a clear edge over the Eastern and Western Wings, with the latter falling significantly behind the others. Fortunately, the gap will show sign of narrowing in near future. In 2000 the ratio of expressway density between the Central PRD and the Eastern Wing stood at 1.5, and that between the Central PRD and the Western Wing was 2.0; in 2020 the respective ratios will decline to 1.2 and 1.4 (Table 1-b).

2.1.2 Key bridges across the Pearl River Estuary

A key geographical feature of the GPRD is the presence of large number of rivers, which include the main channel of the Pearl River and its many distributaries (Figure 1). They form natural waterways, but they also act as barriers to movement over land. The Pearl Estuary, in particular, is a major barrier to transport connection between the Eastern and the Western Wings. Three bridges are to span the Pearl Estuary. From north to south, they are: the Humen Bridge, the Shenzhen-Zhongshan (SZ-ZS) Bridge, and the Hong Kong-Zhuhai-Macau (HK-ZH-MC) Bridge (Figure 2) (Table 2). The Humen Bridge, which connects Nansha District of Guangzhou to Humen Town of Dongguan, started construction in 1992 and began operation in 1997, just before the handover of Hong Kong to China. The bridge has shortened road distance between the Eastern and Western Wing by up to 120 km. It is arguably the most important and busiest link in the expressway network of Guangdong (Zheng and Yang, 1998; Chen and Duan, 2000). In the next decade, with the completion of the HK-ZH-MC Bridge and the SZ-ZS Bridge the tremendous congestion currently plaguing the Humen Bridge will be alleviated. The HK-ZH-MC Bridge in fact is a combination of bridges and tunnels. This 50-km cross-boundary link was estimated to cost USD $10.7 billion. Construction began on 15 December 2009 and was scheduled to open to traffic in 2015 (Hong Kong-Zhuhai-Macau Bridge Authority, 2010). The proposed SZ-ZS link, which is yet to be finalized, may take the form of a tunnel, a bridge, or a combination of both. According to the latest plan, construction will take place after 2015, with the completion date scheduled in 2020 (Guangdong Provincial

Government, 2010). Current construction cost estimate stands at RMB 30 billion[3] or roughly USD 45.2 billion. In addition to the two new bridges, a second Humen Bridge will begin construction in 2011, to be completed in 2015 (Guangdong Provincial Government, 2010). These bridges will significantly augment the interconnection between the Eastern and Western Wings.

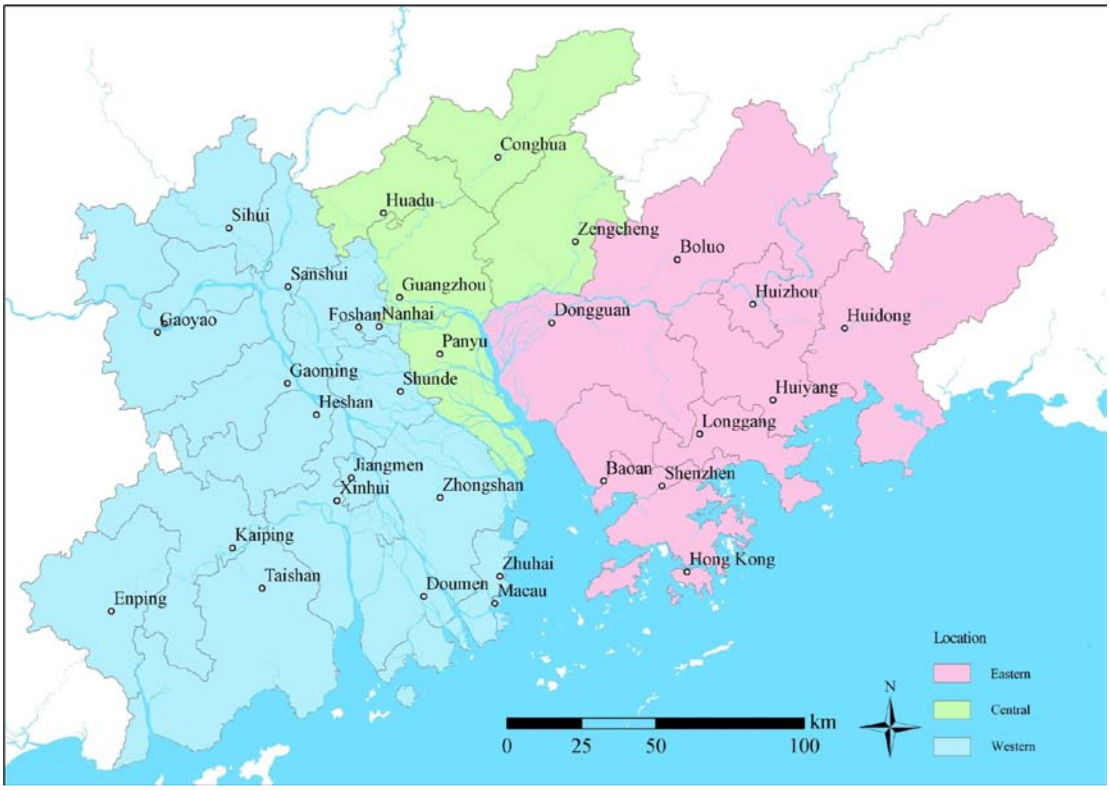

Figure 1. Analysis units in the GPRD and regionalization

3 RMB, or Renminbi, is the currency of China. At the time of writing, the exchange rate is RMB 1 to USD 0.154 approximately.

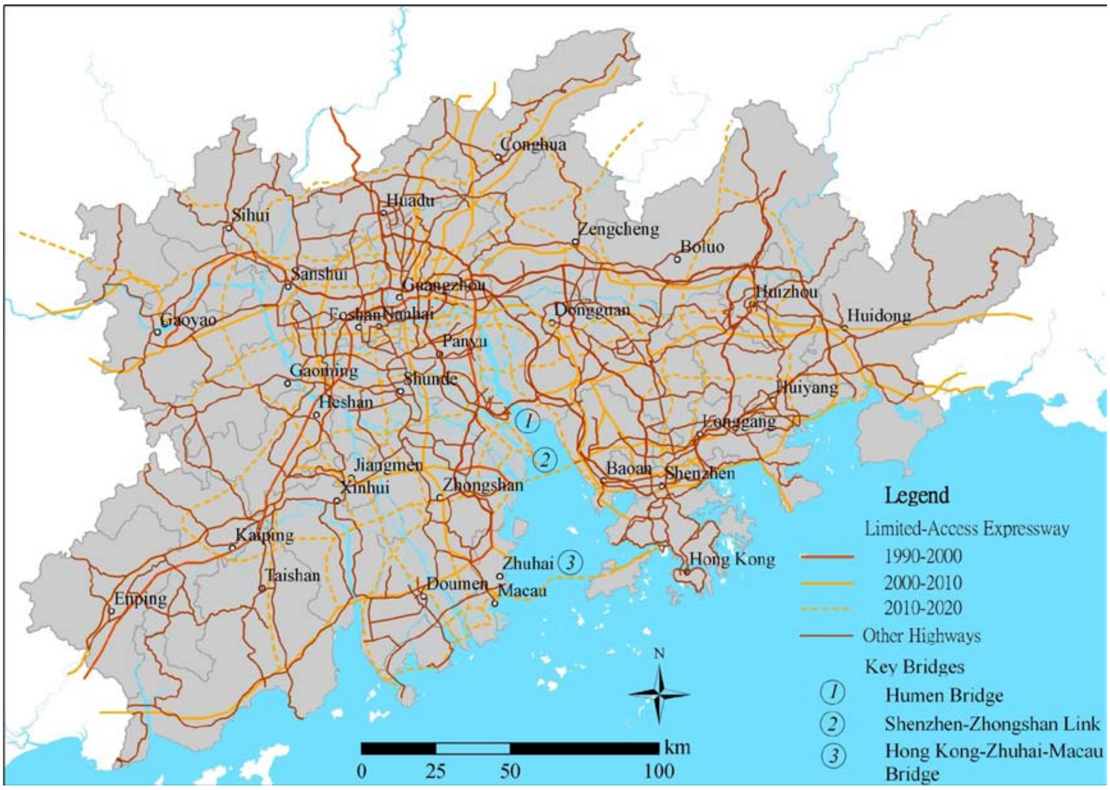

Figure 2. Expressway development in the GPRD, 1990-2010

Table 2. Major bridges across the Pearl River Estuary

Name	Total Length (Main Bridge) (km)	(Estimated) Investment (USD, billion)	Construction Period	Remarks
Humen Bridge	15.8 (4.6)	0.53	Oct. 1992 – Jun. 1997	Change rate as of 1992 was: RMB : USD = 5.515 : 1
Second Humen Bridge	20.9 (~5.0)	1.81	2011 - 2015	The design remains yet to be finalized
Hong Kong-Zhuhai-Macau Bridge	50.0 (35.6)	10.70	Dec. 2009 – 2015/2016	A series of bridges and tunnels
Shenzhen-Zhongshan Passage	50.0 (n.a.)	4.52	2015 - 2020	Including link road to Nansha Harbour

Note: n.a. means not available.

2.2 Railways and intercity rail system

In comparison, Guangdong lags far behind other regions in railway development. By the end of 2008, the total length of railways in operation in the province was 2165 km, or just 2.72% of national total (NBSC, 2010c). This is irrespective of the fact that the Kowloon-Canton (Guangzhou) Railway (KCR) began operation as early as in 1910, and that the Guangzhou-Shaoguan Section of the Beijing-Guangzhou Railway was completed in 1916. Until 1990, there were only three rail lines running across the

PRD, including the aforementioned railways and the one linking Guangzhou to Maoming in the Western Guangdong. In 1993, China started construction of the Beijing-Kowloon Railway, with the view to further incorporating Hong Kong into national railway network. This line was completed in June 1996. Another new, but rather minor, railway is the Pinghu-Nanshan Railway in Shenzhen. This railway started operation in 1994. A noteworthy development is the technological upgrading of the Guangzhou-Shenzhen Railway (the mainland section of the KCR). The railway was electrified in the mid 1990s, and the average speed rose to 160km/h. In 1995, express through-train services were introduced between Hong Kong and Dongguan, Guangzhou, and Foshan (Loo, 1999). Nonetheless, the railway network remained essentially a tree containing no circuits by the first decade of the twenty-first century.

The situation is changing very dramatically in recent years. In November 2003, the Ministry of Railways (MoR) and Guangdong Provincial Government reached an oral agreement that both parties will collaborate to speed up rail development in Guangdong.[4] In particular, the MoR promised to co-invest in inter-city railway developments in the PRD (Nanfang Daily, 2003). Six years later in May 2009 a written agreement was finally reached on further speeding up railway development in Guangdong (MoT and Guangdong Provincial Government, 2009). Following the agreement, rail system was put as the first priority in the integrated development of infrastructures in the PRD over the coming decade (Guangdong Provincial Government, 2010). Of particular interest is the inter-city rail system, which will considerably change the accessibility landscape of the region.

As of now there have been two inter-city rail system development plans in the PRD; one was approved by the central government and the other by the Guangdong Provincial Government. The first one, proposed by the National Development and Reform Commission and approved by the central government in 2005, proposed to construct 600 km of inter-city railways by 2020 (NDRC, 2005). As for the second one, the Provincial Plan on Integrated Development of Infrastructure in the PRD, the total length is expected to reach 970 km by 2020 (Guangdong Provincial Government, 2010). The inter-city railways will cross the Shenzhen-Hong Kong boundary on the eastern side and the Zhuhai-Macau boundary on the western side to form a network

4 The implementation of the oral agreement nonetheless is quite good. The railways proposed in the mutual agreement have now been either completed or nearly completed. As they mainly serve inter-provincial traffics, these railways are not analysed in the present study. A minor development of regular railways is the Huizhou-Daya Bay Railway, which began operation in January 2004.

covering the entire GPRD. By 2020, the railway network in the GPRD will feature several circuits and strategic nodes, in particular Guangzhou in Central GPRD, Hong Kong and Shenzhen on the east, and Macau and Zhuhai on the west (Figure 3).

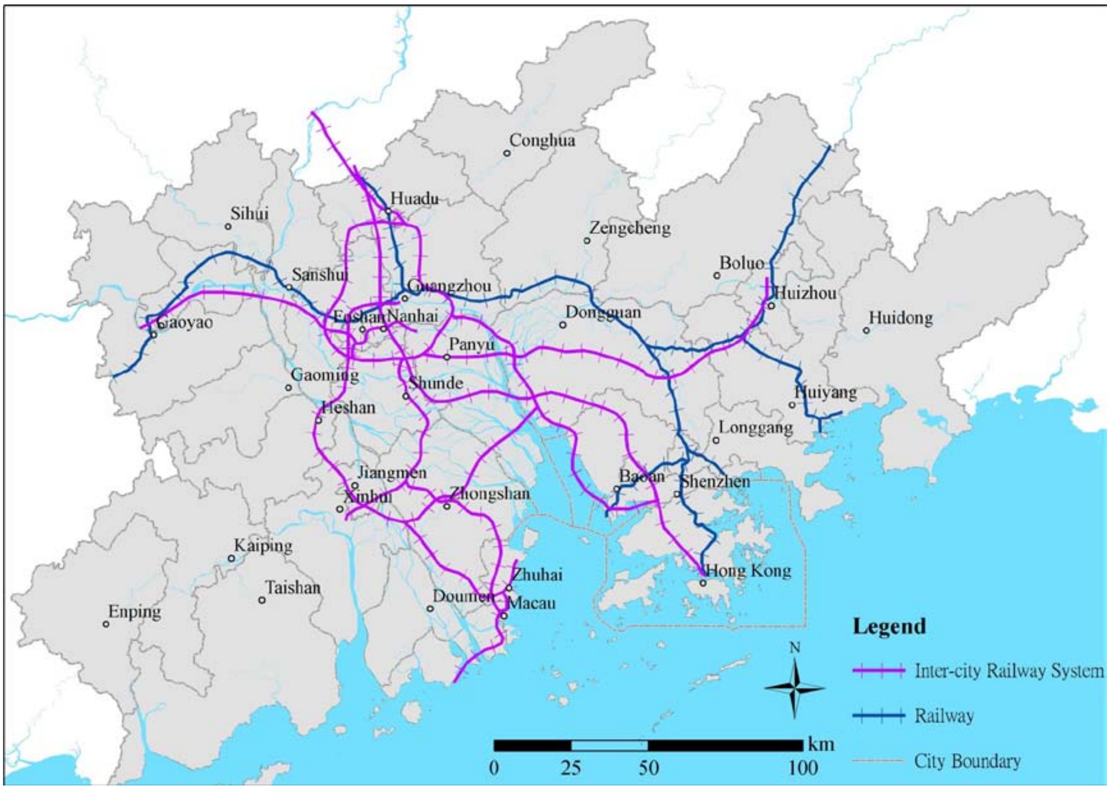

Figure 3. Railway development in the GPRD, 1990-2010

3. Methodology and Data

3.1 Accessibility measurements: average travel time, economic potential and daily accessibility indicator

Transport infrastructure development, such as the construction of bridges, expressways and high-speed railways, results in the "collapse" or "compression" of time and space between places (Janelle, 1969; Harvey, 1989), which can be reflected in the change in accessibility. A typical operationalization of such a concept is the opportunities to which an individual and a company can access (Linneker and Spence, 1992). There are three widely used accessibility indicators, namely, average travel time, economic potential, and daily accessibility indicator. The first one is simply the average travel time between a given place and all others. Economic potential measures the volume of economic activity to which a particular location has access after accounting for the cost/time of covering the distance to that activity. Daily accessibility indicator measures the amount of mass (population or economic activity) that can be reached from a location and permits returning to it within the same day (Gutiérrez, 2001).

Limited-access expressways and inter-city rail systems are characterized by their high speed, which reduces the time needed for travelling from one place to another. For such developments only time distance is needed to measure changes in accessibility (e.g. Murayama, 1994; Gutiérrez *et al.*, 1996; Gutiérrez and Gómez, 1999; Li and Shum, 2001; Zhu and Liu, 2004; Gutiérrez *et al.*, 2010). Following Li and Shum (2001, p. 41), the un-weighted average travel time is adopted in the present work. Network Analyst, an ArcGIS extension, is used to calculate minimum-time routes between the thirty-two cities; an origin-destination travel time matrix is thus derived. Considering the large traffic volume in the region, vehicle speed on limited-access expressways is set to be 90 km/h, slightly lower than 100 km/h as adopted by previous studies (e.g., Li and Shum, 2001; Cao *et al.*, 2005; Wu *et al.*, 2007). Speed of other highways is set to be 60 km/h. The calculation of the travel time matrix is only applied to the expressway network for the 1990 dataset, since at that time trains ran at about 70 km/h, substantially slower than expressway traffic. For later years, the calculation is carried out separately for expressways and railways (in 2020, inter-city railways). An overhead of 15 minutes is added to the travel time by train to compensate for the time buying tickets and bordering. Then, a comparison between travel time on expressways and by train is made, and the lesser one is chosen as the final travel time between cities. A description of the data of the expressway network, inter-city rail system, and population and economic statistics is presented in the following.

3.1 Transport network, population and economic activity data

Covering a relatively long period of thirty years (1990-2020), the transport network data come from a variety of sources. The 1990 highway network data are extracted from the "Digital Chart of the World Files, China" dataset compiled by Environmental Systems Research Institute, Inc. (ESRI) and US Defence Mapping Agency (DMA), which is now part of National Geospatial-Intelligence Agency (ESRI and DMA, 1993). The 2000 data, including railways and expressways, come from the database compiled for a consultant study of land-use pattern in the PRD for the Hong Kong 2030 strategic plan (HKPlanD, 2003). Google Map, the online map service provided by Google, is used to update these geographic data up to 2010. The planned transport network data, including new expressways, new bridges, and inter-city railways, are digitized from the recent approved planning of infrastructure development in the PRD (Guangdong Provincial Government, 2010).

Economic opportunity is typically represented by population and gross domestic product (GDP). In this study, population data for 1990 and 2000 come from the Population Census. Population data for 2010 are linearly projected from 1990 and 2000 data. GDP data for 1990 and 2000 are extracted from the statistical yearbooks of individual municipalities. Data for Macau and Hong Kong, originally recorded in Macau Dollars and Hong Kong Dollars, are converted to RMB, the Chinese currency, using exchange rate at that year. The latest GDP data of 2009 are used as proxies for economic activity volume in 2010. In order to single out the effect of infrastructure improvements on the patterns of accessibility and economic potential, in the computation for 2020 the same 2010 population and GDP data are used in the analysis.

4. Impacts on regional accessibility

4.1 Average travel time

Table 3 reports the average inter-city travel time. Travelling between cities in the GPRD was first facilitated between 1990 and 2010 mainly by expressway development. In 1990, travelling between two cities in the GPRD on average took 157 minutes, or over 2.5 hours. Ten years later in 2000, it took only 115 minutes (1.92 hours), a reduction of 26.8 percent. In addition to expressway construction, the upgrading of the Guangzhou-Shenzhen Railway too contributed to the speeding up of inter-city travels. Trips between Hong Kong and Dongguan (80 minutes), Hong Kong and Guangzhou (120 minutes), Shenzhen and Dongguan (45 minutes), and Shenzhen and Guangzhou (85 minutes) required shorter travel time by train than by road vehicles. Over the following decade (2000-2010), further development of expressways reduced average inter-city travel time to 95 minutes, or slightly above 1.5 hours. Percentage-wise, the reduction in average travel time was 17.7 percent. In percentage terms the marginal effect declined over time. However, over the next ten years (2010-2020), the introduction of inter-city railway service will bring about another round of speeding up. In 2020, for 410 out of 992 or 41.3% of all inter-city trips, it will be faster to take the train than by road transport. With the introduction of the inter-city railway service and further development of expressways, travelling between a pair of cities in the GPRD will need only 73 minutes (1.22 hours) on average. The reduction in average travel time in this decade is equal to 22 minutes, or 22.8 percent (Table 3).

Table 3. Average intercity travel time in the GPRD, 1990-2020

Year	**Travel Time**				**Decrease of Mean (%)**	**Main Reasons**
	Mean (minutes)	**Mean (hours)**	**S.D.**	**C. V.**		
1990	157	2.62	0.58	0.22	--	--
2000	115	1.92	0.41	0.22	26.8%	Expressway development (incl. Humen bridge), and acceleration of Guangzhou-Shenzhen rail
2010	95	1.58	0.30	0.19	17.7%	Expressway development
2020	73	1.22	0.32	0.26	22.8%	Inter-city rail system development, and improvement of expressways (in particular HK-ZH-MC bridge)

The easiness of travelling in the region is not even over space. Travelling from cities in Central GPRD is much less time consuming than trips from other locations for all four time lines. Among the three sub-regions, the Eastern Wing is the most disadvantaged (Table 4). Travelling between cities within Central GPRD, i.e. within Guangzhou Municipality, is always the easiest. This is understandable since, firstly, cities within the municipality are geographically close to each other, and secondly, transport networks within a single municipality could be developed in a more coordinated manner (Wang and Wang, 2008). Trips between localities on the Eastern Wing and those on the Western Wing are the most time-consuming, but nevertheless have witnessed the most significant reduction. Between 1990 and 2000, largely a result of the completion of the Humen Bridge, average travel time between localities in these two sub-regions declined from 3.93 hours to 2.65 hours. In the ten years to 2010, it further decreased to 2.19 hours, due to the extension of expressway networks. The introduction of inter-city railway service, further expansion of expressways, and to a larger extent, the completion of the HK-ZH-MC Bridge and the SZ-ZS link, will again significantly facilitate travelling across the Pearl Estuary. By 2020 average travel time between the Eastern and Western Wings will need only 1.64 hours, a reduction of another hour. Nonetheless, the Eastern-Western link will remain the weakest (Table 4), due to the absence of high-speed train service between the two sub-regions. A recent proposal to address this inadequacy is to make the SZ-ZS Bridge a combined road and rail link.

Table 4. Average intercity travel time in the GPRD, 1990-2020

a. 1990

	Eastern	Central	Western	Overall
Eastern	1.39	2.70	3.93	3.07
Central		1.34	2.17	2.22
Western			1.85	2.51

b. 2000

	Eastern	Central	Western	Overall
Eastern	1.12	1.86	2.65	2.12
Central		1.07	1.70	1.66
Western			1.54	1.88

c. 2010

	Eastern	Central	Western	Overall
Eastern	0.95	1.55	2.19	1.77
Central		0.80	1.40	1.36
Western			1.25	1.54

d. 2020

	Eastern	Central	Western	Overall
Eastern	0.86	1.28	1.64	1.38
Central		0.70	1.18	1.15
Western			0.90	1.16

In terms of spatial distribution, expressway development has relatively minor effects on the pattern of accessibility. During the first decade (1990-2000) of the examination period, the coefficient of variation (CV) remained unchanged at 0.22. In the following ten years, it slightly declined to 0.19 (Table 3). Moreover, the introduction of inter-city railway and the completion of the HK-ZH-MC Bridge and the SZ-ZS link will considerably increase the spatial disparity of accessibility. In 2020, the CV of average inter-city travel time for these thirty-two cities will stand at 0.26. The impacts on accessibility disparity resulting from further expansion of the inter-city railway network remain to be seen.

4.2 Economic potential

Economic potential is a gravity-type measure which takes into consideration of distance decay effect:

$$P_i = \sum_{j=1}^{n} \frac{M_j}{T_{ij}^{\lambda}} \qquad (1)$$

where P_i denotes the economic potential of location *i*, λ is the parameter gauging the rate of distance decay, M_j is the mass of economic activity in location *j*, and T_{ij} is travel cost, here approximated by travel time, between node *i* and node *j*. Following previous studies, the distance decay parameter λ is set to be 1 (e.g., Gutierrez, 2001; Jiang *et al.*, 2010). A complication of economic potential indicator is the self potential, i.e. the need to take into account of internal relationships. To estimate self potential, the internal travel time must be estimated first, which is given by the formula[5]:

$$T = 3 \times \log(P \times 10) \qquad (2)$$

The potentials of individual cities are used to interpolate the field of economic potential in the GPRD, which is shown in Figure 4. The results are further aggregated into the three sub-regions. The average economic potential of each region is given in Table 5-a (absolute values) and in Table 5-b (percentages).

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5 The parameterization of internal travel time is based on amendment of formula in previous studies (e.g., Gutiérrez, 2001), which follows a logarithmic form:

$$T = A \times \log(P \times 10)$$

where T denotes travel time, P for population, and A is a constant parameter. In Gutiérrez (2001), parameter A equals 15. However, such a setting is not applicable to the Chinese context. For example, following this formula, internal travel time of Hong Kong, of which population in 2000 is 6.665 million, will be 117 minutes, which is obviously unrealistic. The parameter A is derived as follow: internal travel time for the most populated city in 2000, Hong Kong, is set to be 24 minutes, the same as that of Paris in Gutiérrez (2001), then parameter A is calculated from formula (3), which equals to 3. Under such setting, the least internal travel time (Doumen-Doumen) is some 19 minutes.

Table 5. Economic potential in the PRD, 1990-2020

a. Average economic potential (GDP billion RMB *yuan* / minute) of individual cities in different sub-regions

Year	Eastern	Central	Western	Overall		
				Mean	S.D.	C. V.
1990	8.2	5.0	4.1	5.4	3.08	0.57
2000	25.9	17.5	14.2	18.0	9.16	0.51
2010	57.1	52.6	47.1	50.8	15.27	0.30
2020	70.9	66.9	68.1	68.7	22.00	0.32

b. Average % of regional total of individual cities in different sub-regions

Year	Eastern	Central	Western	Overall		
				Mean	S.D.	C. V.
1990	4.7%	2.9%	2.4%	3.1%	1.8%	0.57
2000	4.5%	3.0%	2.5%	3.1%	1.6%	0.51
2010	3.5%	3.2%	2.9%	3.1%	0.9%	0.30
2020	3.2%	3.0%	3.1%	3.1%	1.0%	0.32

Note: S.D. refers to standard deviation; C. V. stands for coefficient of variation.

The spatial pattern of economic potential in the GPRD has changed from a single-pole and steep-gradient one to a double-pole and spatially diffusive one. In 1990, Hong Kong was the only pole in the region in terms of economic potential. Hong Kong's role as a single dominant pole remained until 2000, but its dominance somehow declined and the spatial distribution of economic potential became more diffusive during this decade. In 2010, another pole formed around Guangzhou city proper. For the first time, accessibility as measured by economic potential in the GPRD showed a double-pole scenario, which broadly resembles the population potential field as predicted by Xu and Li (1990). By the end of the next decade (2010-2020), the double-pole pattern can still be observed, but the spatial distribution of economic potential will become much more diffusive (Figure 4).

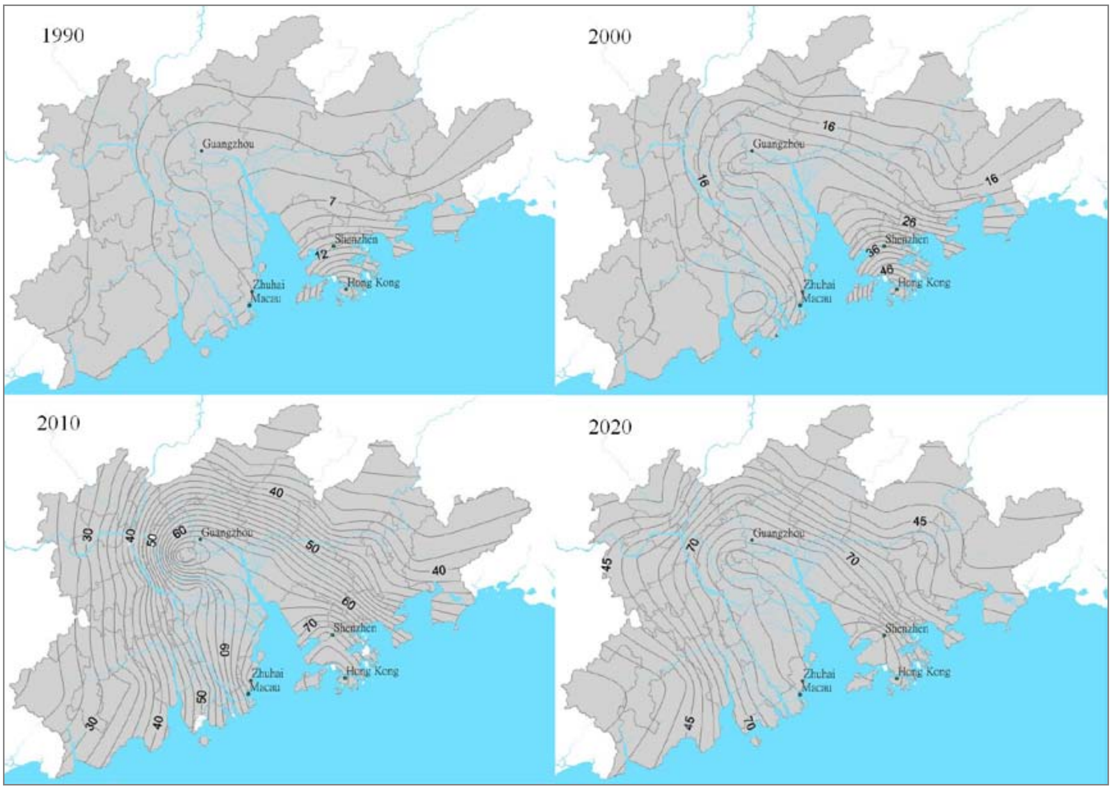
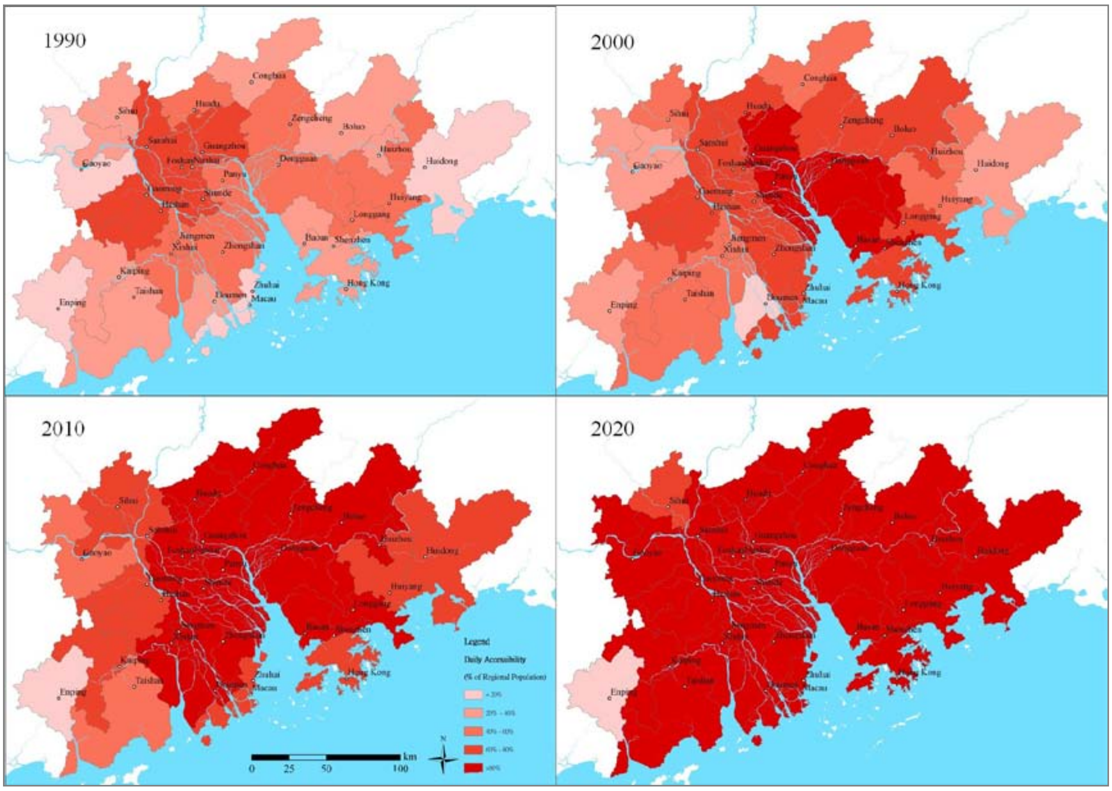


Figure 4. Spatial variation of economic potential of individual cities in the GPRD, 1990-2010

Reflecting the rapid economic growth, the economic potential of the GPRD has increased dramatically over time. In the first ten years (1990-2000), the average economic potential of cities in the region jumped from 5.4 to 18.0, a more than triple increase. The average economic potential tripled again in the following decade, reaching 50.8 by 2010. Even if the size of economy and population remain constant over the period 2010 to 2020, because of transport infrastructure improvements the average economic potential in the next decade will reach 68.7, or increase of 35.2 percent, by 2020. Spatially, economic potential is becoming increasingly evenly distributed. In contrast to its lagging position in average travel time, the Eastern Wing leads in economic potential. But over time, its advantage is diminishing. In 2010 and 2020, the differences in the average economic potential between sub-regions are almost negligible. The CV shows that spatial disparity of economic potential significantly declined during the period 1990-2010, and then slightly increased in the period 2010-2020 (Table 5).

4.3 Daily accessibility

The percentage of population or GDP can be reached within two hours from a locality is taken as the measurement of daily accessibility.[6] The results are shown in Figure 5. Obviously daily accessibility has improved significantly during these three decades. At the beginning of the 1990s, no cities could access more than 80 percent of regional population within two hours. In 2000, several localities around the Pearl Estuary, notably Guangzhou City Proper, Panyu, Dongguan, Baoan, and Shenzhen SEZ, could do so. The change was in part due to expressway development which had shrunk time distance between cities and in part due to the shift of population to the core areas around the Pearl Estuary. The daily accessibility indicator measured by accessible GDP shows similar temporal trend, but with the Eastern Wing taking an apparent leading position in early years (1990-2000), reflecting Hong Kong's overwhelming economic advantage at that time. In later years, however, the spatial pattern of daily accessibility measured either by population or by GDP has become very similar to each other (Figure 5).



6 The choice of time limit involves some degree of arbitrariness. However, "*the limit of four hour travel is considered as a critical cut-off point since it represents a likely limit of comfortable day return business traffic*" (Gutiérrez, 2001, p. 232). Business trip within a region at the scale similar to that of the GPRD is of particular importance for regional integration. Hence we have chosen two-hour as time limit.

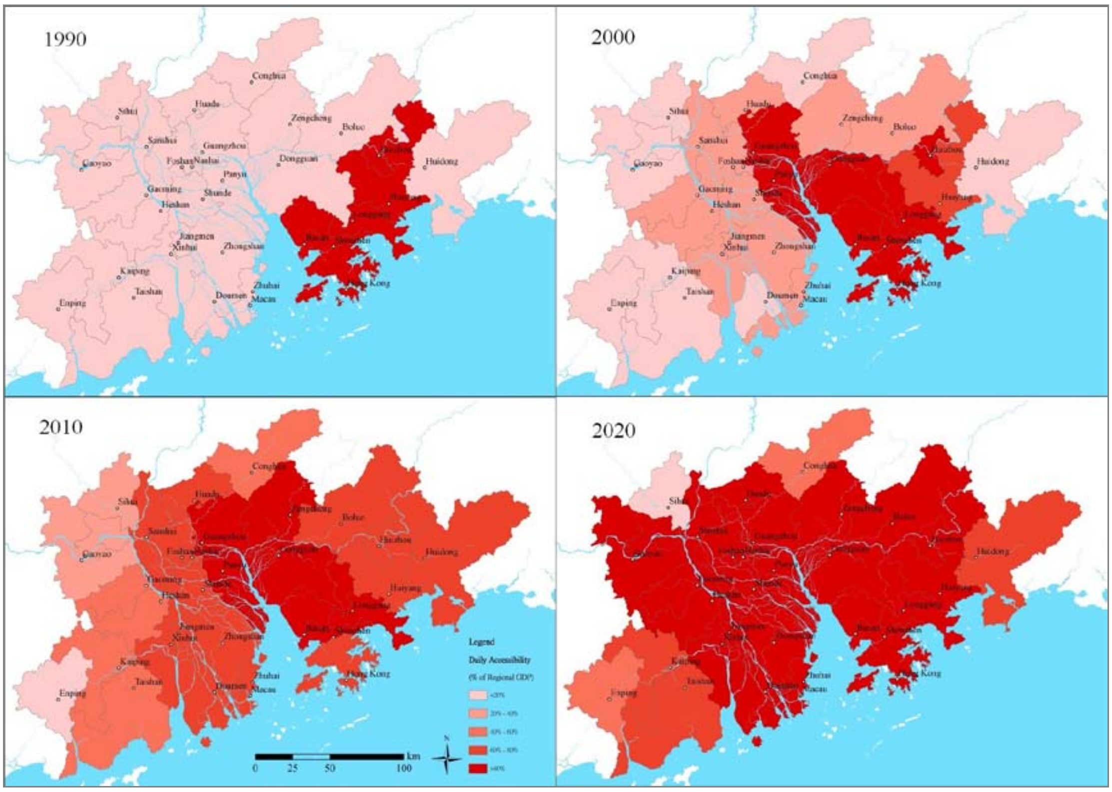


Figure 5. Daily accessibility of cities in the GPRD, 1990-2010
Up: Population accessible within two hours as % of regional total
Bottom: GDP accessible within two hours as % of regional total

5. Discussion

Transport infrastructure development has direct impacts on regional accessibility, as indicated by reduction in travel time or increase in economic and population potentials. In the PRD, it created “a transactional environment conducive to the inflow of foreign capital and the growth of export, manufacturing, and agricultural production” (Lin, 1999, p. 263). Since the initiation of open-door policies in the late 1970s, the PRD witnessed an exo(genous)-urbanization featured by spontaneous and small city- and town-dominated growth driven largely by foreign investment inflows from Hong Kong (Sit and Yang, 1997). At that time, the driving force exerted from Hong Kong, plus high spatial friction, regional development in the PRD tended to create new industrial districts and urban centres along the Hong Kong-mainland border and arterial highways (Sit and Yang, 1997; Lin, 1999). Such a development has resulted in the decreasing primacy of the traditional centre of the region, Guangzhou (Xu and Li, 1990). However, since the mid-1990s, Guangzhou has tried to regain its regional dominance. To do so, Guangzhou has not pursued economic growth enthusiastically, but has also tried to position itself as a hub in the regional transport networks, in particular the expressway networks and the inter-city railway system, principally through its political clout as the provincial capital. Apparently such efforts have paid off, as exemplified by the finding that if both Guangzhou and Hong Kong repeat their economic performance of past five years (2004-2009) in the next decade (2010-2020), Guangzhou will assume a regional centre role comparable to that of Hong Kong by 2020 (Hou and Li, 2011).

Another effort made by Guangzhou to enhance its regional hub position is the strategic planning conducted in 2000. A spatial development strategy of "developing the south and east, upgrading the north, and linking the west (*nan tuo, dong jin, bei you, xi lian*)" was adopted. The emphasis was particularly on the southern part, namely Panyu, which is arguably the most accessible locality in the GPRD as its average travel time to other cities is the lowest. Actually, as early as in the 1980s, it was recognized that once a good road network was established, Panyu could become the regional hub of road transportation for the entire delta (Lin, 1999, p. 255). To enhance its hub position, Guangzhou first incorporated Panyu to a district under its direct management in 2000, and then split the district into two, the new Panyu District and Nansha District, the latter being the outer port of the city.

The spatial pattern of economic development in the PRD has been conditioned by variations in accessibility. More specifically, the Eastern Wing has relied more on exports, while the Western Wing gives more emphasis on domestic markets. The difference was more evident in the early reform period (Li, 2009, p. 189-195). The computations above show that the Western PRD is more accessible to Guangzhou than is the Eastern Wing, implying that Guangzhou's influence is stronger on the Western side. Being the provincial capital, in early reform times Guangzhou, in comparison with other cities in the region, suffered from much greater rigidities imposed not only from upper-level governments but also from its concentration of state-owned enterprises. As such, the city was less receptive to foreign investment for export-oriented industries (Sit and Yang, 1997).

Because of its geographical position, the Eastern Wing has the most convenient transport connection with Hong Kong. Transport convenience facilitated the three cities there, Shenzhen, Dongguan, and Huizhou, in attracting export processing ventures from Hong Kong. However, the situation is quite different on the western side of the Pearl Estuary. Before the completion of the Guangzhou-Shenzhen Expressway and Humen Bridge in the late 1990s, it would be difficult for Hong Kong investors to travel to the Western Wing and return on the same day. In such a context a more endogenous mode of industrialization took place in the Western PRD. For example, town and village enterprises underscored Shunde’s development, while state-owned enterprises were emphasized in Zhongshan (Li, 2009). However, with penetration of rapid transport linkages, such as limited-access expressways and high-speed trains, accessibility disparity is now of much minor importance in differentiating regional development trajectories. A convergence of economic growth trends is evident in recent years (Zhu, 2003; Li, 2009).

The finding of diminishing influence of transport infrastructure development on reducing travel time has implications for economic growth. In the PRD during early development stage before the mid-1990s, the slogan of "road construction generates economic prosperity" (*lutong caitong*) could be found in the headings of newspapers, in major construction sites, and in the entrances of many towns and villages (Lin, 1999, p. 255). Also at that time, the so-called “build road first if you want to get rich” (*yao xiang fu, xian xiu lu*) was the prevailing mentality of officials at various levels. Nowadays such slogans are sensed as something of history and can rarely be seen. The major concerns of municipal governments as well as the Guangdong Provincial Government have shifted to upgrading the manufacturing industries and developing the tertiary and quaternary sectors. In response to this, high speed transport, in particular, limited-access highways and high-speed railways, is embraced by local governments. There is a general belief that high-speed transport can expand service markets, boost tourism spending, broaden regional labour markets, and support the growth of technology clusters, and as a result, helps improve productivity. To summarize, in terms of economic impact, transport development in the PRD has evolved from an independent force that will induce new economic activities (e.g., foreign direct investment, manufacturing industry development and export) to only a facilitator. As Lin (1999, pp. 266-267) puts it, “there is no linear and universally applicable relationship between transportation and regional economic growth and that the relationship may change in time and across space.”

Improved accessibility can facilitate regional integration and co-operation as spatial friction which deters flow of people and goods is reduced. In the GPRD, the situation is complicated by its fragmented governance. In the region are two special administrative regions, Hong Kong and Macau, which in many respects continue to function as quasi-states after the handover, two special economic zones, Shenzhen and

Zhuhai, the provincial capital of Guangzhou, which has tried to reassert its pre-eminent position in the region, and six other prefecture-level cities (Xu and Yeh, 2010). The Guangdong Provincial Government as well as the Beijing Central Government has tried to perform a coordinating role and formulated development plans for the region. The PRD Urban Cluster Coordinated Development Plan of 2005 formulated by the Provincial Government, for example, proposed to make the Guangzhou-Dongguan-Shenzhen corridor as the development backbone (Li, 2009). In the Outline of the Plan for the Reform and Development of the PRD, initiated by the National Development and Reform Commission (NDRC) in 2008 and approved by the State Council in January 2009, elevated the co-operation between Hong Kong SAR and Guangdong Province to be a national policy. With significantly improved convenience of travelling and increasing emphasis on regional co-operation, there is a need for planners in Hong Kong and Macau to think beyond the mainland border, and for mainland localities in the PRD to take Hong Kong and Macau into planning consideration. For instance, Hong Kong and Guangdong authorities can join force together to host major international events such as the Asian Games.

Beyond the GPRD there is the so-called Pan-Pearl River Delta (PPRD), an initiative of the Guangdong Provincial Government in 2004 to coordinate and facilitate infrastructure, business, and governmental development in Guangdong Province, Hong Kong, Macau, and eight neighbouring provinces. One fundamental rationale for the PPRD proposal is that the eight relatively lagging provinces will be able to benefit from business spillovers from the GPRD. At the same time the arrangement can help localities in the GPRD to penetrate much broader hinterlands. Consequently, future development of the PPRD is built on the growing importance of the PRD and its urbanization and industrialization trajectories (Yeung, 2005, p. 78). With considerably improved accessibility and regional integration within the GPRD, its leading position in the PPRD will be enhanced. As such, the spillover effects are not one-sided. The future growth of the GPRD and the PPRD will be mutually augmented.

6. Conclusions

Analysis of expressways and inter-city railway development using three accessibility indicators, more specifically, average inter-city travel time, economic potential, and daily accessibility, showed remarkable time-space convergence in the

GPRD over the period 1990-2020. The reduction in average travel time and increase in economic and population potential exhibited decreasing marginal gains, however. In the initial stage when transport facilities were quite rudimentary, construction of bridges and expressways and expansion and speeding up of rail transport yielded substantial gains; but with the maturation of regional transport networks, further infrastructure development will produce increasingly smaller accessibility improvements. A high degree of unevenness in regional accessibility prevailed in early reform times. Unevenness remained high during initial stage of expressway development, but later the map of accessibility became spatially more balanced. The development of inter-city railways in the second decade of the twenty-first century will once again raise accessibility inequality. Its effects afterwards, however, are yet to be seen.

Naturally, time-space compression has been accompanied by reorganization of economic space at various geographical scales. In the GPRD the divergent paths of industrialization on the eastern and western side of the Pearl Estuary are showing signs of converging along with improvements in transport connection. Local governments in the PRD used to consider transport infrastructure development as an independent force to promote economic growth. Today, transport infrastructures are seen more of a facilitator in response to various economic needs. This notwithstanding, Guangzhou has been able to reassert its position as the economic hub of the GPRD by capitalizing on its status as the provincial capital and its advantageous position in transport connections. Both expressway and inter-city railway developments now focus on the city. Guangzhou’s recent choice of developing Nansha at the northern edge of the Pearl Estuary as its outer port and auto and high-tech production centre is another example of the city’s attempt to make the best of its central location within the GPRD.

Acknowledgements

The research was supported by the General Research Fund (GRF) from the University Grants Committee of Hong Kong SAR (project HKBU 243209), the Hong Kong Baptist University Faculty Research Grant (project FRG2/09-10/100), and the 2010-2011 Dissertation Fellowship provided by Peking University-Lincoln Institute Centre for Urban Development and Land Policy (PKU-Lincoln Centre).

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