Research on The Development of Highspeed Railway Impact on The Local Economy

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Abstract

High-speed railway(HSR) as a competitive intercity transport solution in areas of high population density have been constructed rapidly in the last decade. Due to the expensive construction and maintenance costs, many researchers have discussed the high speed railway benefit and impact on local economic developments from different aspects by different methodologies. To assess and evaluate the effectiveness of the newly constructed highspeed railway, it is necessary to designate a transport-economy analysis framework. Among most of the research, accessibility measurements have been frequently mentioned and tested with various definitions, indicators, and processing methods for assessing traffic system utility. Traditional accessibility measurement methods are diverse, but due to different scholars having their own distinct definitions, calculation methods, and application processes for accessibility, the resulting indices are difficult to compare and often lack practical significance. This presents challenges for city planners and transportation system designers when adopting specific indicators. Additionally, in the analysis of economic and trade issues, there is a lack of a unified approach for linking accessibility with specific economic statistical variables and applying them in real-world contexts. This limits the broader application of accessibility in various fields.

To improve the accessibility measurement and application, an analysis framework with an improved method of accessibility measurement based on travellers' profitability is introduced in this research. Three levels of accessibility indicators, Daily Commuting Accessibility (DACC), Daily Work Commuting Accessibility (DWACC), and Weekly Return Accessibility (WACC) were designed based on different commuting frequencies

and purposes. The average traveller's income and local living cost were integrated to simulate the real commute scenario and assess the status of the transport system. In the case study, a series of statistics, containing 50 lines of travelling data and 11 years of economic data, was collected from the historical railway service record and local economy yearbook, in an area with 11 cities connected by conventional normal-speed and upgraded high-speed railway networks in the east of China. The index sheets measuring the three levels of accessibility indicated the changes in the travel benefit ratio throughout the test period following the popularisation of the high-speed railway service.

To validate the practicability of the new accessibility system, four empirical analyses, including the Optimal Intercity Traffic Service Speed analysis, Population Accessibility analysis, Dynamic Population Accessibility analysis and Industry Accessibility analysis were implemented. The first case, Optimal Intercity Traffic Service Speed analysis, discussed the travellers' benefit level under different intercity railway service speeds. A series of accessibility values were estimated according to the service speed from conventional train service to the faster Maglev. The results indicated how the average traveller benefited from the faster service speed, stable journey cost and economic development. The second case introduced the local demographic data into the panel data regression model to illustrate the population migration impacted by the high-speed railway service. In the result, Daily Accessibility Coefficient (DACC) showed a negative impact on the registered population difference (RPD) with a coefficient of -1.281, indicating that high-speed rail services help to balance population distribution between departure and destination cities. In contrast, conventional rail services, represented by the Weekly Accessibility Coefficient (WACC), had a positive effect on RPD, with a coefficient of 0.3839, suggesting that conventional rail services tend to increase population disparities, proving that the high-speed railway service is more effective in reducing population aggregation than the conventional railway service. The high-speed railway service could help to rebalance the local uneven population distribution and promote the progress of urbanisation. The third case, Dynamic Population-Accessibility Effectiveness analysis, extended the second case to discuss the impact cycle and period of a newly operated service. The result showed an average of 4 to 5 years' fluctuation in population migration and a hypothesis of urbanisation progress based on accessibility testing results was proposed. The last case analysed the relationship between the development of three sectors of the economy and intercity railway line construction. The tertiary and secondary sectors exhibited greater sensitivity to changes in traffic conditions, indicating that the more advanced industries in the economy have a higher demand for speed in intercity commuting. Even inside each group, the high-speed railway service presented a higher influence and stronger relationship on the industry development than the normal-speed railway service.

This study makes several key contributions to the field of transportation economics and regional development. By introducing a new accessibility measurement framework, it offers a practical tool for assessing the economic benefits of high-speed railway systems. The empirical analysis of the East China HSR network demonstrates how enhanced accessibility can improve economic integration, population mobility, and industrial growth, particularly in developing cities. The study also highlights the limitations of current HSR systems in terms of cost-effectiveness for daily commuters. The findings provide valuable insights for policymakers and urban planners, suggesting that while HSR drives regional development, careful planning is required to maximise its economic potential and ensure long-term sustainability.

Keywords: High-speed railway, Accessibility, Intercity commuter, Traveller's behaviour and living strategy, Population growth, Industry development, Urbanisation.

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Glossary of Terms / List of Abbreviations

Term	**Explanation / Meaning / Definition**
HSR	Highspeed railway
TGV	Train à Grande Vitesse, French highspeed train
CRH	China Railway High-Speed, China highspeed railway service
UK	United Kingdom (Great Britain and Northern Ireland)
ICE	InterCity Express, German highspeed railway
AVE	Alta Velocidad Española, Spanish highspeed railway service
KTX	Korea Train eXpress, Korean highspeed railway
SAA	Special area analysis
GIS	Geographic information system
PPA	Potential path area
PPS	Potential path space
STP	Space-time prism accessibility
OPP	Accessibility opportunities, travel benefit
VOT	The Value of Time
DFT	Department for Transport

Term	Explanation / Meaning / Definition
USODT	Department of Transport (United States)
TCF	Traveller's cost function
ACC	Accessibility
DACC	Daily intercity commuting accessibility
DWACC	Daily intercity commuting accessibility with 8 hours work time budget
WACC	Weekly return accessibility
SACCD	Single-city accessibility difference
CPI	Consumer Price Index
GDP	Gross domestic product
RPD	registered resident population difference
LTPD	Long-term resident population difference
PS	Primary sector
SS	Secondary sector
TS	Tertiary sector

Chapter 1. Introduction

1.1 Research background and objectives

Over the past 30 years, high-speed railway(HSR) has experienced rapid development. Japan constructed the world's first high-speed railway, the Shinkansen, from Tokyo to Osaka in 1964, reducing travel time to two and a half hours. By 1970, an extension to Shin-Osaka was completed. In subsequent years, the Shinkansen expanded northeast across the island. Within two decades, a network connecting Sendai, Morioka, and Shin-Aomori was established, forming the core of the Japanese high-speed railway network(Zhou & Shen, 2011). Today, the high-speed railway spans the Japanese islands, handling the pressures of extremely high passenger density and significantly contributing to the modernisation of Japanese society and economy. The European HSR plan started in the 1970s in France. The first Euro high-speed railway, French TGV, was operated from Lyon to Pairs in 1981. In the following years, the other lines, ATANTIQUE, MEDITERRANEE, and EST were constructed and located as the radial structure with the core hub of the city of Paris. 1280 km tracks connecting Nancy, Lille, and Bordeaux, etc, transported over 700 million passengers(Pepy & Perren, 2006). The German ICE is also one of the important parts of the European HSR network. The high-speed line, Hanover–Würzburg and Mannheim–Stuttgart, sent 48 million passengers in 1995(Vickerman, 1997). In the country like Spain and Italy, the high-speed railway service was also covered and connected to the European network. The HSR application in the Euro cooperated with the Union’s economic development and changed people's travel preferences. CRH, China Railway High-speed service, developed rapidly in the past 20 years. The first CRH train from Beijing to Tianjin was inaugurated in 2007, achieving speeds of 250 km/h. In 2010, the longest route from Beijing to Shanghai was launched, covering a distance of 1,400 km and reaching a maximum service speed of 350 km/h. The overnight travel time between Beijing to Shanghai was sharply reduced to 4 hours. After 7 years, the CRH service covered 29 provinces with over 20,000km, which took over 60% of the world's high-speed railway mileage. Over 3 billion people travel through CRH each year(Paul Amos, 2010). The HSR has become the most popular intercity traffic mode and the Chinese economy also experienced a boost period.

The advent of high-speed railways has markedly reduced the distance between cities, broadened markets, and transformed lifestyles. Such developments have stimulated consumer spending, unleashing significant demand and expanding the market, thereby enhancing product supply and contributing to the continuous growth of the national economy. HSR presents numerous benefits, including lower emissions, faster speed, higher reliability, and capacity. However, it also poses considerable challenges, such as the substantial costs associated with construction and maintenance. In regions with dense populations, HSR has emerged as a prime solution for alleviating transport congestion caused by large volumes of passengers. Often, the construction and operation of new high speed railways are linked with local economic uplift. With increasing numbers of countries planning to construct new HSR lines, determining the impact of HSR on local economic development and assessing the cost-effectiveness of these expensive projects have become crucial issues for policymakers to address. Many scholars have discussed the external benefits of an HSR service to the economy.

1.1.1 HSR-Economy Research in Europe

In Europe, Vickerman's research reviewed European HSR network development and the corresponding urban economy's development progress (Vickerman, 1997). Masson's work discussed local tourism industry changes affected by Spanish HSR and French TGV (Masson & Petiot, 2009). Bonnafous explores the TGV's influence on regional development and urban connectivity, highlighting its role in economic growth and the redistribution of activities across regions(Bonnafous, 1987). In Roth's research, he presents the Train à Grande Vitesse (TGV) as a transformative force within the rail industry, focusing on its technological innovation, economic advantages, commercial achievements, and the broad socio-economic benefits it delivers(Roth, 1990). Gutiérrez applied a distance accessibility indicator to analyse economic benefits in different areas brought about by improvements in railway infrastructure(Gutiérrez et al., 1996). Behrens' work focussed on the high-speed railway crossing the Channel from London to Paris and discussed the intramodal competition between HSR and air service(Behrens & Pels, 2012). A similar market share competition analysis between an HSR and conventional railway service was performed by Chaug-Ing(Hsu & Chung, 1997). Vickerman discussed how the perception of HSR has shifted from merely enhancing rail capacity to being recognized for its role in boosting competitiveness and cohesion within European regions, incorporating case studies on the Paris-Brussels line and Paris-London line (Vickerman & Ulied, 2006). Other TGV researches were also done by Streeter (Streeter, 1992) and Chen (Chen & Hall, 2015), etc. In German, Ebeling's research provides a comprehensive review of the development, implementation, and impacts of InterCity Express(ICE). This study evaluates the technological advancements, operational efficiencies, and the broader economic and environmental contributions of HSR to Germany's transport infrastructure, emphasizing the significant role that HSR play in enhancing national mobility, reducing travel times, and supporting Germany's commitment to sustainable transport solutions(Ebeling, 2005). Heuermann and Schmieder investigated the influence of HSR expansion on labour market dynamics in Germany. Their study revealed that improved transportation infrastructure significantly enhances worker mobility and demonstrated that a 1% decrease in travel time increases inter-regional commuting by 0.25%, with notable shifts towards rail transport, especially over medium distances, facilitating access to a broader range of employment opportunities and potentially leading to more optimal labour market matching(Heuermann & Schmieder, 2019). Furthermore, in Spain, Coto-Millán researched the economic impacts of high-speed rail networks, Alta Velocidad Española (AVE), specifically analysing the Madrid–Seville and Madrid–Barcelona–French Border routes. It discussed broader economic and social effects of HSR investments, including the enhancement of regional economic development and the stimulation of market integration through improved accessibility and connectivity(Coto-Millán et al., 2007). Other researches focusing on AVE were done by Rus. He analysed the costs and benefits level of an HSR project (de Rus & Inglada, 1997) and estimated the minimum demand requirement for HSR investment to be profitable (de Rus et al., 2007). His later research expanded the case study to all European HSR networks, offering an insightful examination of the financial and socio-economic implications of implementing high-speed rail systems (de Rus Mendoza, 2012). In other places in Europe, Fröidh's research indicated that the Swedish railway travel market share increased from 6% to 30% due to the new HSR service(Fröidh, 2005). In Italy, Pagliara's analysis provided empirical evidence of the significant positive impact that HSR infrastructure has on tourism development, underscoring its role as a catalyst for enhancing the attractiveness and competitiveness of tourist destinations (Pagliara et al., 2017).

1.1.2 HSR-Economy Research in Asia

In Asia, the construction of the high-speed railway and socio-economic development have also been discussed by many scholars. In Korea, Kim researched the population distribution and land-use changes alongside the Korea Train eXpress (KTX) railway from Seoul to Pusan throughout the time(Kim, 2000), and kept tracking and forecasting the spatial equity development in 2018(Kim & Sultana, 2015). In 2018, his new research discussed the station location choice and revealed that HSR stations significantly contribute to regional economic growth by attracting businesses, boosting employment, and enhancing property values in the surrounding areas (Kim et al., 2018).

In Japan, after World War II, the construction of the Shinkansen accompanied Japan's rapid economic development and also attracted many scholars to discuss the impact of high-speed railway services on the economy. In 1976, Okabe's research included the planning and organizational strategies behind the Shinkansen, its socio-economic effects, environmental considerations, and the technological advancements that underpin its operation. Through various contributions, the proceedings examine the Shinkansen's role in enhancing mobility, contributing to economic growth, and the challenges and solutions associated with integrating such a transport system into Japan's broader socio-economic fabric. (Okabe, 1976). In 1992, Taniguchi reviewed historical development, engineering aspects, services, economic results, environmental impacts, and discussed future expansion. This study also discusses the challenges including cost management and competition with other modes of transportation(Taniguchi, 1992). Hiroshi Okada illustrated Shinkansen's economic impact from the perspective of environmental protection and energy efficiency(Okada, 1994). In the later 1990s, Sasaki investigated the Shinkansen's effect on spatial distribution and regional development. By using a supplyoriented regional econometric model, the result illustrated that the denser Shinkansen network does not necessarily lead to regional dispersion. His analysis divided the railway impact into short-run effect focusing on changes in accessibility without altering the level of transport-related social overhead capital, and long-run effect which considered the cumulative effect of infrastructure development on regional economic structures(Sasaki et al., 1997). After 2000, Givonis reviewed the Shinkansen service from Tokyo to Osaka, summarised the HSR's substitution effect on the other traffic modes, and proposed a detailed HSR service standard(Givoni, 2006). In 2021, Hayakawa assessed the impact of Japan's high-speed rail network on economic activity and welfare by employing a spatial quantitative general equilibrium model that incorporates trade between firms, commuting, and residential choices. The result indicated that the highspeed service significantly boosts gross welfare than highways, due to its critical role in facilitating business-to-business services. (Hayakawa et al., 2021).

In China, the HSR started to be constructed in 2005. Scholars also discussed economy-related topics. Yang delved into the dynamic interplay between HSR and air travel, examining how their competition influences fare pricing, carrier profits, and overall consumer welfare(Yang & Zhang, 2012). Zheng tested the impact of the high-speed rail network on urban agglomeration around megacities in China (Zheng & Kahn, 2013). The study finds that the introduction of bullet trains in China, which started in 2007, has led to increased real estate prices in secondary cities near megacities, indicating a positive economic impact. Through the market potential model, the highspeed railway stimulated the development of second and third-tier cities and offered a larger variety of location choices for households and firms. In 2015, the research done by Chen indicated the substantial economic benefits of HSR infrastructure on local real estate markets, especially the value added to communities situated near these transportation hubs(Chen & Haynes, 2015). Shaw's research separated the evolution of China's HSR network into four stages, from before the introduction of HSR to the addition of new lines and adjustments in train speeds and ticket pricing. Employing a timetable-based accessibility evaluation approach, the research assesses changes in travel time, cost, and distance accessibility due to HSR developments. Findings indicate that HSR has significantly enhanced connectivity between urban areas, reducing travel times and reshaping the spatial accessibility pattern of cities(Shaw et al., 2014). Cheng's research discussed the impact of HSR systems on fostering economic integration and encouraging regional specialization within China and Europe. The study examines how HSR networks contribute to the seamless connection of markets, promoting the flow of capital, labour, and information across vast distances(Cheng et al., 2015). Jiao discussed how HSR influenced economic development through improved accessibility, connectivity, and spatial interdependence among cities in China. The study provides empirical evidence that HSR significantly contributes to economic growth by enhancing the flow of goods, services, and labour between interconnected regions(Jiao et al., 2020). There are many other studies on different fields, such as tourism(Wang et al., 2012), industry output(Xiaoyan et al., 2010), population dispersion(Wang et al., 2019), etc.

1.1.3 HSR-Economy research review discussion

Research on high-speed rail (HSR) and its impact on economic development across Europe and Asia has provided significant learnings. In Europe, key findings reveal that HSR enhances regional economic cohesion by improving accessibility between major cities and peripheral regions, thereby boosting competitiveness and reducing economic disparities. However, the full extent of its long-term economic effects, particularly in less developed regions, remains unclear. Studies have also highlighted the complexities of measuring the indirect impacts of HSR on housing markets and long-term regional development, where benefits might take time to materialise. Moreover, there are challenges in evaluating the interaction between HSR and other transport modes, such as air travel, which could affect network efficiency and overall economic returns. In Asia, especially in Japan and China, HSR has been instrumental in reshaping population distribution and accelerating urbanisation. It has facilitated the movement of people from congested megacities to regional hubs, supporting more balanced economic development. Nevertheless, challenges remain, particularly in understanding how to optimise the integration of HSR with existing transport infrastructure and how to maximise its economic benefits across regions with varying levels of development. Additionally, more research is needed to assess the environmental and social impacts of HSR expansion, especially in terms of land use and property values, which are often affected by rapid infrastructure growth. Future studies should focus on more nuanced evaluation methodologies that can capture the wider economic, social, and environmental effects of HSR. Further exploration is needed to understand the indirect and long-term impacts, particularly in less economically developed areas, and to investigate how to better integrate HSR with other modes of transportation. Addressing these gaps will provide deeper insights into how HSR can continue to evolve as a key driver of regional and national economic development.

On the other hand, it can be found that designing a general transport-economy analysis frame is necessary and helpful in measuring the utility and economic influence of high-speed railway and economy research. Normally, high-speed railway as a transport mode was assessed by indicators such as service speed, and train capacity from the technical aspect, or other indicators, like construction and operation cost, and investment profit to measure its financial performance from the economic aspect. To comprehensively measure the high-speed railway's impact on the economy, an analysis indicator or a structure needs to be designed, playing the role of a bridge linking the railway technical data and economy statistics. The integrated indicator is expected to illustrate the area's change intuitively with the new high speed railway service and help to generate a fixed but extendable analysis frame to contain more and different traffic modes to compare the effect between them. Throughout many years of research, a definition, Accessibility, was mentioned frequently in most studies, combining the information of the information of geographics, transport systems, and economy. It is necessary to summarise and make clear the main accessibility definitions and measuring methods.

1.2 Accessibility measurement methods and application review

Accessibility, which was initially designed as a geographical concept, has been widely used and tested with various definitions, indicators, objectives, and calculation processes in transport research for describing a traffic system's utility. Following the progress in transport technology, the accessibility measuring methods were also upgraded and iterated with different forms and principles.

1.2.1 Physical Distance Accessibility and Topological Accessibility

The physical distance is a traditional indicator measuring accessibility. In early times, Ingram's research applied distance as the core indicator to measure the accessibility between two points, which was called 'relative accessibility'(Ingram, 1971). With an empirical analysis at Hamilton in the USA, he derived the point-to-point measurement to a large regional area scale through an average distance matrix, which was called ‘integral accessibility’. Based on Ingram’s accessibility measurement, Baxter and Lenzi pointed out that the direct airline distance could cause matrix errors and imprecise results in a small urban area using the relative accessibility measurement. He also proposed Abstract Network Patterns and geographical constraint information to improve the accessibility of data accuracy(Baxter & Lenzi, 1975). In practical economy research, Guy measured the accessibility of local shopping opportunities based on the distance measurement between home and store location(Guy, 1983). Stanilov introduced relative accessibility with the average distance to a local CBD and discussed the suburban land-use changes after 1960 in Seattle(Stanilov, 2003). The content of the relative accessibility was also extended, including traffic information, such as travel time. Willigers and Van Wee applied distance accessibility indicators to the Random Parameter Logit choice model, with high-speed-train and car travel time, analysing the international companies’ office location choice and spatial distribution under the effect of the Netherlands HSR service(Willigers & Van Wee, 2011).

Topological measurements are another traditional methodology to assess accessibility focusing on the traffic network structure. An optimised network structure can achieve better area accessibility and connectivity with higher efficiency. Taaffe introduced an application case in an American road traffic network in 1973 in his book. A comprehensive topological accessibility database was built with connectivity statistics between the vertex cities and edge cities of the network(Taaffe, 1996). One of the applications done by Wang included evaluating overall network connectivity, constructing a distance matrix, and computing nodal accessibility coefficients, to understand the network's expansion and optimization in terms of accessibility(Wang et al., 2009). Liu et al. explore the impacts of high-speed rail (HSR) network development on airport traffic and traffic distribution in China and Japan (Liu et al., 2019). The study introduces degree centrality and harmonic centrality to assess how well airports are connected within the HSR network and how accessible they are to other cities, respectively. The findings show that, as HSR connectivity increases, airports in China experience a decline in domestic and total traffic, while in Japan, the effects are more modest. The traditional distance and topological measurement focused on reflecting the regional accessibility by geographical information and basic traffic information, but it lacks the passenger's preference from the view of the traffic system demand side in transport economy research.

1.2.2 Utility Accessibility and Restricted Opportunity Accessibility

Some transport economy researchers have established the indicator from the view of the passenger. Utility accessibility, which was proposed by Ben-Akiva and Lerman in the 1980s(Ben-Akiva & Lerman, 1979), was designed based on a travellers' behaviour and demand model, measuring the maximum achievable utility through a target traffic system. In Baradaran and Ramjerdi's research, they summarised that the utility approach is deeply related to a single traveller's personal experience, which could improve accessibility accuracy but required a vast amount of individual data in economy-related research(Baradaran & Ramjerdi, 2001). The empirical application, performed by Niemeier, investigated mode-destination accessibility in Washington state(Niemeier, 1997), and another study, undertaken by Levine, analysed jobs-housing balance(Levine, 1998). A measurement of restricted opportunity evaluated the volume of potentially achievable opportunities under limited travel conditions, such as fixed travel time or distance. In practical analysis, Martin Wachs and T. Gordon Kumagai investigated the relationship between wage level, travel cost, commuting time, and employment distribution around Los Angeles(Wachs & Kumagai, 1973). An opportunity accessibility test framework measured the number of achievable healthcare points and job opportunities at a certain point under 30, 60, and 90-minute travel time. The result proved that the restricted opportunity accessibility indicator is effective in explaining the spatial location difference in residence and economic development. Cracknell's research discussed the leisure traffic accessibility from a core urban area to the countryside to estimate how a new marginal residence area absorbed recreational traffic flow, and forecasted the overload of the road network, following the growth of the population and car ownership(Cracknell, 1967). His accessibility indicator was built based on the road length and traffic capacity from the city centre to a rural area in a fixed radius around the main cities. Another application of the restricted opportunity measurement was performed by Sherman et al. through SAA (special area analysis) and cross-modal comparisons under the existing highway network around Boston(Sherman et al., 1974). Ennio proposed a new behaviour definition of an accessibility and corresponding measurement model, which combined the advantage of both the utility approach and the restrained opportunity approach with a case study in the Naples metropolitan area in Italy(Cascetta et al., 2016). After the 1990s, following the development of intelligent traffic systems and information technology, some new accessibility measuring approaches were raised, pushing the analysis deeper and making complicated data collection and individual accessibility measurements possible. Miller designed STP, space-time prism accessibility, which is a derivation of the individual restricted opportunity measurement(Miller, 1999), and he applied it through a geographic information system (GIS)(Miller & Wu, 2000). By setting the travel purpose, the potential path area (PPA) and potential path space (PPS) described travellers' possible destinations under current traffic systems and estimated the economic activity accurately. Berglund's research tested the STP accessibility measurement through a GIS in the case of the Swedish railway network in the Stockholm region (Berglund, 2001). He pointed out that the accessibility index in long-distance travel becomes more insensitive compared to that of a short journey.

Yang et al. examined the spatial patterns and influencing factors of rural settlements in Guangdong Province, China, using a combination of remote sensing data and accessibility modelling(Yang et al., 2019). The study applied the minimal cumulative resistance (MCR) model to assess road traffic accessibility and its impact on the distribution of rural settlements. By incorporating factors such as road types, travel speeds, and physical geography (elevation, slope, etc.), the study concluded that road accessibility has a significant influence on settlement distribution, particularly in lowland areas with easy access to nearby towns. The kernel density and logistic regression methods used in the study provide a quantitative approach to understanding how geographic and infrastructural factors shape rural settlement patterns. The Utility accessibility and the restricted opportunity accessibility are designed from two opposite sides. The Utility accessibility is expected to reflect individual behaviours and preferences from the view of a single traveller. The restricted opportunity method assessed the accessibility more geographically, based on confirmed traffic restrictions and conditions set by the researcher subjectively.

1.2.3 Attractiveness Accessibility

The attractiveness measurement is the most popular method in transport economy research, which considers the traveller's decision-making process, and it splits travel behaviour into attractiveness and resistance. The attractiveness part includes the opportunity or travel benefit that promotes the travelling motivation, and the resistance, which is also known as travel friction, indicates the power and cost that may hinder the trip from happening. The attractiveness accessibility indicator is designed to measure the spatial distributing level of attractiveness and the opportunities discounted by the resistance. In Hansen’s research, a basic attractiveness measurement and its main derivation, the gravity model, were first proposed with a case study around Washington, D.C., USA (Hansen, 1959). Dalvi and Martin’s research expanded attractiveness accessibility from point-to-point calculation to zonal aggregation measurement and tested it in the area around London (Dalvi & Martin, 1976). Linneker and Spence addressed two types of accessibility indicators, Hansen’s attractiveness accessibility and the potential transport costs accessibility measurement proposed by Harris(Harris, 1954),(Linneker & Spence, 1992). They applied the two methods in analysing the impact of the M25 London highway construction and also introduced the theory of generalised cost, which supports a new form of travel resistance. Gutiérrez integrated three indicators, average travel times, economic potential, and daily accessibility, for predicting the local economic impact of the new Spain–France HSR (Gutiérrez, 2001). Haynes reviewed the impact of HSR on travel accessibility and fluctuations of the local labour force and population in the cities along the new Shinkansen line, accessing the local development potential based on the gravity-type accessibility model(Haynes, 1997). In Liu and Zhang’s work(Liu & Zhang, 2018), the gravity model is applied to measure accessibility in Chinese city-cluster regions, with employment serving as a measure of destination attractiveness and travel time by rail as the measure of impedance. This model has proven effective in capturing how transportation infrastructure, such as high-speed railway, alters accessibility by reducing travel times, thus increasing the potential for economic productivity through improved connectivity. The gravity model is particularly valuable for analysing agglomeration effects and understanding how transport networks influence regional disparities in accessibility. Ferrari et al. also employed a gravity model to evaluate the accessibility of Ligurian ports (Genoa, La Spezia, and Savona) to their hinterlands and to measure the impact of container traffic diversion to competing ports (Ferrari et al., 2011). The study compared real traffic flows with those predicted by a spatial interaction model, revealing significant frictions (e.g., infrastructural bottlenecks) that hindered hinterland connectivity. Ennio's research discussed the economic growth and transport accessibility changes in Italy in the ten years since the HSR was first constructed. The attractiveness-based accessibility indicator contained the number of employees as travel attractiveness, and the railway generalised cost as the travel friction part, which creatively integrated the travel time and cost through the value of time (VOT)(Cascetta et al., 2020). Moyano, Rivas, and Coronado (Moyano et al., 2019) conducted an analysis of the efficiency of high-speed rail (HSR) connections in Spain, focusing on same-day trips for both business and tourism purposes. The study evaluates how various factors, such as timetable suitability, ticket prices, and local accessibility to/from HSR stations, influence the overall efficiency of HSR services. Their findings reveal that cities located in peripheral regions of the HSR network tend to benefit more from business trips, while intermediate cities show higher efficiency for tourism-related trips. In China, the attractiveness accessibility has also been implemented and incorporated with other models and methods in recent research. In Wang's work, the measurement of attractiveness was combined with an iso-tourist model and a grid net space model to illustrate the development of local tourism under the effect of a new high-speed service (Wang et al., 2012). Xiaohua tested the attractiveness strength of 15 high-speed service hub cities and 45 smaller cities along the Beijing–Shanghai HSR, classifying multiple levels of the HSR economic radiation effect area and indicating that an HSR can bring more benefit to areas with a higher population density (Xiaohua et al., 2015). Another analysis, performed by Deyou and Yuqi, replaced the traditional distance impedance with the travel time cost and was validated using a case study in the HSR network in the east of China (Deyou & Yuqi, 2009). Xiaoyan's research introduced the Grey prediction method, which forecasts economic growth without the HSR effect, and integrated it with attractiveness analysis to compare the strength of the economic connection with or without the HSR effect between Beijing and Tianjin (Xiaoyan et al., 2010). In recent research conducted by QiongYang's team, Hansen's accessibility form, which includes the destination population for attractiveness and travel time for friction, was introduced and combined with the computable general equilibrium model to analyse the HSR impact on economic growth and regional disparities(Yang et al., 2023). The application of the accessibility and general equilibrium model was also performed by Chen, who investigated how high-speed railway infrastructure development stimulates the local economy(Chen, 2019). Wang et al. examined the spatial and economic effects of the Bohai Strait Cross-Sea Channel (BSCC) on transportation accessibility and economic linkages between Chinese coastal cities(Wang et al., 2017). Using Dijkstra's algorithm to measure changes in travel times and the gravity model to assess economic interactions, the study found that the BSCC would significantly reduce travel times and strengthen economic connections, particularly in northeastern China.

Although the attractiveness measurement is widely used, limitations are also noticeable. In most of the research, the value is defined by a 'ratio' between travel attractiveness and resistance. Meanwhile, travel attractiveness and resistance have various forms. The attractiveness could be income, industry output, or even perceived inexpressible feelings, and the resistance could be the travel distance, money cost, or travel time. It caused the calculation result to stay at the 'index level', and this was hard to explain, independently. The calculation process in different research was also different, making the accessibility index itself incomparable

1.2.4 Accessibility measurement discussion

The measurement of accessibility is a key aspect in transport and geography research, with various methods developed to capture different dimensions of accessibility across different transport modes and contexts. Table 1 summarises these existing methods, highlighting both their strengths and limitations.

Table 1 – Accessibility measurement comparison

Accessibility Measurement	**Characteristics and Advantages**	**Limitations and Disadvantages**
Physical distance accessibility and Topological accessibility	Pure geographical indicator; Ideal for transport and geography analysis.	Not comprehensive; Lacking traveller's preference information.
Utility accessibility	From the view of the individual passenger; Ideal for travel behaviour analysis	Need excessive volume of travellers' data; Hardly quantify testers' subjective feelings
Restricted opportunity accessibility	Ideal for urban planning and transport management; Accuracy and deep with modern GIS assistance.	Need excessive volume of traveller and geographical data; Big analysis difference between the depth of technology assistance
Attractiveness accessibility	Widely used accessibility measurement; High compatibility; Various derivations for different scenarios.	Many different attractiveness and resistance forms; Incomparable results between different case studies. Need a better explanation of the index itself.

Physical distance accessibility is one of the earliest methods, focusing purely on the geographical distance between two points. This method is ideal for straightforward geographical or transport analysis. However, it does not account for the preferences and behaviour of travellers, making it less useful for studies involving passenger decisions. Similarly, topological accessibility focuses on the structure of the transport network itself, evaluating the efficiency of the network in connecting various points. While topological methods are highly useful for network design and expansion studies, they too fail to consider individual traveller behaviours or preferences.

Utility accessibility, developed from individual traveller preferences and behaviours, takes into account the potential utility or benefit a traveller might gain from a journey. This method is valuable for behavioural analysis, particularly in terms of commuter decision-making. However, it requires vast amounts of individual traveller data, making it difficult to apply in large-scale studies. Additionally, quantifying subjective factors like perceived utility remains a challenge.

Restricted opportunity accessibility is highly useful for urban planning and transport management, particularly with the integration of Geographic Information System (GIS) technology. It allows for the analysis of achievable opportunities within certain constraints, such as time or distance limits. However, similar to utility accessibility, it requires extensive traveller and geographical data. The results of restricted opportunity studies can vary significantly depending on the quality and depth of technological assistance.

Attractiveness accessibility has become a widely used method, as it offers flexibility in adapting to different scenarios by adjusting the definition of travel attractiveness and resistance (or friction). It allows for compatibility with various other models and methods, making it an ideal tool for comprehensive studies. However, the use of different forms of attractiveness (e.g., income, industry output) and resistance (e.g., travel time, distance, cost) can result in incomparable outcomes between studies. Furthermore, the index itself often lacks clarity, requiring better explanations to ensure its utility across different cases.

1.3 Innovation and value

In this research, a comprehensive HSR economy analysis structure with an improved accessibility measuring indicator is designed. The new accessibility indicator was redesigned based on attractiveness accessibility measurement. The improvement and innovation in this study included:

- In this research, compared to the traditional attractiveness accessibility structure, the improved methods introduced the traveller's income and travel cost into the calculation to reflect the real-world travel motivation.
- In the section of methodology design in Chapter 2, the commute trip became the focal point of the research, and the accessibility measuring method was designed to simulate the passenger's intercity travel process, as opposed to the traditional attractiveness measurement which often provides an untouchable and incomparable definition that lacks practical significance.
- Meanwhile, three levels of indicators were designed to represent intercity commuting accessibility under different speeds and scenarios in Chapter 2, which replace the traditional single index with a group of composite indices. Differing from traditional measurement methods describing travel resistance with distance, the new measurement method not only considered the actual fare expenditure of passengers as a factor but also integrated travel time cost

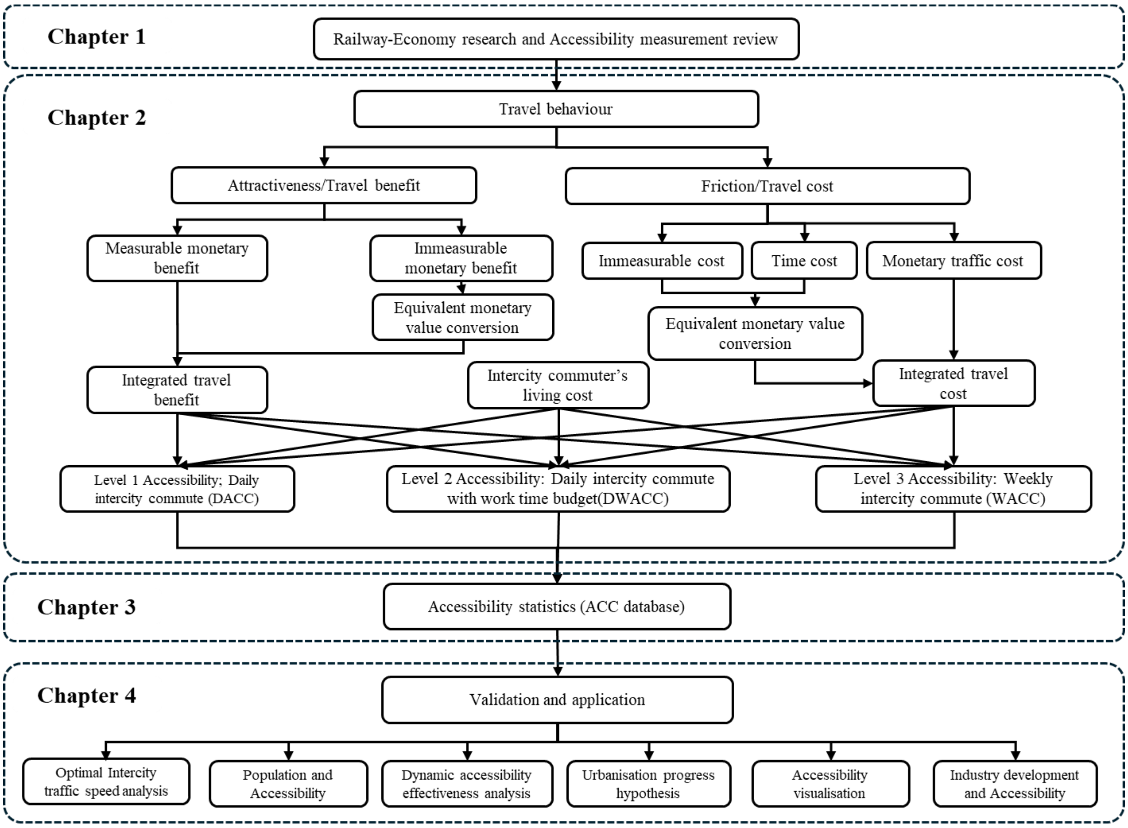
through Value Of Time(VOT) estimation, simulating the travel fiction in a real-world scenario.

- In Chapter 3, Eleven sample cities were selected, encompassing data from over 50 normal-speed and high-speed railway services, along with eleven years of economic data. This compilation has generated a comprehensive accessibility database for future research and application.
- In Chapter 4, the accessibility indicators were tested and verified by four groups of empirical analysis, regarding the benefit of faster railway service speed, population migration, urbanisation development, economic impact cycle and period.

1.4 Thesis structure

The research content and thesis structure will be presented following the structure map shown in Figure 1.

Figure 1-Thesis structure



In Chapter 1, the background part initially introduced the high-speed railway development and construction progress in different countries in history. The related high-speed railway and economy research are integrated and summarised according to different topics. Then the main content focused on reviewing the accessibility research history, including definition, indicator design and application.

Chapter 2 will illustrate the methodology mainly including accessibility modelling design ideas in this project. Starting from travellers' behaviour, the travel benefits and friction were defined first. According to the different travel destinations, intercity living strategy and intracity living strategy were distinguished and cleared as the two major accessibility test scenarios. Three levels of the accessibility indicator were proposed with the calculation method. The required economic and traffic statistic indicators were listed as well. To validate the accessibility indicator, an econometrical model was introduced, including structure design and variable setting.

Chapter 3 is the section of the case study, which specifically contains the measuring and calculating results of the three levels of the Accessibility index. In the beginning, the research case area and the period were introduced Then, the detailed accessibility measuring case of the city of Hefei was selected specifically to illustrate the calculation process. After that, all three levels of statistical data were listed with analysis, which is also the data source for the following sub-research module.

Chapter 4 will introduce several sub-modules and empirical analyses which validate the accessibility data and apply them in analysing the real word problem to test the practicability of the designed indicators. The first module analysed the relationship between railway service speed and passenger accessibility index and analysed the travelling profitability under different service speeds. The second model is the econometric analysis of the accessibility and area population flow, aiming to discover how the city traffic condition affects local demographics. A short discussion which is attached, based on population flow research, was extended to how the high-speed railway service became profitable for most people and promoted the urbanisation development and the necessity of ultra-high service speed. The third module was the accessibility indicator application on the three economy sectors, primary, secondary, and tertiary industry to analyse which part of the social economy was influenced more by the development of high-speed railway.

The final Chapter 5 will conclude the overall research result and summarise the entire study project.

Chapter 2. Methodology

2.1 Accessibility measurements

According to the literature review and the understanding of traffic network utility, the city accessibility is redefined and cleared in this research, for building the connection between the transportation and economy indicators. Compared to the traditional measurement, the connotation is enriched with the traffic accessibility description, in terms of the travellers' behaviour, travel motivation, attractiveness, and friction. The accessibility of a certain area or a network, should not only focus on the travel cost, time and money, transport capacity, or the volume of the network's topological structure. In the real world, all outcomes of travel planning and decision-making are derived from a balance among a series of factors.

2.1.1 Accessibility definition and initial indicator design idea

In the field of transport research, the potential gains from travel are often categorised as 'Opportunity' or 'Attractiveness'. Such benefits can motivate people to become potential travellers. Typically, the behaviour of travellers originates from a basic desire or need, with the aim of seizing these opportunities and deriving associated benefits, such as an exhilarating trip, a lucrative job, or a crucial business meeting. This also suggests that travel benefits can take various forms, ranging from tangible rewards like money to intangible and elusive benefits, such as the enjoyment experienced on a leisurely journey. Quantifying and standardising these opportunities is also a crucial topic in transport research. On the other hand, the transport system offers a variety of travel modes to meet consumer demands with different levels of efficiency, and cost speed, which are referred to as ‘travel friction’ or ‘travel impedance’ from the passengers' perspective. This friction encompasses not only monetary costs but also travel time, both of which are taken increasingly seriously in the modern transport system. Nowadays, faster aviation and high-speed railway transport play a significant role in contemporary regions such as the EU and East Asia.

In this research, accessibility is conceptualised as a measure of the transport service's utility and the passengers' ability to utilise the target transport system, viewed through the lens of the entire travel behaviour's benefits and costs. It aims to mirror the efficacy of the transport service as a facilitator, enhancing passengers' access to opportunities and serving as a benchmark for the level of benefit that can be attained by travelling through the transport system. The proposed updated accessibility indicator seeks to bridge the gap between traditional accessibility data, traffic economic data, and traveller lifestyle data. This is designed to simulate the travel decision-making process, providing a realistic reflection of actual usage scenarios.

2.1.2 High-speed railway character and accessibility

The new accessibility indicator is designed to adapt to the railway transport character and illustrate the accessibility improvement after high-speed service was applied. The relative speciality of high-speed service is summarised. Compare the to the traditional traffic modes:

- The faster speed and larger capacity decreased the travel time dramatically and made the longer daily commute possible.

- High-speed railway service is stable and punctual, rarely affected by the rush hour and bad weather. High-end technology can support extremely dense timetables and reduce the operation headway with dynamic solutions.
- The high-speed railway system has high compatibility with other city public transport systems. Integrated transportation facilities and traffic hubs can guide the main line passenger flow to inner city traffic, linking the 'final one mile' to the destination.
- The high-speed railway system is better suitable for the city clusters and the area populations. It has been widely used in massive mid-range inter-city travel scenarios in the EU, Japan and China.

Following the trend of urbanisation and economic development, gathering population and increasing traffic demand would become the soil for the birth of high-speed and punctual service. And when the regional economy grows to a certain high level, the high speed railway could be a better way than the other intercity transportation modes. The high speed railway as an invisible bridge strengthens and shortens the connection among the cities bringing positive effects.

2.2 Accessibility indicator and measurement methodology

2.2.1 Passenger's Intercity and Intracity commuting trip and living strategy

In daily life, the commuting trip is the most common type of journey that many people would experience every day. People may travel between home and workplace by various traffic modes, such as on foot, cycling, driving or public transport service. For transport system designers, commuting travel represents the most stressful scenario that they need to face. The system efficiency including service speed, cost and capacity would not only affect the service supplier’s business but also deeply change the local people's living style and external economic development. In this research, passengers’ commuting behaviour is assumed to be the main test scenario to discuss the system performance and economic impact. Due to the character of the railway transport system, the commuter is classified into two categories, intracity commuter and intercity commuter.

An intracity commuter is a passenger who lives and works in the same city. This type of traveller took a large percentage of our lives. The daily working income and living costs were limited inside the city. They are the main consumer of the intracity transport system. The lifestyle of the people who have their whole daily affairs and commuting journey in one city is called ‘Single city life’. The intercity commuter is the passenger who lives and works in two or more different cities. The longer distance commuting trip is necessary for them every day. The intercity commuter could have more choices among the areas connected by service, which enriched the opportunity and cost combination for living strategy. In contrast to ‘Single city life’, if a person lives and works in different cities every day, this scenario is called ‘Dual city life’(Only the two cities' situation was concerned in the research.). The basic idea of accessibility measurement is to simulate and evaluate the personal travel behaviour and economy scenario by assuming people are forced to use

In this research, a commuting trip is defined as a journey made by an individual travelling through the studied transport network to their workplace and returning home at the end of the day. For the purposes of data collection and integration, leisure trips and other types of journeys were excluded due to the complexity of their purposes and motivations.

Therefore, only trips made for work are considered as commuting trips. high speed service and live a ‘dual city life’.

2.2.2 Accessibility attractiveness and friction

In this research, travel attractiveness and friction description variables need to be cleared and also should be able to practically reflect the real travel scenario in different cases with high compatibility. To differentiate from other studies, this simulation will incorporate detailed information from every stage of the journey, rather than focusing solely on the main segment of the high-speed train travel. In some megacities in East Asia, additional time costs, such as the time taken to access the station from home or to the destination, may constitute a significant portion of the overall journey time. Therefore, it is essential to consider these additional elements to estimate accessibility accurately and comprehensively.

2.2.2.1 Travel attractiveness and friction

Theoretically, any potential trip should be beneficial to a traveller. In accessibility research, attractiveness is the motivation or the travel benefit for the traveller. The trip profit mainly contains two forms, virtual human feeling and physical, touchable income. In this research, OPP is the travel attractiveness. The average salary per day of working in the corresponding city would be considered as the travel benefits to measure the accessibility of daily work commutes on an average level. If the traveller lives in city i and works in city j, the attractiveness would be OPP_j, which is equal to the average salary in city j per day. The other activities, like sightseeing, shopping, leisure or other business meetings, are not considered, only including the general daily commute and work to reflect the average level.

The travel friction represents the whole traveller's cost in a certain trip, which has two main forms, the currency cost and the time cost. Both types of costs can be subdivided according to the different travel stages.

If a passenger travels through a high-speed railway from city i to city j, he will need to pay:

- C_{ai} access currency cost and T_{ai} access time cost from the start point to the railway station i;
- T_{si} the station time including transfer time and wait time at station i;
- C_{ij} main journey currency cost and T_{ij} main journey time cost from station i to station j;
- T_{sj} the station time cost including transfer time and wait time at station j;
- C_{aj} the access currency cost and T_{aj} access time cost from the railway station j to the destination;
- TC_{ij} the total cost from i to j.

These variables contain all the costs of currency and time in a hypothetic journey from city i to city j. In general, the personal travel cost and living cost could affect traffic mode utility respectively. For assessing the real passenger's decision-making process and traveller behaviour, the living cost is also taken into account. It can be classified as an accommodation expanse and food expanse which supports basic human life. In the test scenario, the 'Dual city life', the traveller is assumed to commute by high-speed train and work in another city, which means the passenger needs to pay the living fares in city i and get the salary from working in city j. Two variables are set to describe the living expenses:

- R_i the rent fares in the city i;

- C_{fi} the food cost in the city i;
- C_{li} the total living cost in the city i;

Figure 2 shows all costs in a single journey from city i to city j.

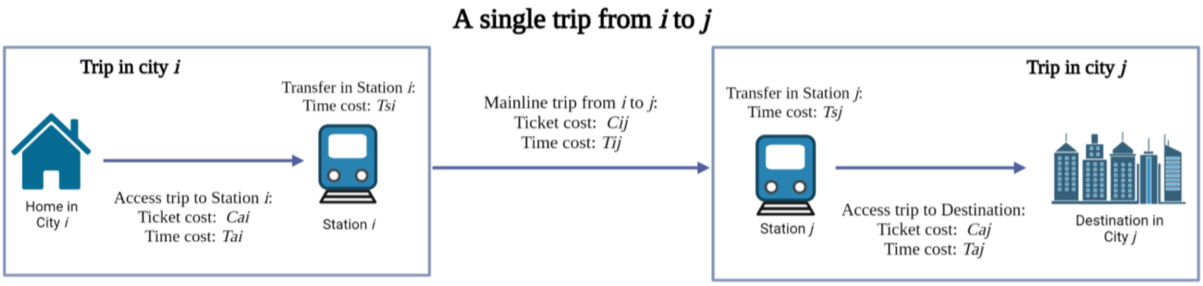


Figure 2- A single trip cost from city i to city j

2.2.3 The travel time monetary measurement

The travel friction was described in two parts, containing the time cost measured by time unit and monetary cost measured by currency unit, which caused the mass for the calculation unit and accessibility index explanation. The travel time needs to be transited into a monetary measuring unit for integrating the monetary cost and time cost. The process was indicated as $f(T_{ij})$ in the equation.

There are many ways to measure the equal monetary value of travel time. According to the literature review, the Generalised Cost model is one of the methodologies mentioned in the monetary time unit transition and is widely used in modern traffic planning (Lesley, 2009). The travel time cost could be subdivided into access time, wait time, travel time, congestion time, etc, and transited into monetary units according to the suggested Value of Travel Time (VOT) supported by the traffic research organisation or the government transport department. Some scholars were against the generalised cost methodology because of the conflict with the traditional consumer demand theory in the early years

(Goodwin, 1974; Searle, 1978). The following researcher regulated the assumption and relationship between the marginal VOT and personal income (Bruzelius, 1981; Train & McFadden, 1978). In the Victoria Transport Policy Institute report about transport Cost and Benefit analysis, the VOT estimation was introduced in detail (Litman, 2020). In the UK, the Department of Transport (DfT) estimated that average of 6.6 pence per minute for daily commuting and 5.9p/per minute for other, which does not include business trips (Mackie et al., 2003); In the United States, the US department of transport (USDOT) also assessed the VOT based on different traffic modes (Transportation, 2014). For surface traffic like road traffic and other slowspeed service except for highspeed trains, the VOT of personal travel is around 12 dollars each hour and 22.90 dollars for business in 2011. However, these data cannot be applied somewhere else, because of the different cases, traffic conditions and criteria. Some of the VOT tests aimed at the scale of intracity traffic rather than intercity travel. Therefore, it is necessary to clear a specific VOT process for this accessibility measurement. Travel time saving and Willingness-to-pay are essential parts of the VOT estimation and have been tested in a lot of transportation empirical case studies. Mark tested the value of the travel time for faster travel on Katy Freeway toll lanes, and concluded that average travellers' VOT ranged from 2 to 9 dollars per hour, but over 10% of the drivers would like to pay for the faster lanes charge with VOT of 40 dollars per hours (Burris et al., 2016); Brownstone's research also drew a similar value from 10 to 40 in commute travel analysis (Brownstone & Small, 2005). In Europe, Gunilla tested willingness to pay volume for better comfort travel with lower passenger density need approximately over 2 British pounds (Björklund & Swärdh, 2015). According to the different travel modes' characters among the transport system, the gradient of the duration and price provide passengers with various choices. The more expenditure paid for faster travel speed could be considered as the price that the passenger would like to pay for saving time. The willingness-to-pay part represented the time value of a passenger.

$$VOT = \left|\frac{C_{fast} - C_{slow}}{T_{fast} - T_{slow}}\right| = \frac{dc}{dt} = Marginal\ cost\ of\ faster\ travel\ speed, \qquad 2\text{-}1$$

$$Journery\ monetary\ time\ cost = f(T_{ij}) = T_{ij} \times VOT \qquad 2\text{-}2$$

- VOT: the value of time;
- C_{fast} and C_{slow}: the monetary cost of fast and slow service;
- T_{fast} and T_{slow}: the time cost of fast and slow service;
- dc: the change in the travel monetary cost for faster service;
- dt: the change in the travel time cost for faster service;
- T_{ij}: the travel time from point i to j;
- $f(T_{ij})$: journey monetary time cost calculating process.

The ideal perfect market, shown in Figure 3, can supply ‘differentiable’ traffic services, and passengers can select the most suitable and affordable service with full freedom. The price and travel time can be fit by a ‘certain curve’, which is normally discontinued because the transport system supplied fixed types of traffic modes for the passenger and the travel strategy is limited in real life. The marginal cost is the value of the time. In this research, the case study scale is limited to high speed service and lower speed service. While discussing the VOT of travelling by highspeed service, the relative travel plan and time evaluation need to be cleared, and the common passenger’s preference is assumed to choose to pay more cost within the capability for faster service speed to save more travel time, ignoring the people with special demand to the slow speed service, like the personal interest.

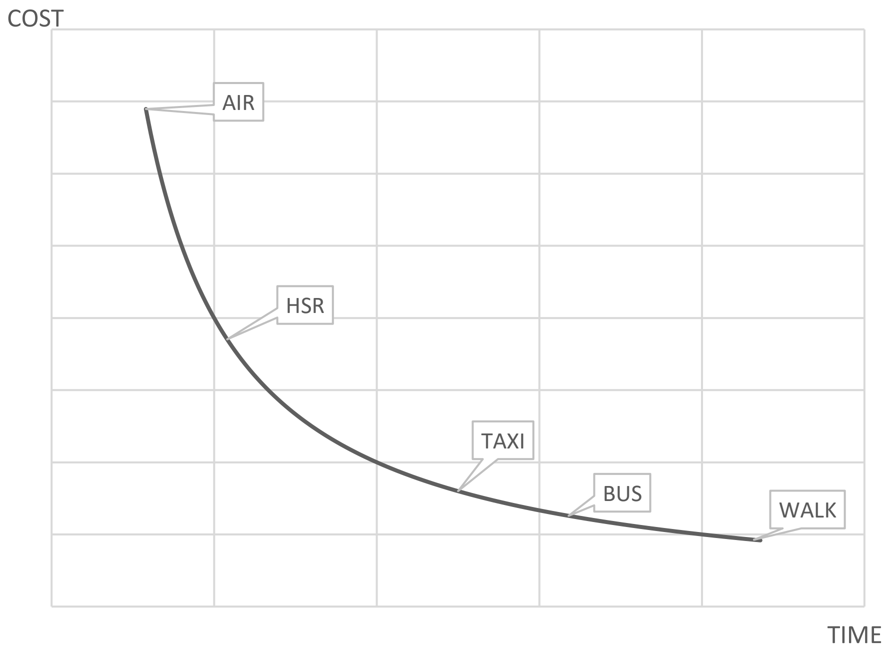


Figure 3 – Value of the travel time

2.2.4 The different levels of the accessibility indicator

In modern society, most people work 5 days and rest at the weekend, and they frequently commute from home to the workplace daily or weekly. For measuring the accessibility of 'Dual cities' life', the indicators were designed with three levels and classifications to describe the travel beneficial ratio under different conditions, regarding different time budgets and data availability.

Level 1: Daily Commuting Accessibility(DACC) – This indicator focuses on passengers who travel to a destination and return within the same day without a fixed work-time budget. It primarily reflects the benefits of daily intercity commuting facilitated by high-speed railway, highlighting the convenience and efficiency provided by rapid transit.

In a journey from i to j, the Level 1 accessibility(DACC):

Travel time with return: $$2 \times (T_{ai} + T_{ij} + T_{aj}) \quad \text{2-3}$$

Travel monetary cost:	$2 \times C_{ij} = 2 \times \left(C_{ai} + C_{ij} + C_{aj}\right)$	2-4
Living cost:	$C_{li} = R_i + C_{fi}$	2-5
Total cost:	$TC_{ij} = f\left(2 \times T_{ij}\right) + 2 \times C_{ij} + C_{li}$	2-6
DACC value:	$DACC = \frac{OPP_j}{f\left(T_{ij}\right) + C_{ij} + C_{li}} \left(T_{ij} \leq 24h\right) or\ DACC = 0\ (T_{ij} > 24)$	2-7

Level 2: Daily Work Commuting Accessibility(DWACC) – This indicator assesses a more intense commuting scenario. It applies to passengers who travel to their destination via high-speed railway, complete a fixed 8-hour work schedule, and return to their home city all within one day. This measurement tests the feasibility of maintaining a dual-city lifestyle, evaluating whether high-speed railway services can meet the commuting speed requirements essential for such a routine.

In a journey from i to j, the Level 2 accessibility(DWACC):

Travel time with return:	$2 \times (T_{ai} + T_{ij} + T_{aj})$	2-8
Travel monetary cost:	$2 \times C_{ij} = 2 \times \left(C_{ai} + C_{ij} + C_{aj}\right)$	2-9
Living cost:	$C_{li} = R_i + C_{fi}$	2-10
Total cost:	$TC_{ij} = f\left(2 \times T_{ij}\right) + 2 \times C_{ij} + C_{li}$	2-11
DWACC value:	$DWACC = \frac{OPP_j}{f\left(T_{ij}\right) + C_{ij} + C_{li}} \left(\left(T_{ij} + \mathbf{8h} \leq 24h\right)\right)$ $or\ DWACC = 0\ (T_{ij} + \mathbf{8h} > 24)$	2-12

Level 3: Weekly Return Accessibility(WACC) – This indicator is designed for passengers who commute between a work city and a home city weekly, typically spending five days in the work city and weekends at home. The Level 3 accessibility indicator addresses a lighter-use scenario, often served by normal-speed railway services. It also explores the potential for high-speed railway to replace conventional rail by comparing the travel costs

in terms of both money and time, assessing if the faster service offers a substantial improvement over the slower options.

In a journey from i to j, the Level 3 accessibility(WACC):

Travel time with return:	$5\ Workdays\ living\ at\ j:\ \mathbf{5}\times\left(\mathbf{2}\times\boldsymbol{T_j}\right),\ Tj\!: single\ travel\ time\ in\ j$ and $2\ weekend\ i\ to\ j: 2\times\left(T_{ai}+T_{ij}+T_{aj}\right)$	2-13
Travel monetary cost:	$5\ Workdays\ living\ at\ j:\ \mathbf{5}\times(\mathbf{2}\times\boldsymbol{C_j}),\ Cj\!: single\ travel\ cost\ in\ j,$ and $2\ weekend\ i\ to\ j: \mathbf{2}\times\boldsymbol{C_{ij}}=2\times\left(C_{ai}+C_{ij}+C_{aj}\right)$	2-14
Living cost:	$5\ Workdays\ living\ at\ j:\ \mathbf{5}\times C_{lj}=5\times(R_j+C_{fj})$ and $2\ weekend\ i\ to\ j:$ $2\times C_{li}=2\times(R_i+C_{fi})$	2-15
Total cost:	$TC_{ij}=\left[f\left(2\times T_{ij}\right)+2\times C_{ij}+2C_{li}\right]+5\times\left[f\left(2\times T_j\right)+2\times C_j+C_{lj}\right];$	2-16
WACC Calculation	$WACC=\dfrac{5\times OPP_j}{\left[\boldsymbol{f}(\mathbf{2}\times\boldsymbol{T_{ij}})+\mathbf{2}\times\boldsymbol{C_{ij}}+\mathbf{2}\boldsymbol{C_{li}}\right]+\mathbf{5}\times\left[\boldsymbol{f}(\mathbf{2}\times\boldsymbol{T_j})+\mathbf{2}\times\boldsymbol{C_j}+\boldsymbol{C_{lj}}\right]}$	2-17

The DACC indicator, reflecting the average profit level of dual city life based on a daily return trip by HSR, has a flexible time restriction, which only limits the total travel time within 24 hours, without any fixed working time requirement in j. The tester needs to get an income in j and pay the living cost in i and the travel cost between the two cities. The DWACC indicator has a more severely restricted time budget. The test traveller has a fixed 8 hours of working time at place j and commutes on HSR between i and j within one day. The time budgets of level 1 and level 2 accessibility represent the efficiency under different transport network speed levels. In an ideal situation, the result should indicate that the fast traffic service can support daily intercity commuter travel over a longer distance, breaking the level 1 economic accessibility value from 0. If the speed is fast enough, allowing the extra working time budget, the level 2 value would also increase to above 0. Level 3 accessibility, WACC, has the most relaxed time budget, representing the benefit level of travelling on the normal-speed railway service. The traveller would spend five days in place j and return to i at the weekend, with five days' income and living cost at the average level in j, two days' travel and living costs in i, and weekly intercity travel cost. Sometimes, the slow intracity traffic takes even more time than the intercity journey on HSR. To evaluate the influence of the low-efficiency access time on the overall journey, the original plan considered multiple intracity travel modes. Due to the difficulty of collecting historical data, the bus service was considered to be the only approach for inner-city travel between the station and destination in the case study.

2.3 Accessibility validation and Economic analysis

An econometric panel regression model was constructed to validate the applicability of the accessibility indicator and analyse the differences in economic factors influenced by differences in transport connection or living profit level, such as population migration, labour force supply, industry outputs, etc, in empirical analysis. The accessibility measurement is directional because DACC, DWACC, and WACC are calculated based on a service's direction and the results for the two directions between two cities could be dramatically different due to the exchange of working and living places. Therefore, it optimised the usage of statistical data by generating two groups of accessibility values and doubling the data size with only one service and two cities' statistical data.

In addition to the three accessibility indicators as the explaining variables, a control variable $SACCD$, the Single city accessibility difference, was introduced, to represent the difference in single-city living profit level. The reason for development disparity should not only contain the intercity travel accessibility but also need to consider the local profit level difference. The regress result is expected to acquire the corresponding parameter β, of each accessibility indicator. The parameter’s robustness check and value could explain what the highspeed and slowspeed railway services can bring, how much they can impact the target, and if the intracity lifestyle starts to shift to an intercity one.

$$D_{ij} = ACC_{ij}{}' \times \beta_{ACC} + z'_i\delta + u_i + \varepsilon_{it} \qquad \text{2-18}$$

$$ACC_{ij}{}' = \begin{pmatrix} DACC_{ij}^{t1} & DWACC_{ij}^{t1} & WACC_{ij}^{t1} & SACCD_{ij}^{t1} \\ \vdots & \vdots & \vdots & \vdots \\ DACC_{ij}^{tn} & DWACC_{ij}^{tn} & WACC_{ij}^{tn} & SACCD_{ij}^{tn} \end{pmatrix}; \beta_{ACC} = \begin{pmatrix} \beta_{DACC} \\ \beta_{DWACC} \\ \beta_{WACC} \\ \beta_{SACCD} \end{pmatrix} \qquad \text{2-19}$$

i and j: Start point and destination;

t: Research period, 1 to n;

D_{ij}: Explained variable; the difference (population, industry output) between i and j;

ACC_{ij}: Accessibility value matrix;

$DACC_{ij}$: Daily accessibility; $DWACC_{ij}$: Daily working accessibility with a fixed 8-hour working time budget; $WACC_{ij}$: Weekly working accessibility; $SACCD$: Difference in single-city accessibility between i and j (control variable);

β_{DACC}, β_{DWACC}, β_{WACC}, β_{SACCD}: Parameters of the different levels of the corresponding ACC index;

$z'_i\delta$: Time-invariant variable; $u_i + \varepsilon_{it}$: composite error term.

2.4 Conclusion

The methodology presented in this chapter introduces an enhanced accessibility framework designed to evaluate the impact of high-speed railway systems on regional economic development. The fundamental method centres on accessibility modelling that incorporates both travel time and monetary costs to better simulate real-world commuter behaviour. By integrating econometric models, the study evaluates the effectiveness of the transportation network in facilitating economic opportunities.

This approach offers several key contributions to the field. It introduces a novel accessibility indicator that moves beyond traditional distance-based measures by incorporating both travel time and cost to better capture commuter decision-making. The introduction of a three-tiered accessibility system—Daily Commuting Accessibility (DACC), Daily Work Commuting Accessibility (DWACC), and Weekly Return Accessibility (WACC)—enables a more comprehensive understanding of intercity travel patterns. Additionally, the study offers a comprehensive dataset, covering multiple cities and years of economic and transportation data, which enhances the applicability of the findings. Empirical validation of the proposed methods further strengthens their utility in assessing real-world phenomena such as population migration and industrial growth.

Compared to traditional methods, the proposed approach provides several advancements. Traditional models focused primarily on physical distance or topological accessibility, often neglecting the real-world costs of travel. The method developed in this study differs by incorporating actual travel costs, including Value of Time (VOT), offering a more realistic reflection of commuter choices. Furthermore, previous accessibility measures, such as attractiveness accessibility, relied on abstract indicators that were often difficult to compare. In contrast, this thesis offers a composite indicator system, which presents structured and scalable measurements that are more meaningful and comparable across different contexts. By integrating income levels and economic motivations into the accessibility framework, this method addresses a gap in prior research, making it more robust and aligned with actual commuter behaviours.

Through these innovations, the methodology in this thesis not only refines accessibility modelling but also provides a framework that can better explain the interplay between transportation infrastructure and economic development. The enhanced indicators and comprehensive dataset ensure that this methodology is well-positioned to offer insights into future transportation and economic studies.

Chapter 3. Accessibility measurement and database

3.1 Sample selection and scale

3.1.1 Sample city selection and introduction

Since 2008, high-speed railways have seen rapid development in Eastern China, with most provinces becoming interconnected by an extensive network of high-speed services over the subsequent decades. Accompanied by economic growth, the high-speed railway has become an integral part of daily life. Accessibility measures the benefit and cost levels of specific city-to-city trips by considering relative traffic and time information. This index value will be utilised as a variable in the econometric model. The ideal scenario for constructing a model to investigate the impact of high-speed railways on the social economy is a ‘pure scene’—one with a limited number of high-speed lines and cities. This scenario minimises data interference that could be caused by population and market variables. In East China, a large expansion of high-speed railway services occurred in a short span from 2008 to 2012. The complexity of the railway network, coupled with the region’s large population and substantial economic size, makes case analysis more intricate. The potential for observing a single city's development process influenced by a linked high-speed line may be complicated by the city quickly integrating into the broader network and thus losing its analytical clarity. Therefore, the initial accessibility measurement will focus on several hub cities throughout Eastern China, taking into account the overall network effect. The samples are classified into two categories: core high-speed network hub cities and network edge cities. At this stage, all research samples are the capital cities of each province, providing a strategic overview of high-speed rail's effects at significant urban nodes. The case study will be expanded to more prefectural-level cities or counties in the future. The selected samples are shown in Figure 4 and Figure 5.

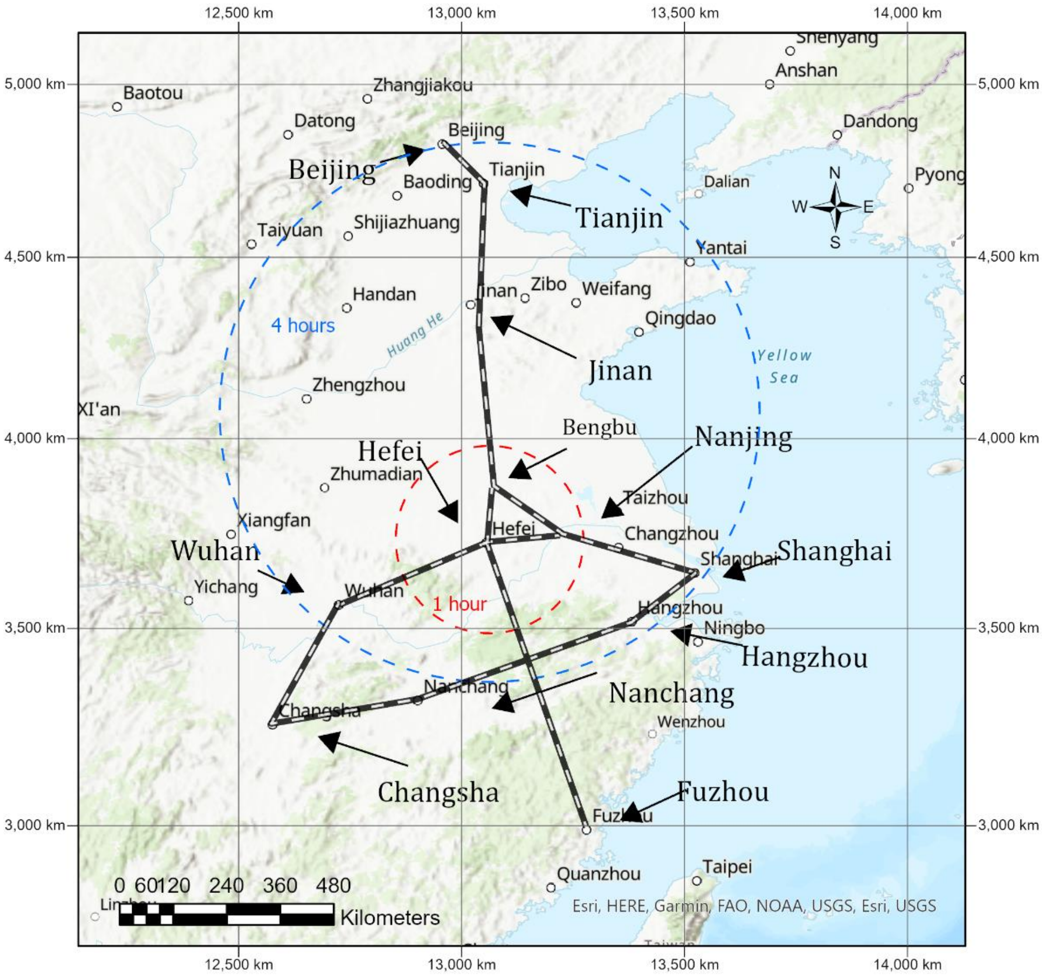


Figure 4 – The sample cities' network structure

- Core high speed railway hub city: According to the development timeline, five cities pioneered high-speed railway construction and emerged as local high-speed service hubs in Eastern China. These cities are Hefei, Wuhan, Nanjing, Shanghai, and Hangzhou. They are considered the primary accessibility measurement samples and serve as the starting points and destination for all journeys assessed in this study.

- Network edge cities: Besides the five core hub cities, six cities on the periphery of the Eastern high-speed railway network are included to assist the analysis, only as destinations. These cities are Beijing, Jinan, Changsha, Tianjin, Nanchang, and Fuzhou.

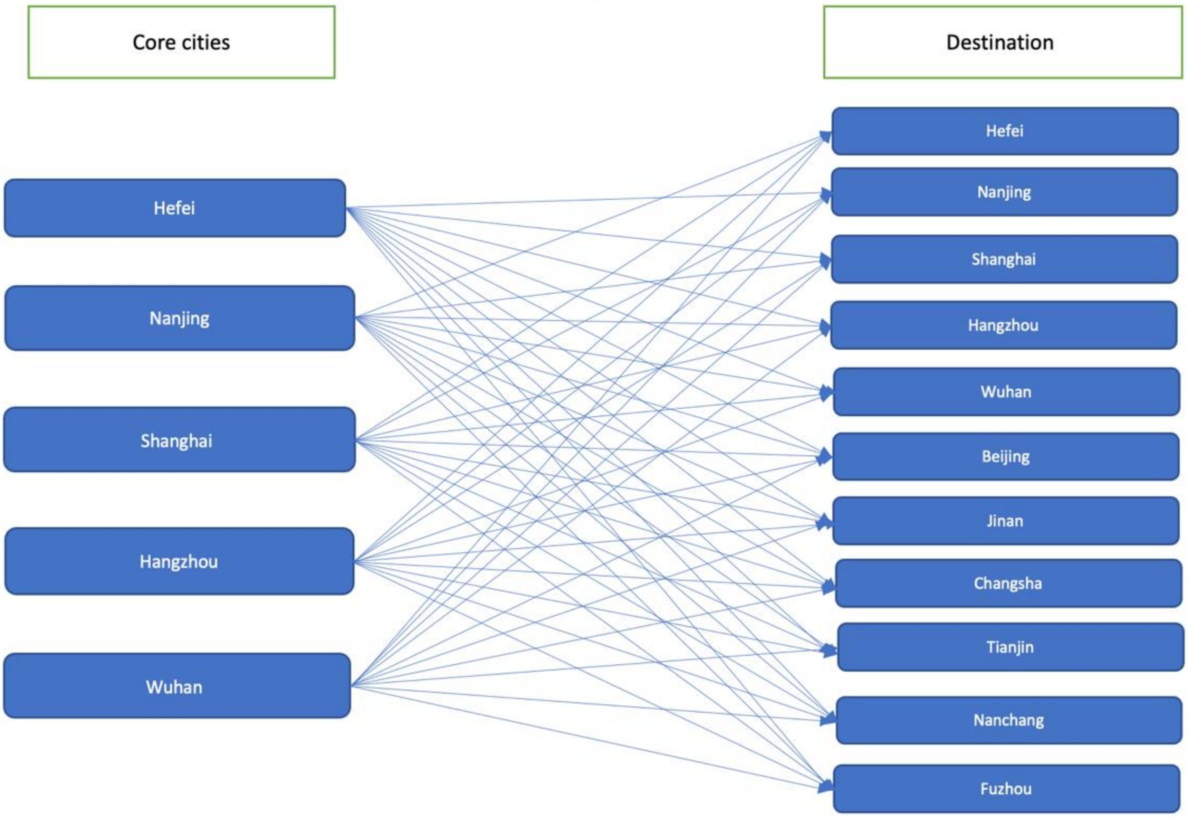


Figure 5 –High speed railway service case structure

3.1.2 Research period

- The research data of sample cities from 2005 to 2015 were collected.

In the east of China, the main high speed railway network structure was formed in the decade after 2008. In August 2008, the first high speed railway line in the east of China from Hefei to Nanjing was completed. In the following two years, two important high speed lines, Shanghai to Beijing and Nanjing to Shanghai, were opened and connected the Chinese economic centre and the political centre covering hundreds of millions of populations. More branch lines were constructed in the later period. By searching the relevant documents, economic statistics stands of many indicators were adjusted from 2013 to 2015. The data consistency and accuracy could not be guaranteed. And many historical data become incomparable as well. In the following empirical analysis part, the data with the problem will be adjusted and indicated in red colour in the form.

3.1.3 Indicators selection and collection

Groups of economic and traffic indicators which are shown in Table 2 are set for each case city in accessibility measurement.

Table 2 – Accessibility measurement variables

Indicator	Unit
Disposable income per capita per year (2005-2015)	CNY (¥)
Food expenditure per capita per year (2005-2015)	CNY (¥)
Traffic expenditure per capita per year (2005-2015)	CNY (¥)
Accommodation expenditure per capita per year (2005-2015)	CNY (¥)
Estate price (2005-2015)	CNY (¥/m^2)
Population (2005-2015)	-
Consumer price index (2005-2015)	-
City access travel time cost	Hour(h)
City access travel cost	CNY (¥)
High speed railway timetable	-
High speed railway travel time cost	H
High speed railway travel currency cost	CNY (¥)
Normal speed railway timetable	-
Normal speed railway travel time cost in previous years	Hour(h)
Normal speed railway travel currency cost in previous years	CNY (¥)
*Road coach travel time cost in previous years	H
*Road coach travel currency cost in previous years	CNY (¥)

- *The economic data are collected city's official Statistical Yearbook published by the statistical bureau of every city in every year.*
- *High-speed and normal-speed railway service timetables and data are collected from www.12306.cn, which is the official railway information platform published by China State Railway Group Company, Ltd.*
- *The city access information is collected from www.amap.com, which is a professional geographic information system (GIS).*

3.1.4 Data integration and process

According to the railway service in the cases, a total of 11 cities and 50 railway trips' data are collected for three levels of accessibility measurement. Because of the data complexity and compatibility, some necessary data process and integration work need to be done before accessibility calculation. The data process of the case of high-speed railway service between Hefei and Nanjing is exhibited as an example.

- Consumer price index(CPI)

The Consumer Price Index (CPI) is a key economic ratio indicator that measures the average change over time in the prices paid by consumers for a basket of goods and services. It is widely used to assess inflation by tracking the cost of essential items, such as food, housing, transportation, and medical care. Because of inflation and economic development, the price level kept floating during the eleven years' time. To eliminate the price discrepancies, the year 2005 is set as the Base Period. All the price data of different indicators in different cities from 2005 to 2015 will be converted to the price level in 2005, including the intercity travel cost and intracity access travel monetary cost.

Table 3 – Hefei economy data process

Years	Hefei CPI	Hefei CPI (Price 2005)	Hefei Food cost per capita per year(¥)	Hefei Food cost per capita per year 2005-Price(¥)
2005	100.90	100.00	3384	3384.00
2006	100.90	100.90	3767	3733.40
2007	105.60	106.55	4233	3972.77
2008	106.40	113.37	4657	4107.80
2009	99.10	112.35	4713	4194.95
2010	102.70	115.38	5010	4342.07
2011	105.70	121.96	5970	4895.07
2012	102.20	124.64	6421	5151.53
2013	102.7	128.01	7283	5689.49
2014	102	130.57	6134	4697.93
2015	101.6	132.66	6651	5013.67

- The intracity travel information collection

The accessibility measurement contains intra-city access travel information because the access travel sometimes even takes more time than the mainline travel in some megacities. Properly estimated access travel time and cost could increase the reliability of the final assessing result and enhance the traveller's behaviour simulation. In the eleven sample cities, most of them are the capital city of each province taking up a large area with many sub-districts. The modern high speed railway stations are usually very far away from the city centre. For reflecting the real access time and monetary cost from different locations in sample cities to high speed stations, the start point and destination are assumed at the geographical centre of each sub-district. The access time and money cost are equal to the average value from the station to these places. Although most cities experienced rapid economic development and expanded the scale from 2005 to 2015, the access time is still assumed to be the same as now for reducing the stress of searching the very detailed history data. The monetary cost was also assumed to be the current public transport cost because only an average less ¥5 price increase in these sample cities during 11 years according to the limited history of city traffic material, which just took a very small part of the whole journey cost.

- The main intercity travel modes

The Value of travel time estimation relied on how much the traveller would like to pay for the faster transport modes, the willingness-to-pay methodology. In this research, the different modes, such as air, road coach, railway and private driving, are all initially involved. But the historical data is still the problem. The intercity road coach transport was massive in China and also brought an extremely complicated market which increased the difficulty of collecting accurate information in the early years. Therefore, the normal-speed train was considered to be the only slower traffic than high speed railway modes for the passengers during Value of time estimation.

3.2 Accessibility measurement process example

3.2.1 Hefei to Nanjing intercity travel accessibility statistics

Accessibility measurement is calculated through the EXCEL because irregular raw data format and statistical standards could be easier to be modified manually. To demonstrate the whole process, the case of the Hefei-Nanjing high speed line would be introduced as an example. In this case, Hefei is the home city as the starting point, and Nanjing is the work city as the travel destination. The traveller needs to spend the necessary cost with the price level of Hefei, including food, accommodation and the traffic cost to Nanjing. In terms of the opportunity, the assumed traveller works in Nanjing and gets paid with Nanjing's average salary. All the monetary costs are converted to the price level in 2005 by the deflator of the living city, Hefei. If the case direction is reversed, from Nanjing to

Hefei, the traveller would pay for living in Nanjing and the fares need to be converted by the deflator of Nanjing as well. The data process is shown below in Table 4. The bottom red font indicates the data influenced by statistical standard modification after 2014.

Table 4 – Hefei-Nanjing dual city living cost

Years	OPP (Daily Nanjing income-PRICE 2005, ¥)	Daily Hefei Personal food cost (Daily/ 2005-Price, ¥)	Daily Hefei Personal traffic cost (Daily/ 2005-Price, ¥)	Daily Hefei Personal accommodation cost (Daily/ 2005-Price, ¥)
2005	41.09	9.27	0.96	1.87
2006	47.25	10.23	0.96	2.04
2007	52.78	10.88	0.91	2.23
2008	56.56	11.25	1.74	2.60
2009	62.32	11.49	1.98	4.10
2010	66.40	11.90	2.27	3.52
2011	71.65	13.41	3.09	3.06
2012	78.69	14.11	4.76	4.57
2013	84.13	15.59	5.41	4.89
2014	87.53	12.87	3.83	8.98
2015	92.94	13.74	4.65	9.50

The travel time cost and monetary cost are shown in the table below, Table 5. The whole process for commute travel process from Hefei to Nanjing was listed with the relevant cost value. The access time, high-speed railway travel time and normal-speed railway(SSR) travel time are collected from the integrated data. The station time, including the waiting time, transfer time and others, was assumed to be 10 minutes. The 'real daily work time restriction' and 'reachable time restriction' is the work time budget for accessing if the high speed commuting service or normal speed commuting service could support enough 8 hours of work time or just let the travellers do a return trip in one day. The value '1' means yes and the '0' means no. In the following part, the monetary cost is listed with the same structure, and it is also converted by the home city's deflator. The year 2008 is the first year with high-speed service, the travel cost change can be recognised clearly. From Table 5, the round trip between travel from Hefei to Nanjing need to take 5.64 hours by highspeed railway with cost of ¥140, and normal speed railway service needs 7.22 hours and cost ¥89.

Table 5 – Hefei- Nanjing travel friction

Travel time	**Process**	**Hours(h)**		**Hours(h)**
Hefei	Home to station	0.75		
	Station time	0.17		
	HSR travel time	0.97	SSR travel time	1.76
Nanjing	Station time	0.17		
work		8		
Nanjing	Destination to Station	0.76		
	Station time	0.17		
	HSR travel time	0.97	SSR travel time	1.76
Hefei	Station time	0.17		
	Station to home	0.75		
	HSR Travel time sum	5.64	SSR Travel time sum	7.22
Real daily work time restriction	1		1	
Reachable time restriction	1		1	
Travel Cost	**HSR Trip**	**Cost(¥)**	**SSR Trip**	**Cost(¥)**
Hefei	Home to station	1.5		
	HSR travel cost	67	SSR travel cost	41.5
Nanjing	Station to Destination	1.5		
Nanjing	Destination to Station	1.5		
	HSR travel cost	67	SSR travel cost	41.5
Hefei	Station to home	1.5		
	HSR cost sum	140	SSR cost sum	89
Year	**Hefei CPI 2005**		**Travel cost(¥)**	**Travel cost (Price-2005) (¥)**
2005	100		89	89.00
2006	100.9		89	88.21
2007	106.5504		89	83.53
2008	113.3696256		140	123.49
2009	112.349299		140	124.61
2010	115.38273		140	121.34
2011	121.9595457		140	114.79
2012	124.6426557		140	112.32
2013	128.0080074		140	109.37
2014	130.5681675		140	107.22
2015	132.6572582		140	105.54

After integrating the cost data, the monetary time cost conversion can be processed, shown in Table 6. The passenger's travel time value is estimated according to the passenger's willingness to pay calculation method. In the case of the journey from Hefei to Nanjing, the slow speed service(SSR) with 1.76h was considered as the only way to travel, the mainline time monetary cost per hour was 23.580 in 2005. The new high speed railway service increased its value to 28.472, in 2005 price level, but the total journey time cost dropped to 160, which indicates that high speed railway travel time is worth more but the dramatic volume of the saved time brings more benefits. The support of steady ticket prices and CPI dates by the government lowers travel costs further.

Table 6 – Hefei-Nanjing Value of travel time

HSR travel cost(¥)	**67**	**HSR travel time(h)**	**0.97**
SSR travel cost(¥)	**41.5**	**SSR travel time(h)**	**1.76**
SSR Travel time sum(h)	**7.22**	**HSR Travel time sum(h)**	**5.64**

Years	SSR travel cost(¥)	HSR travel cost(¥)	Willingness to pay(¥)	Travel VOT(¥)	Travel VOT PRICE-2005(¥)	Monetary total time cost(¥)
2005	**41.5**	**-**	**41.5**	**23.580**	**23.580**	**170.244**
2006	**41.5**	**-**	**41.5**	**23.580**	**23.369**	**168.726**
2007	41.5	-	41.5	23.580	22.130	159.778
2008	41.5	67	25.5	32.278	28.472	160.581
2009	41.5	67	25.5	32.278	28.730	162.040
2010	41.5	67	25.5	32.278	27.975	157.780
2011	41.5	67	25.5	32.278	26.467	149.271
2012	41.5	67	25.5	32.278	25.897	146.058
2013	41.5	67	25.5	32.278	25.216	142.218
2014	41.5	67	25.5	32.278	24.722	139.430
2015	41.5	67	25.5	32.278	24.332	137.234

The last form, Table 7, shows the final accessibility value of the Hefei-Nanjing case. The accessibility value is a variation of the benefit and cost ratio, which assumes that travellers live in one city and work in other cities with intercity commutes through high speed railway service. The three classified indicators measured accessibility under different travel behaviours and objectives. The Daily Commuting accessibility and Daily Work Commuting Accessibility may show the same value because the travel attractiveness and friction part used the same value, the only difference is the 8-hour work time requirement. If the 8 hours cannot be satisfied in the time budget check, the DWACC would show a '0', which means the attractiveness is unachievable. In addition, the Weekly return accessibility needs to consider the 5 days' living cost in the work city and 2 days' living cost in the home city, which illustrates travellers' weekly return lifestyle. The full accessibility database is listed in the next chapter.

Table 7 – Hefei-Nanjing 3 level Accessibility

Years	**DACC**	**DWACC**	**WACC**
2005	**0.097**	**0.097**	**0.277**
2006	0.111	0.111	0.311
2007	0.132	0.132	0.366
2008	0.124	0.124	0.336
2009	0.137	0.137	0.366
2010	0.154	0.154	0.406
2011	0.180	0.180	0.462
2012	0.203	0.203	0.502
2013	0.223	0.223	0.537
2014	0.234	0.234	0.561
2015	0.255	0.255	0.596

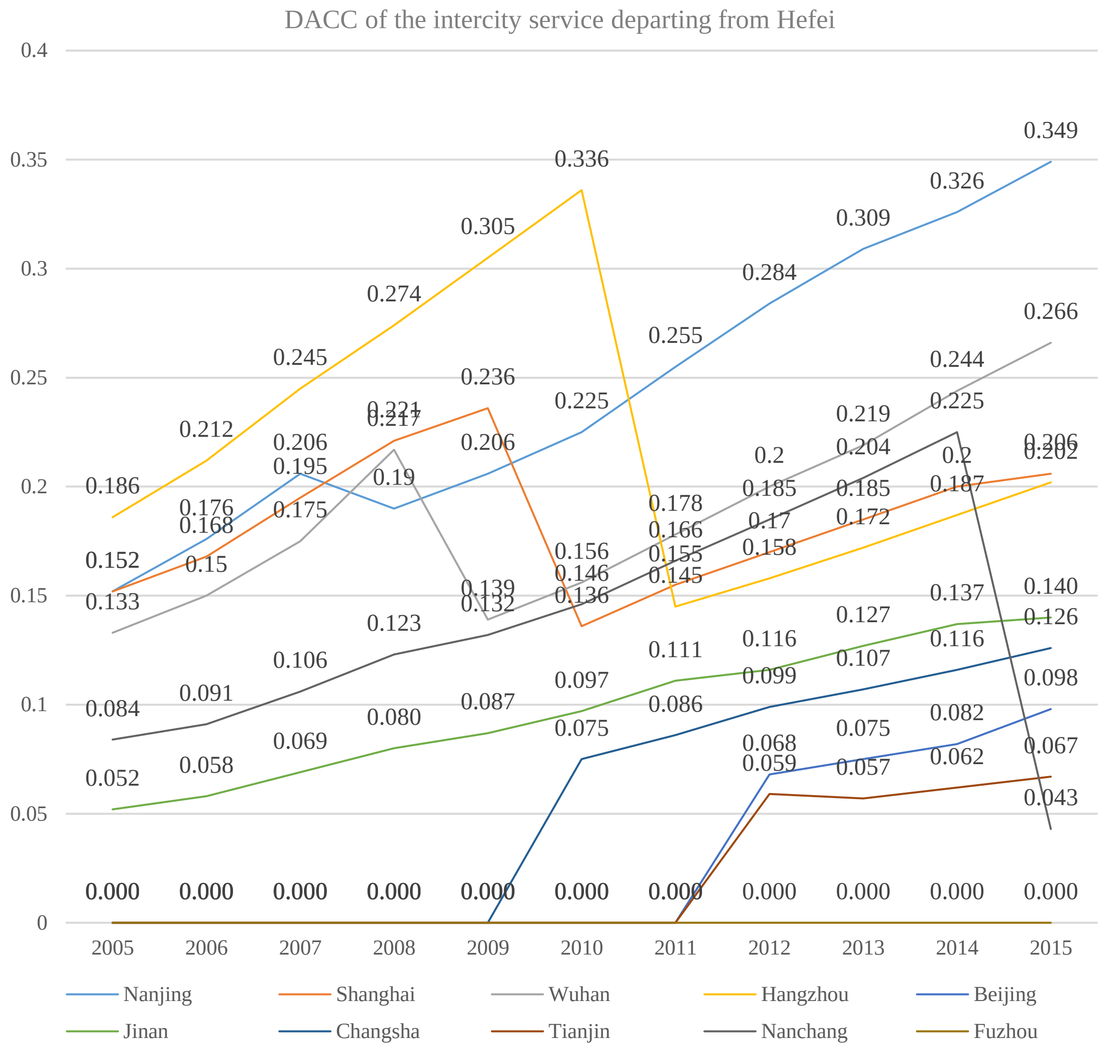
3.3 Accessibility statistics

In this section, all three levels of the passengers' accessibility database are listed respectively with the intercity travel direction, following the time order from 2005 to 2015.

3.3.1 Daily Commuting Accessibility (DACC)

- Hefei Daily Commuting Accessibility measurement

Table 8 – Hefei DACC

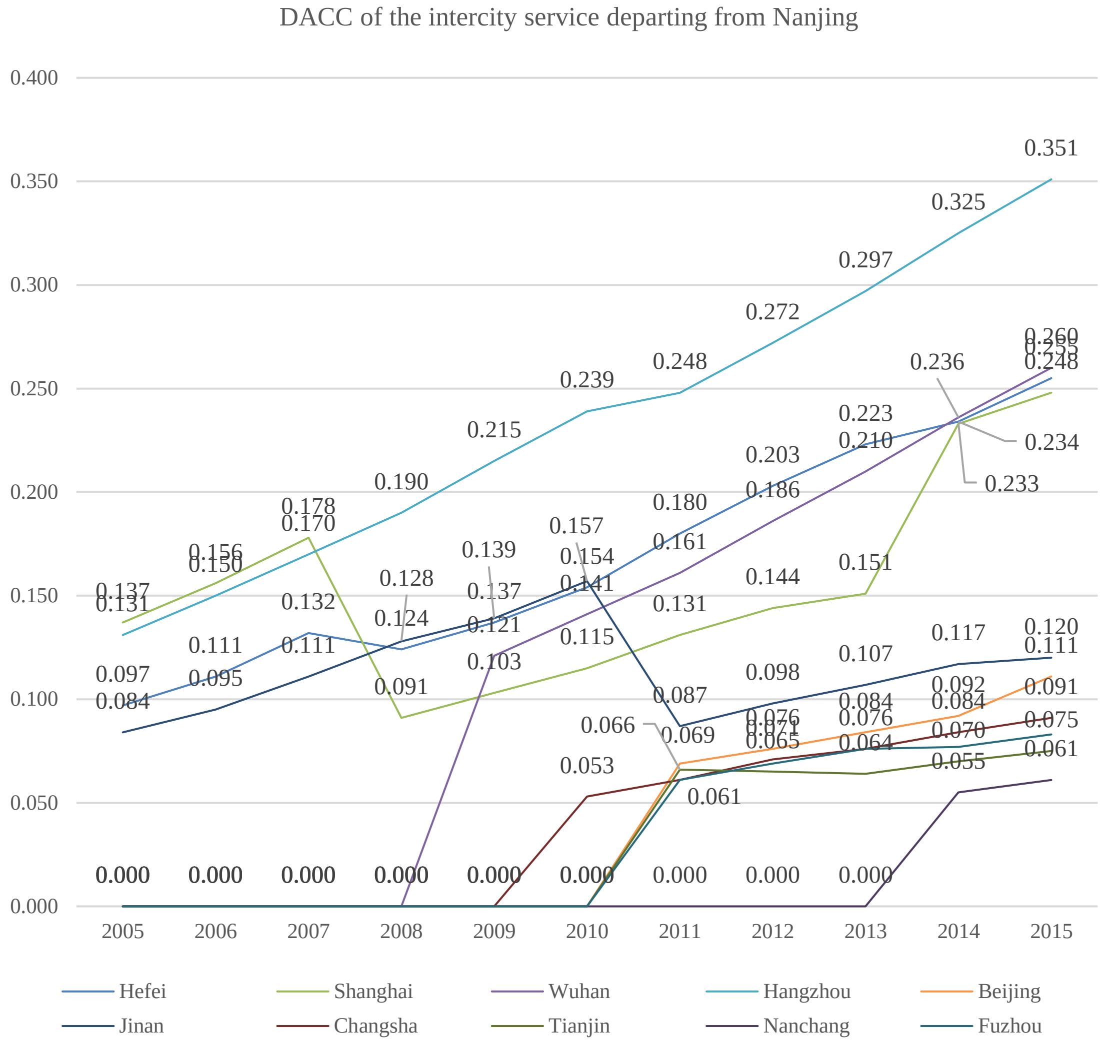


DACC	Hefei to Core					Hefei to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	2.032	0.152	0.152	0.133	0.186	0.000	0.052	0.000	0.000	0.084	0.000
2006	2.109	0.176	0.168	0.150	0.212	0.000	0.058	0.000	0.000	0.091	0.000
2007	2.311	0.206	0.195	0.175	0.245	0.000	0.069	0.000	0.000	0.106	0.000
2008	2.172	0.190	0.221	0.217	0.274	0.000	0.080	0.000	0.000	0.123	0.000
2009	2.139	0.206	0.236	0.139	0.305	0.000	0.087	0.000	0.000	0.132	0.000
2010	2.267	0.225	0.136	0.156	0.336	0.000	0.097	0.075	0.000	0.146	0.000
2011	2.227	0.255	0.155	0.178	0.145	0.000	0.111	0.086	0.000	0.166	0.000
2012	1.983	0.284	0.170	0.200	0.158	0.068	0.116	0.099	0.059	0.185	0.000
2013	1.921	0.309	0.185	0.219	0.172	0.075	0.127	0.107	0.057	0.204	0.000
2014	2.087	0.326	0.200	0.244	0.187	0.082	0.137	0.116	0.062	0.225	0.000
2015	2.031	0.349	0.206	0.266	0.202	0.098	0.140	0.126	0.067	0.043	0.000

Table 8 shows the daily commute accessibility value, the DACC, from Hefei to the other city. The blue fonts indicated the data in the year when the new high speed railway service was opened. The first column, which listed the Hefei intracity living DACC index, was the reference scenario measuring one most common scenario of the most people who live and work within a single city. It shows the highest value crossing the entire DACC value sheet, starting at 2.032 in 2005 and keeping fluctuation above 2 in the research period. According to the accessibility value and benefit-cost ratio calculating method, the travellers' living cost and income level changes stay relatively steady, and the high profitability makes the single city living strategy the most suitable and profitable for normal people. Compared to the intracity value, the DACC value of intercity life is much lower and only has no more than 10% DACC level of intracity life, throughout the 11 years. Two service groups, one from Hefei to the other network core cities and another one from Hefei to the far network edge cities, also show a huge difference. In the first group, all the values from 2005 are above 0, but smaller than 1. It means the intercity trips, between Hefei to the other high speed railway hub cities, were feasible before high-speed railway service was operated. The speed of conventional railway service could satisfy the requirement of daily return trips without a working time budget. By comparing the value vertically, the first year's data decreased sharply but quickly rose again. In the case of Hefei to Nanjing, the DACC level was 0.206 in 2007. In 2008 with the new high speed railway service, the DACC value decreased to 0.19 and it grew back to 0.206 in 2009 and kept rising in following years. In some cases, like the service from Hefei to Shanghai, the DACC value recovered much slower, and it hardly reached the original level of normal speed service value until the final year of the research period. In the second group of the service from Hefei to network edge cities, the effect brought by new high-speed trains can be seen clearly. The trip to the cities located far away from Hefei, like Beijing, and Tianjin, was originally dominated by air and overnight normal speed train services. The new high speed railway deeply changed the market and it started to support daily return trips, pushing the DACC value above 0. In some cases, in which the old normal speed railway has already satisfied daily commute travel, like the service between Jinan to Hefei, the new high speed railway didn’t affect the growth trend DACC level as the service from Hefei to other core cities. The value kept increasing in the first year without a decrease. The new high-speed railway service from Hefei to Fuzhou was completed at the end of 2015. Therefore, the DACC level is kept at 0 level.

- Nanjing Daily Commuting Accessibility measurement

Table 9 – Nanjing DACC



DACC	Nanjing to Core					Nanjing to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	0.097	2.011	0.137	0.000	0.131	0.000	0.084	0.000	0.000	0.000	0.000
2006	0.111	2.098	0.156	0.000	0.150	0.000	0.095	0.000	0.000	0.000	0.000
2007	0.132	2.256	0.178	0.000	0.170	0.000	0.111	0.000	0.000	0.000	0.000
2008	0.124	2.256	0.091	0.000	0.190	0.000	0.128	0.000	0.000	0.000	0.000
2009	0.137	2.240	0.103	0.121	0.215	0.000	0.139	0.000	0.000	0.000	0.000
2010	0.154	2.385	0.115	0.141	0.239	0.000	0.157	0.053	0.000	0.000	0.000
2011	0.180	2.306	0.131	0.161	0.248	0.069	0.087	0.061	0.066	0.000	0.061
2012	0.203	2.357	0.144	0.186	0.272	0.076	0.098	0.071	0.065	0.000	0.069
2013	0.223	2.313	0.151	0.210	0.297	0.084	0.107	0.076	0.064	0.000	0.076
2014	0.234	2.454	0.233	0.236	0.325	0.092	0.117	0.084	0.070	0.055	0.077
2015	0.255	2.549	0.248	0.260	0.351	0.111	0.120	0.091	0.075	0.061	0.083

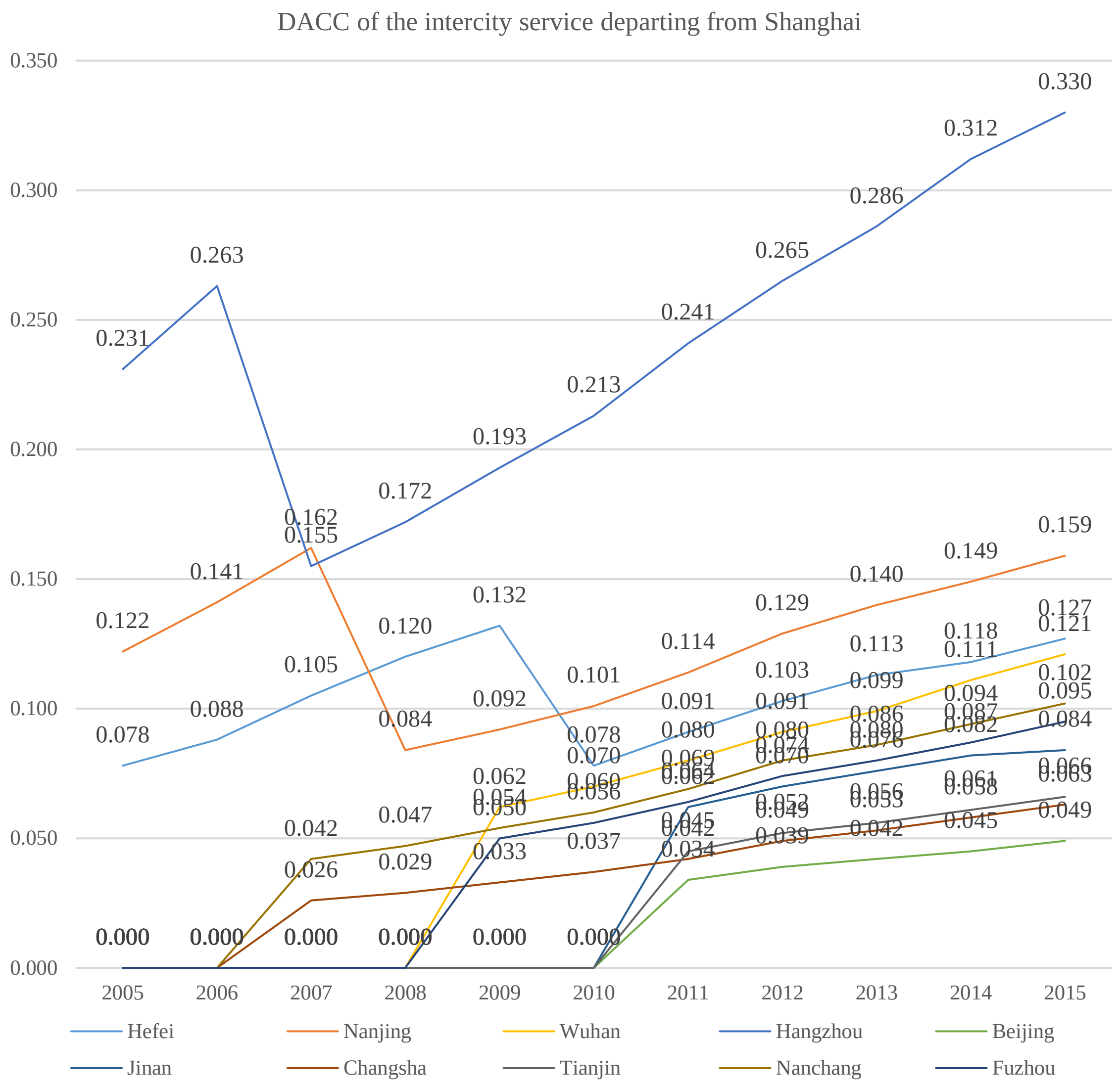
Table 9 indicates the DACC level of the intercity commute travel accessibility of the railway service departing from Nanjing. The blue fonts indicated the value of the first year with high-speed railway service and the red fonts indicated the value affected by the different statistical standards.

The DACC value was also separated into two groups. The first group was the service leaving Nanjing to the other core cities and the second part was to the network edge cities. The second column is the single city accessibility of Nanjing, which indicates the profit level of intracity life with income and living costs in the same city. In 2005, the Nanjing single city DACC value was 2.011. And it kept rising to the level of 2.5 in the following years, far exceeding the value of dual city life. The single city life is the best strategy for citizens in Nanjing with the best return. In the other case between Nanjing and railway hub cities, the DACC level stays at a very low level and much smaller than 1. The intercity life strategy showed extremely poor profitability which didn't fit most of the people. In the case from Nanjing to Hefei, the DACC value started at 0.097 in the year 2005, when the normal speed railway was the main choice for intercity travel, and it only achieved 4% performance of single city life in Nanjing. At the same time, by comparing the data of the service from Hefei to Nanjing, the DACC value of the journey from Nanjing to Hefei only has 64% level in the reverse direction, which indicates a typical scenario of the intercity traffic service performance between a developed city and a developing city. It can be seen that the commute trip from a developing city to a more developed one is more beneficial. In 2008, the high-speed railway service was open and the Nanjing-Hefei DACC level was slightly decreased to 0.124, which is lower than the level in 2007 of 0.132. In the following years, the travel performance increased quickly and exceeded the peak profit level brought by the normal-speed railway service. In 2013, which is the final year with a steady statistical standard, the DACC value achieved 0.223, about 9.6% of the Nanjing single city DACC level. Another important line in the East high-speed network is the service from Nanjing to Shanghai. the normal speed railway service could originally satisfy the daily return commute trip with a DACC level of 0.137 in 2005 and 0.178 in 2007 before the new high speed train was opened. After 2008, the new DACC value also experienced a downtrend to 0.091, which is a relatively large decrease with a 48% reduction. From 2009 to 2013, the DACC value kept increasing steadily. In 2013, the high-speed railway service could support the DACC level of 0.151, which is close to the normal speed railway peak level in 2007. In the years 2014 and 2015, due to data collection problems, the calculation result shows abnormal growth with large errors. But the increasing trend is still observable. The result of the service from Nanjing to Wuhan indicated the scenario of the high speed railway application on longer distances. Before 2009, the normal speed railway service is not fast enough for the daily return trip between Nanjing to Wuhan, any activity through the railway service is unavailable. Therefore, the DACC value from Nanjing to Wuhan stays at the 0 level. After 2009, the new high speed railway service achieved the speed requirement of one-day return trips and pushed the DACC value up from 0 to 0.121. In the following years, the DACC value kept rising from 0.141 in 2010 to 0.210 in 2013, with 49% growth under the same statistical criteria. The last case of the service connecting to the core city is from Nanjing to Hangzhou. The speed of the conventional speed railway service could support the daily return trip in early time. In 2005 the DACC index reached 0.131, which is close to the level of the service from Nanjing to Shanghai. In 2010, the value was increased to 0.239 under the same railway traffic condition. The profit level is mainly devoted to income growth in Hangzhou and stable commute prices. In 2011, the new high-speed train was operated on the upgraded track with the same service route. What is different compared to the other case is that the new DACC level was increased to 0.248 in the first year with high-speed service, skipping the value dropping stage caused by the suddenly increased travel cost. In 2013, the DACC value was increased to 0.325, which is nearly 3 times higher than the level in 2005 and far exceeds the result of all other cases, becoming the best intercity living destination. In 2015 The result reached 0.351. It is a very high value throughout all DACC value records.

The second group indicated the calculation result of the service from Nanjing to the destination which is located at the edge of the network. The value changes in the first year with high speed railway service can be seen clearly. The original normal speed railway service is too slow to satisfy most of the daily commute trips on these longer distance services, except the journey from Nanjing to Jinan, which had the highest performance in the group throughout 11 years. In 2005, the normal speed service from Nanjing to Jinan could support a DACC level of 0.084. Before the high-speed railway service was operated, the final DACC value under normal speed service was increased to 0.157 in 2010. In the next year, affected by the increasing cost of new high speed trains, the commuter profit ratio decreased to 0.087, bringing the intercity traveller's earning ability back to 2005. After 2011, the DACC value climbed slowly reaching 0.107 in 2013 and 0.120 in 2015, which achieved the highest level among the services connecting edge cities but still only half of the services linking core cities. The result of the other cases in the second group indicated that the new high-speed railway made same-day intercity commuting a reality, breaking the 0 DACC value. And as the economy continued to develop, the DACC value was also on the rise. But the entire level is still at a very low level about 1/4 of the core cities connection.

- Shanghai Daily Commuting Accessibility measurement

Table 10 – Shanghai DACC



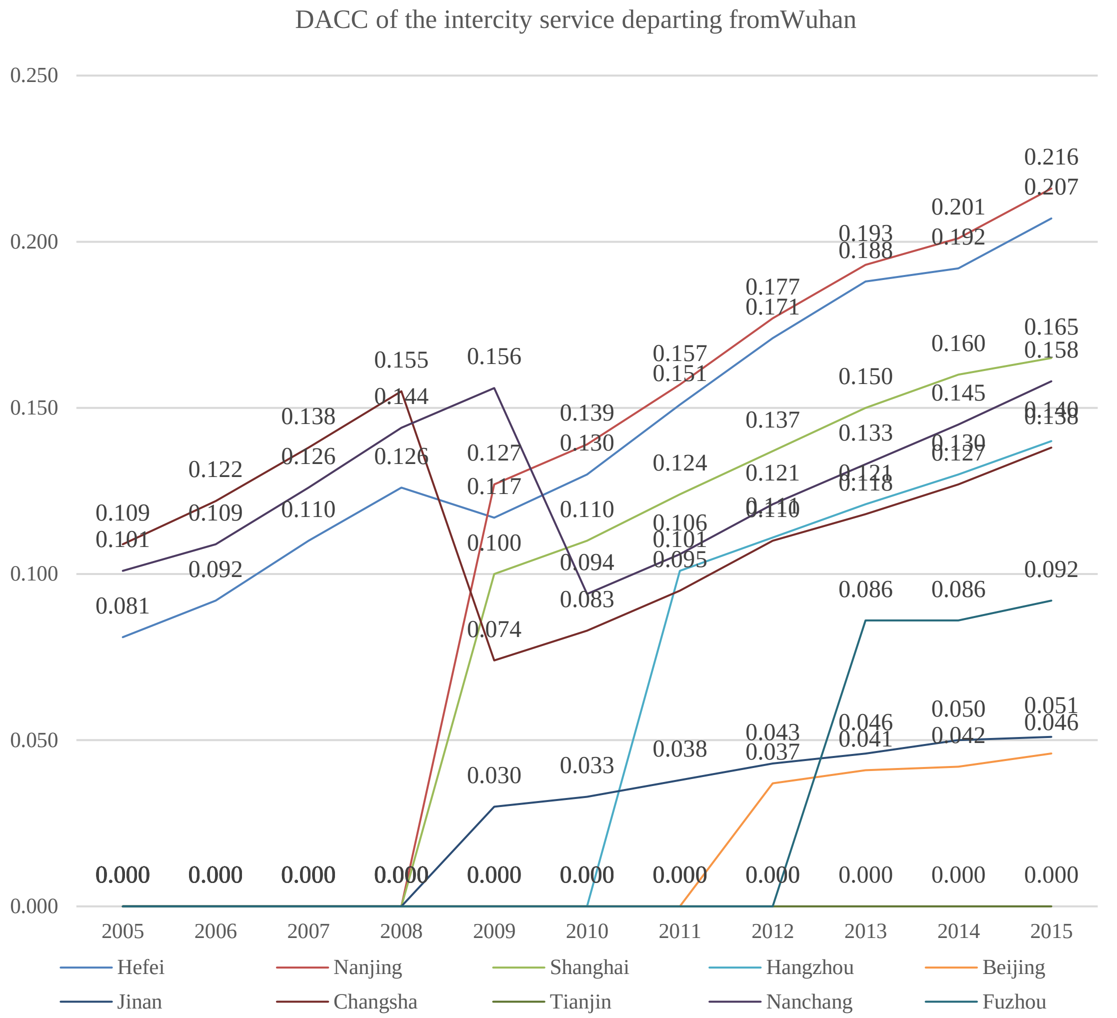
DACC	Shanghai to Core					Shanghai to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	0.078	0.122	1.807	0.000	0.231	0.000	0.000	0.000	0.000	0.000	0.000
2006	0.088	0.141	1.821	0.000	0.263	0.000	0.000	0.000	0.000	0.000	0.000
2007	0.105	0.162	1.706	0.000	0.155	0.000	0.000	0.026	0.000	0.042	0.000
2008	0.120	0.084	1.721	0.000	0.172	0.000	0.000	0.029	0.000	0.047	0.000
2009	0.132	0.092	1.774	0.062	0.193	0.000	0.000	0.033	0.000	0.054	0.050
2010	0.078	0.101	1.759	0.070	0.213	0.000	0.000	0.037	0.000	0.060	0.056
2011	0.091	0.114	1.932	0.080	0.241	0.034	0.062	0.042	0.045	0.069	0.064
2012	0.103	0.129	1.953	0.091	0.265	0.039	0.070	0.049	0.052	0.080	0.074
2013	0.113	0.140	1.980	0.099	0.286	0.042	0.076	0.053	0.056	0.086	0.080
2014	0.118	0.149	2.032	0.111	0.312	0.045	0.082	0.058	0.061	0.094	0.087
2015	0.127	0.159	2.036	0.121	0.330	0.049	0.084	0.063	0.066	0.102	0.095

Table 10 lists the DACC calculation result of the service departing from Shanghai to the other sample cities. Compared to the cities of Nanjing and Hefei, Shanghai has the largest urban area and most developed economy. People who work and live in Shanghai could have higher income levels but also need to face more expensive living costs. In terms of the single city living strategy, Shanghai had a lower single city DACC level. In 2005, the single city DACC value was 1.807 which is lower than the level in Hefei and Nanjing. In 2013, the DACC value was increased to 1.980 under stable data collection criteria. The overall Shanghai intracity accessibility index didn't indicate that higher average profitability can be achieved by living and working in a developed mega-size city. In terms of the intercity commute cases, the result of the service departing from Shanghai showed weak strength as well, due to the expensive living cost in Shanghai and lower income in destination cities. Within the cases between Shanghai to other core cities, the service to Hangzhou, with the shortest distance and most frequent timetable, reached the highest accessibility level in the research period. The DACC level of the service started from 0.231 in 2005 and increased to 0.263 before the high-speed railway service opened in 2006. In the following year with the new service, the DACC value dropped to 0.155 with a 41% decrease caused by the increased cost of the new high-speed railway service. In the following years, the strength kept increasing and reached 0.33 in 2015, with a total 113% growth compared to the first year with high-speed railway service. According to the overall accessibility index, the profitability of intercity life between Shanghai and Hangzhou is much closer to the level of making positive benefits, indicating a deeper urbanisation development between Shanghai and Hangzhou. In the other cases, Nanjing and Hefei had similar performances in the research period, but less than the result of service to Hangzhou. Due to the higher average daily income in Nanjing, the daily commute trip from Shanghai to Nanjing showed a stronger accessibility connection than the service to Hefei. In 2005, the commute trip to Hefei and Nanjing had DACC levels of 0.078 and 0.122 respectively. In 2008, the high-speed railway service from Shanghai to Nanjing was opened decreasing the DACC level to 0.084 from 0.162 in the before. In 2010, the high-speed service from Shanghai to Hefei was opened as well. The DACC value was decreased to 0.078 from the peak normal speed railway accessibility level of 0.132. Following the development of the economy, the accessibility index recovered in the years later. In 2014, the DACC value of the service to Hefei and Nanjing was 0.118 and 0.149 respectively. The commuters' benefit ability of the service from developed city to smaller city is not competitive to the trip in its reverse direction or the other service between the evenly developed area, due to the longer travel distance and unbalanced economic level. The last case in the first group is the railway service from Shanghai to Wuhan. According to the network structure, Shanghai and Nanjing are located at the easternmost and westernmost ends of the service network. The high-speed railway service connecting them was opened in 2009. Before that, the daily return trip made using normal-speed railway service took a considerable amount of time, exceeding 24 hours. This prolonged travel time resulted in the DACC value remaining at a stagnant 0 level. In the first year with the new service, the DACC value increased to 0.062. Six years later, the Shanghai-Wuhan DACC level climbed to 0.121, which was slightly less than the result of the service from Shanghai-Hefei, but with a much longer travel time. The significant improvement in passenger travel benefits was evident due to the optimisation of intercity traffic conditions between two far developed cities. This resulted in long-distance travel, which previously incurred higher costs and longer durations, reaching a profit level of service comparable to that of connecting closer to developing cities.

In the second group of the service linking network edge cities, the DACC level illustrated how the intercity commute benefit level changed throughout the research period for longer distance journeys. Among the six case cities, the normal speed railway service was insufficient to accommodate the daily return trip from Shanghai, resulting in a DACC level of 0. In 2007, the introduction of high-speed service linking the western area led to reduced travel time from Shanghai to Changsha and Nanchang, raising the DACC levels to 0.026 and 0.042, respectively. In 2009, the new high-speed service from Shanghai to the southern province significantly improved the commuters' profit ability in Fuzhou, raising the DACC level from 0 to 0.5. In 2010, the Shanghai-Beijing high-speed railway enhanced the Accessibility index for the northern area, and cities along the main high-speed line such as Beijing, Jinan, and Tianjin all surpassed the 0 DACC level. In the final year of the research, the service to Nanchang achieved the highest Accessibility level of 0.102 among all trips from Shanghai to the cities on the edge of the high-speed railway network. However, the service to the capital, Beijing, only reached a DACC level of 0.049 due to the higher cost associated with longer trips.

- Wuhan Daily Commuting Accessibility measurement

Table 11 – Wuhan DACC



DACC	Wuhan to Core					Wuhan to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	0.081	0.000	0.000	2.333	0.000	0.000	0.000	0.109	0.000	0.101	0.000
2006	0.092	0.000	0.000	2.244	0.000	0.000	0.000	0.122	0.000	0.109	0.000
2007	0.110	0.000	0.000	2.286	0.000	0.000	0.000	0.138	0.000	0.126	0.000
2008	0.126	0.000	0.000	2.309	0.000	0.000	0.000	0.155	0.000	0.144	0.000
2009	0.117	0.127	0.100	2.439	0.000	0.000	0.030	0.074	0.000	0.156	0.000
2010	0.130	0.139	0.110	2.301	0.000	0.000	0.033	0.083	0.000	0.094	0.000
2011	0.151	0.157	0.124	2.226	0.101	0.000	0.038	0.095	0.000	0.106	0.000
2012	0.171	0.177	0.137	2.021	0.111	0.037	0.043	0.110	0.000	0.121	0.000
2013	0.188	0.193	0.150	2.055	0.121	0.041	0.046	0.118	0.000	0.133	0.086
2014	0.192	0.201	0.160	1.937	0.130	0.042	0.050	0.127	0.000	0.145	0.086
2015	0.207	0.216	0.165	1.918	0.140	0.046	0.051	0.138	0.000	0.158	0.092

Wuhan is a pivotal city in the network hub, situated in the western region of the system. In the initial plan for high-speed railway development, Wuhan served as the western endpoint, connecting the existing conventional railway network to provinces in the west.

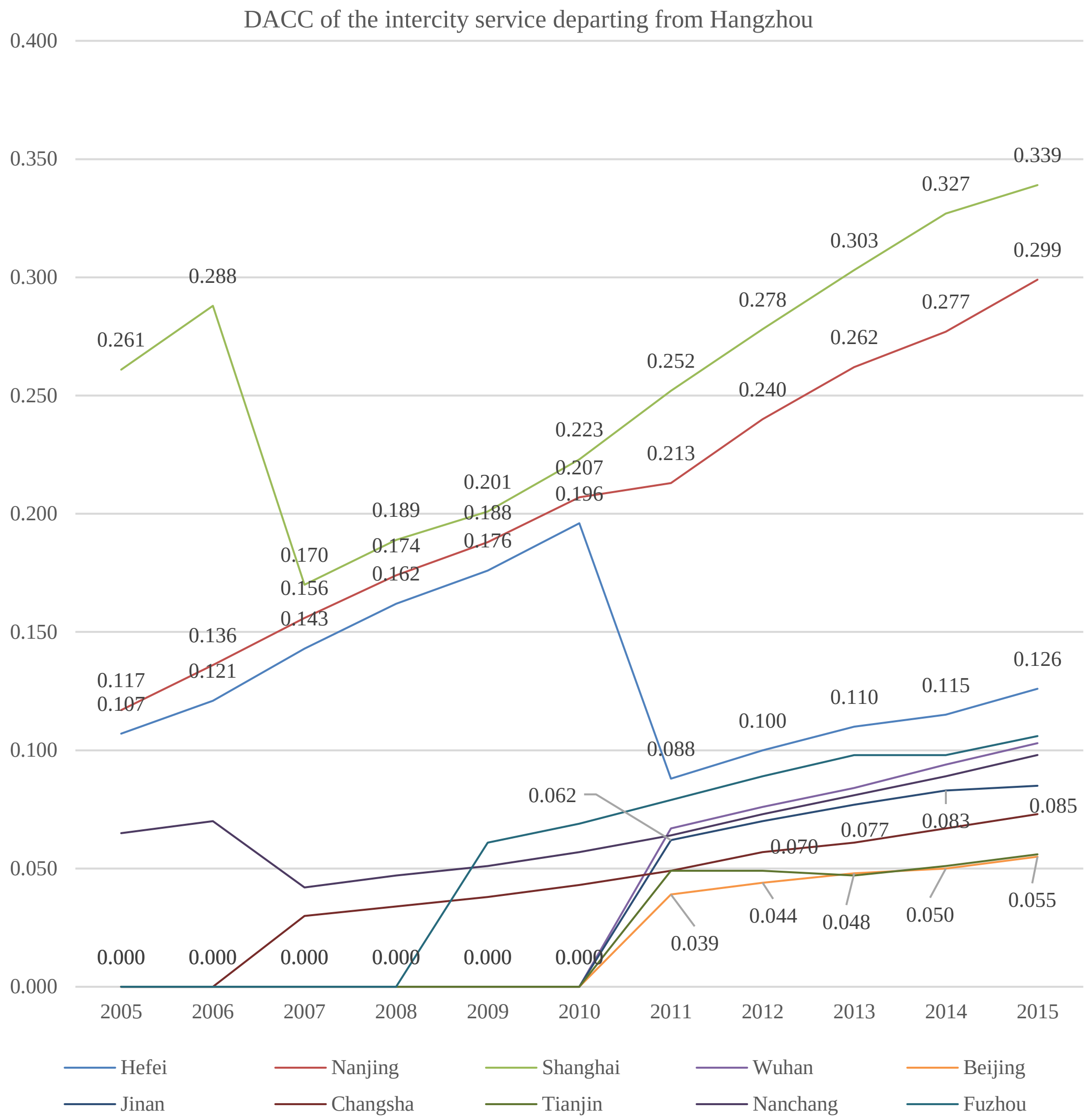
According to the results in Table 11, the fifth column represents the level of accessibility of single city living city strategy in Wuhan. In comparison to Hefei, Nanjing, and Shanghai, residents of Wuhan experienced the highest level of benefit and maintained a stable accessibility value above 2 until the statistical criteria were changed. This was primarily due to the lower cost of living in the central provinces of China. In terms of the accessibility measurement of intercity living strategy, passengers are assumed to reside in Wuhan, incurring local costs for food and accommodation, while working in their destination city to earn income at the local level.

In the first group of cases involving core cities, except for the service from Wuhan to Hefei, the conventional railway service could barely meet the speed requirements for daily round trips. In 2005, the daily accessibility index for commuters travelling on the daily return trip from Wuhan to Hefei was only 0.081, accounting for about 3% of Wuhan's single-city accessibility level. However, in 2008, the daily accessibility index increased to 0.126, marking a growth of over 50%. In 2009, the high-speed railway from Wuhan to Shanghai was inaugurated, connecting Hefei and Nanjing in the middle. In the direction towards Hefei, the accessibility value dropped to 0.117. Conversely, in the direction towards Nanjing, the new high-speed railway service pushed the daily accessibility value to 0.127, making daily round trips feasible. Similar growth was observed for trips to Shanghai, with the accessibility level exceeding 0 and reaching 0.1. However, the daily return trip to Hangzhou, the city located further east, remained inaccessible, with a profit level of 0. Until 2011, the new high-speed service made daily return trips to Hangzhou possible, traversing the entire network from west to east with a DACC level of 0.101. In the same year, the DACC values for services to Hefei, Nanjing, and Shanghai reached 0.151, 1.157, and 0.124 respectively, representing an increase of 29%, 23%, and 24% compared to the results of 2009. By 2013, the final year with consistent statistical criteria, the DACC level continued to climb, nearing 0.2 with values of 0.188 and 0.193. Also in 2013, Shanghai and Hangzhou, as destinations at a greater distance, reached DACC levels of 0.150 and 0.121. The overall profit difference between intercity and intracity living styles in Wuhan had narrowed over the 10-year research period.

In the group of services connecting network edge cities, the speed improvements brought about by the new railway service were evident as well. The return trip duration via normal speed trains exceeded 24 hours in most cases involving network edge cities. Due to time restrictions, their DACC values remained limited to 0. However, cities closer to Wuhan, such as Changsha and Nanchang, performed better throughout the research period. The normal speed railway service was able to achieve sufficient speed for daily return trips, with DACC levels of 0.155 to Changsha and 0.156 to Nanchang in the year before the introduction of high-speed rail services. After the new services were introduced, the benefit level of journeys that were previously not satisfied by the normal speed railway service began to increase from level 0. On the other hand, the profitability of daily return trips to Changsha and Nanchang decreased rapidly due to changes in cost and time, but sooner recovered in the following years. The level of the cases in Beijing, Jinan and Fuzhou also increased as well, but slower. Until 2015, service to Tianjin was still unavailable remaining the DACC value at 0.

- Hangzhou Daily Commuting Accessibility measurement

Table 12 – Hangzhou DACC



DACC	Hangzhou to Core					Hangzhou to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	0.107	0.117	0.261	0.000	1.612	0.000	0.000	0.000	0.000	0.065	0.000
2006	0.121	0.136	0.288	0.000	1.579	0.000	0.000	0.000	0.000	0.070	0.000
2007	0.143	0.156	0.170	0.000	1.788	0.000	0.000	0.030	0.000	0.042	0.000
2008	0.162	0.174	0.189	0.000	1.798	0.000	0.000	0.034	0.000	0.047	0.000
2009	0.176	0.188	0.201	0.000	1.787	0.000	0.000	0.038	0.000	0.051	0.061
2010	0.196	0.207	0.223	0.000	1.720	0.000	0.000	0.043	0.000	0.057	0.069
2011	0.088	0.213	0.252	0.067	1.733	0.039	0.062	0.049	0.049	0.064	0.079
2012	0.100	0.240	0.278	0.076	1.994	0.044	0.070	0.057	0.049	0.073	0.089
2013	0.110	0.262	0.303	0.084	2.018	0.048	0.077	0.061	0.047	0.081	0.098
2014	0.115	0.277	0.327	0.094	2.034	0.050	0.083	0.067	0.051	0.089	0.098
2015	0.126	0.299	0.339	0.103	2.115	0.055	0.085	0.073	0.056	0.098	0.106

Compared to the city of Wuhan, Hangzhou holds a significant position within the railway network. Situated further southeast and near the major hub city of Shanghai, Hangzhou's high-speed railway system primarily serves as an extension of the line to Shanghai, functioning as a satellite component within the system. Similar to other scenarios, we assume that travellers reside in Hangzhou but work in other cities, incurring living expenses in Hangzhou and benefiting from travel to their destination.

In the calculation results in Table 12, the data presented in the sixth column represents the accessibility value of the single city living strategy in Hangzhou, serving as a reference point for the profit potential of intercity travellers. The accessibility data for Hangzhou's single-city strategy consistently hovers around 1.7 over eleven years, mirroring the urbanisation progress observed in the closely situated cities of Hangzhou and Shanghai. Most intracity travellers, utilizing the single-city living strategy, tend to reside in developed megacities like Shanghai and Hangzhou, which offer better income opportunities due to their higher travel attractiveness and profit, but also entail elevated living expenses, significantly affecting overall profit potential.

The intercity accessibility statistics for service to core cities demonstrate similarity to the results observed in Shanghai. In 2005, the Daily Accessibility value from Hangzhou to Shanghai under normal-speed railway service stood at 0.261, surpassing Hefei's and Nanjing’s by more than double. The reduced travel time and ticket expenses stemming from the shorter distance enhanced the profit potential of intercity travel. Nonetheless, intercity commute costs still constituted a substantial portion of the overall travel benefits. The DACC level from Hangzhou to Shanghai in 2005 amounted to only 16.3% of Hangzhou's intracity living accessibility. In 2007, the introduction of high-speed railway service connecting Hangzhou and Shanghai resulted in a 41% accessibility decrease compared to the previous year. In subsequent years, the DACC value steadily increased, reaching 0.339 in the final year, which was twice as high as that in 2007.

Regarding railway services to Hefei and Nanjing, high-speed railway services were launched in 2011. Before this, normal-speed railways in 2005 provided DACC levels of 0.107 to Hefei and 0.117 to Nanjing. By 2010, the last year without high-speed railway service, both accessibility values had increased to 0.196 and 0.207, respectively. Following the launch of the new service, the DACC value for Nanjing continued to rise to 0.213, while for Hefei, it dropped to 0.088, marking a 55% decrease in passenger profit potential. In the final year of research, the DACC level increased to 0.126 for the service to Hefei and 0.299 for the service to Nanjing. The increased costs associated with the new high-speed service significantly impacted the effectiveness of intercity travel, further accentuating the profit potential gap between different destinations operating under distinct economic scales. The railway line to Wuhan was comprised of three sections. The first section opened in 2008 from Hefei to Nanjing, followed by the second section in 2009 from Hefei to Wuhan, and the third section opened in 2011, connecting Nanjing to Shanghai with a short link to Hangzhou. Consequently, Wuhan became the last destination to be supported by daily return commute trips via the new high-speed railway service, resulting in a DACC value of 0.067 in 2011. By the final year, this value had grown to 0.103.

Within the group of services connecting network edge cities, the overall accessibility values remained significantly lower than those for services to core cities due to higher ticket prices and longer travel times, maintaining DACC values below 0.1 throughout the years. Nanchang stands as the sole destination within the edge city group that supported daily commute trips via normal-speed railway service in 2005, with a daily accessibility level of 0.065. However, two years later, the DACC level declined to 0.042 following the introduction of the new high-speed railway service with increased costs. In 2015, the accessibility level rebounded to 0.098, marking a 133% growth driven by increased travel income and economic expansion. Among all the edge cities departing from Hangzhou, the service to Fuzhou achieved the highest accessibility level. In 2009, the construction of a high-speed line connecting the southern region, encompassing Fujian province, was completed, enabling daily commute trips. The DACC level from Hangzhou to Fuzhou stood at 0.061 in the initial year, and it increased to 0.106 in the final year, reflecting a 73% growth and reaching its pinnacle.

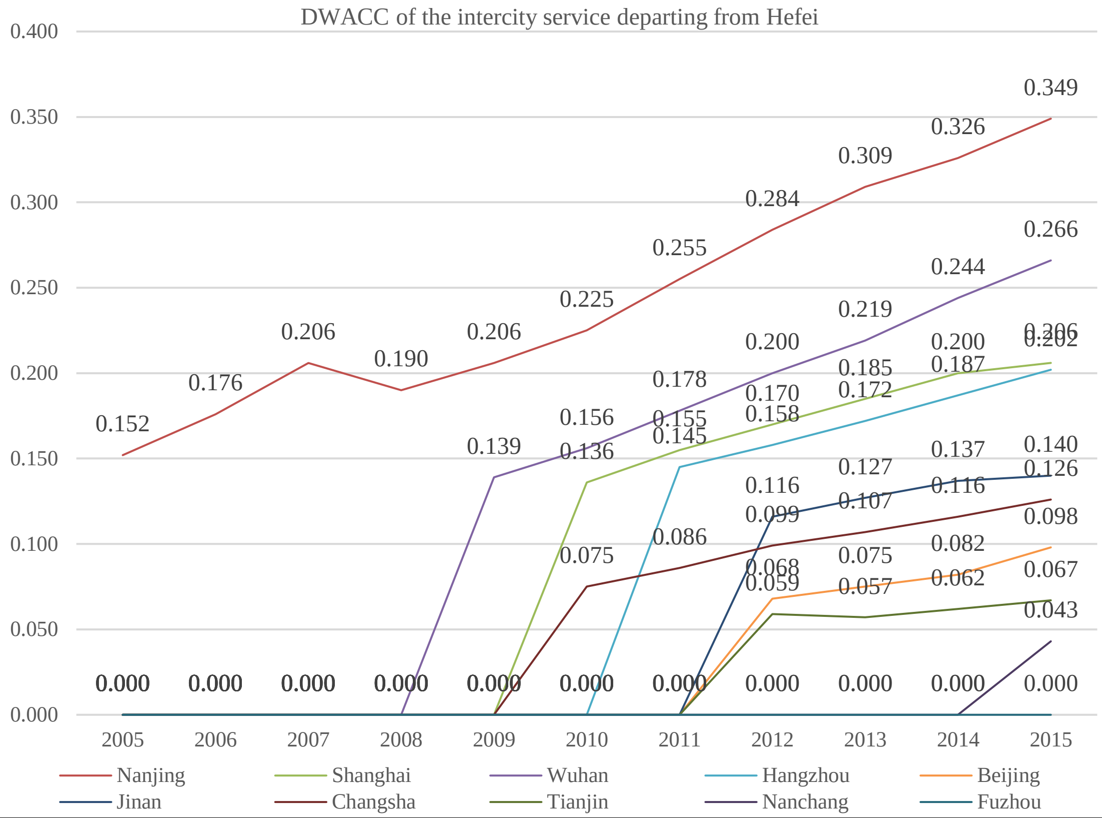
3.3.2 Daily Work Commuting Accessibility (DWACC)

The DWACC indicator was designed based on the daily commuting accessibility index, which considered the 8-hour working time budget. Intercity commuters are forced to stay at their destination for 8 hours to work to receive income, improving the practicality. Therefore, the DWACC statistic is considered and introduced as a promoted auxiliary part for the accessibility analysis.

- Hefei daily work commuting accessibility measurement

In Table 13, the DWACC statistic of the service departing from Hefei was listed. Compared to the DACC result, only the service from Hefei to Nanjing can satisfy the daily round trip requirement with a strictly restricted 8-hour working time budget. The other case indicated the travel speed improvement brought by the new high-speed railway. The new service made the further destination reachable and achieved nearly the same passenger profitability as the level of the service to Hefei in the early years.

Table 13 – Hefei DWACC

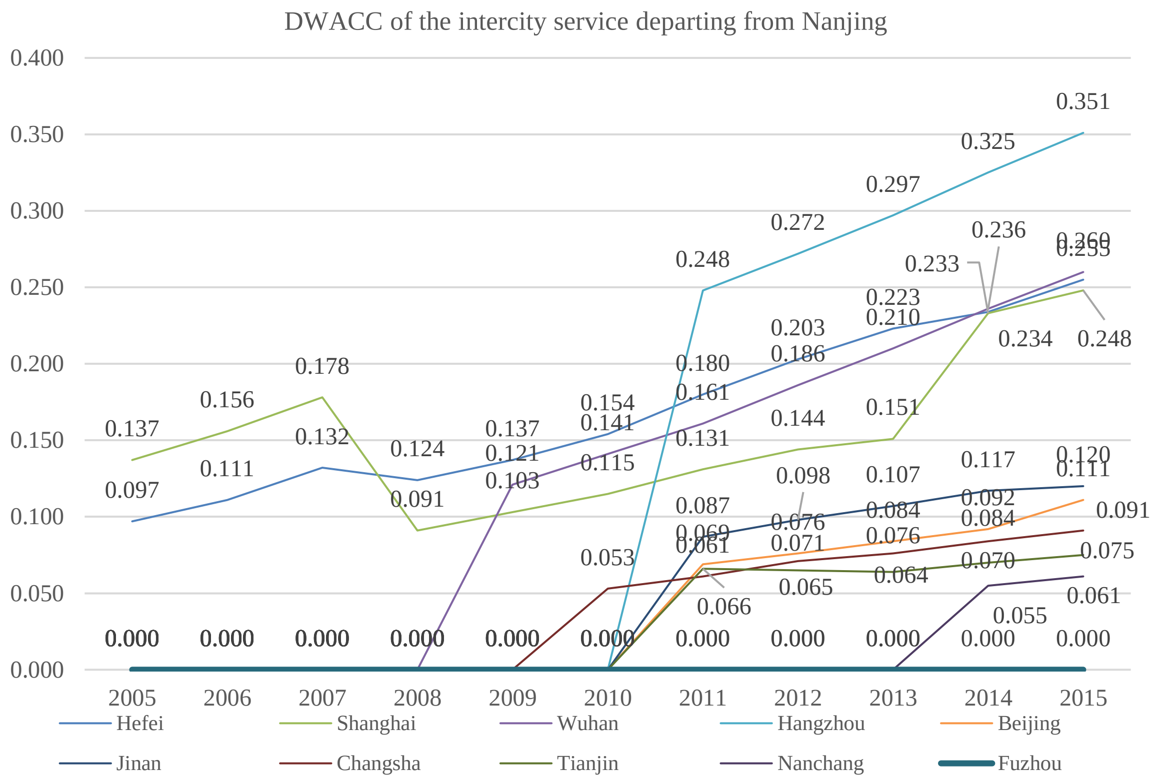


DWACC	Hefei to Core					Hefei to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	2.032	0.152	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2006	2.109	0.176	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2007	2.311	0.206	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008	2.172	0.190	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	2.139	0.206	0.000	0.139	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	2.267	0.225	0.136	0.156	0.000	0.000	0.000	0.075	0.000	0.000	0.000
2011	2.227	0.255	0.155	0.178	0.145	0.000	0.000	0.086	0.000	0.000	0.000
2012	1.983	0.284	0.170	0.200	0.158	0.068	0.116	0.099	0.059	0.000	0.000
2013	1.921	0.309	0.185	0.219	0.172	0.075	0.127	0.107	0.057	0.000	0.000
2014	2.087	0.326	0.200	0.244	0.187	0.082	0.137	0.116	0.062	0.000	0.000
2015	2.031	0.349	0.206	0.266	0.202	0.098	0.140	0.126	0.067	0.043	0.000

- Nanjing daily work commuting accessibility measurement

Table 14 shows the DWACC value of the service departing from Nanjing. As the city is geographically located at the network centre of the East China area, Nanjing has a slightly better DWACC level. Without high-speed railway service, travellers could finish 8 hours of work in the city of Hefei and Shanghai and travel round trip as intercity commuters.

Table 14 – Nanjing DWACC

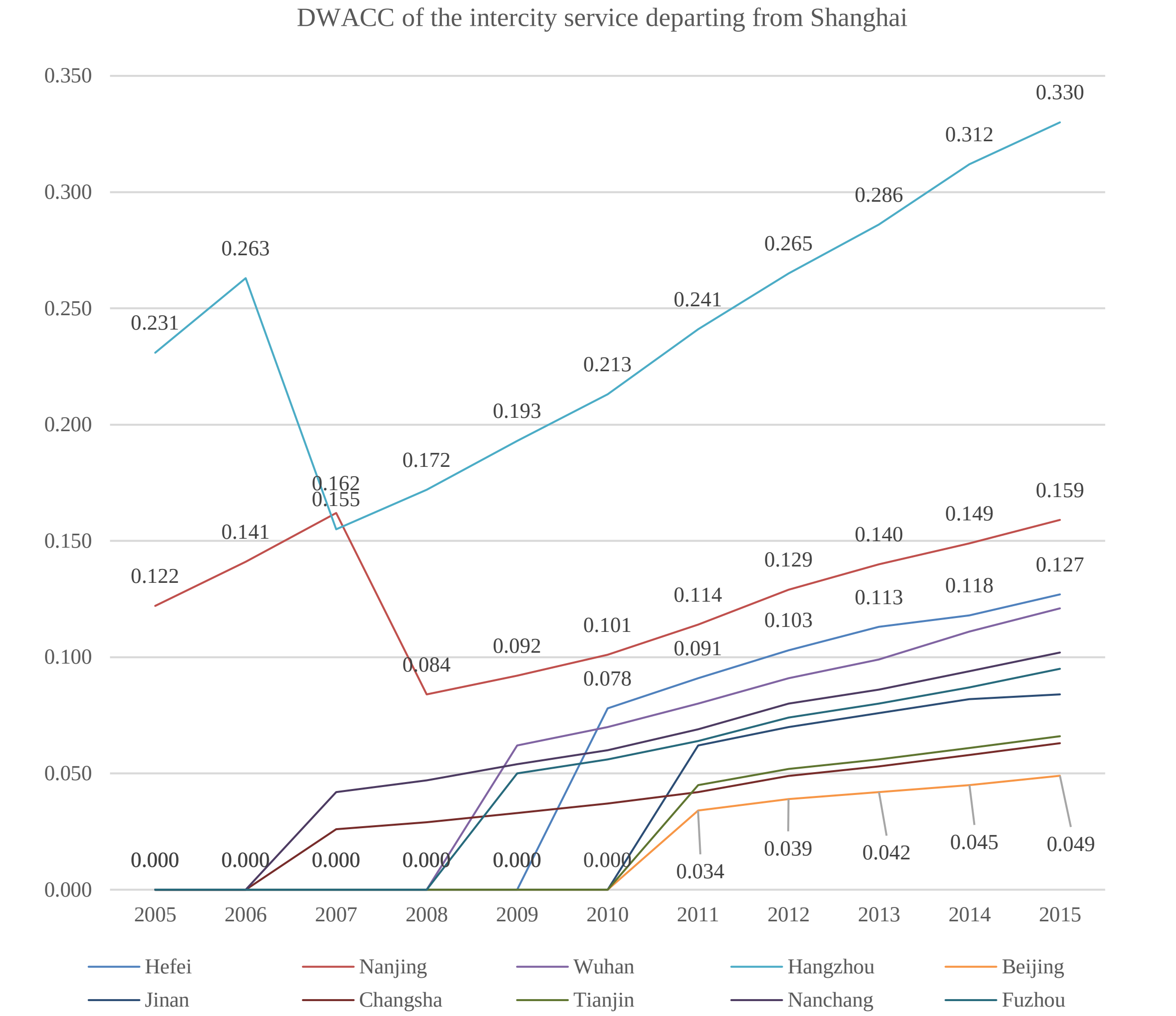


DWACC	Nanjing to Core					Nanjing to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	0.097	2.011	0.137	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2006	0.111	2.098	0.156	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2007	0.132	2.256	0.178	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008	0.124	2.256	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	0.137	2.240	0.103	0.121	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	0.154	2.385	0.115	0.141	0.000	0.000	0.000	0.053	0.000	0.000	0.000
2011	0.180	2.306	0.131	0.161	0.248	0.069	0.087	0.061	0.066	0.000	0.000
2012	0.203	2.357	0.144	0.186	0.272	0.076	0.098	0.071	0.065	0.000	0.000
2013	0.223	2.313	0.151	0.210	0.297	0.084	0.107	0.076	0.064	0.000	0.000
2014	0.234	2.454	0.233	0.236	0.325	0.092	0.117	0.084	0.070	0.055	0.000
2015	0.255	2.549	0.248	0.260	0.351	0.111	0.120	0.091	0.075	0.061	0.000

- Shanghai daily work commuting accessibility measurement

Table 15 indicates the DWACC level of the intercity service from Shanghai. Compared to the DACC calculation result, the service to Hangzhou passed the 8-hour work time budget test. The daily intercity commute round trip from Shanghai to Nanjing was also supported by both normal speed and high speed railway service, whereas the DWACC value was much lower than that of the reverse direction.

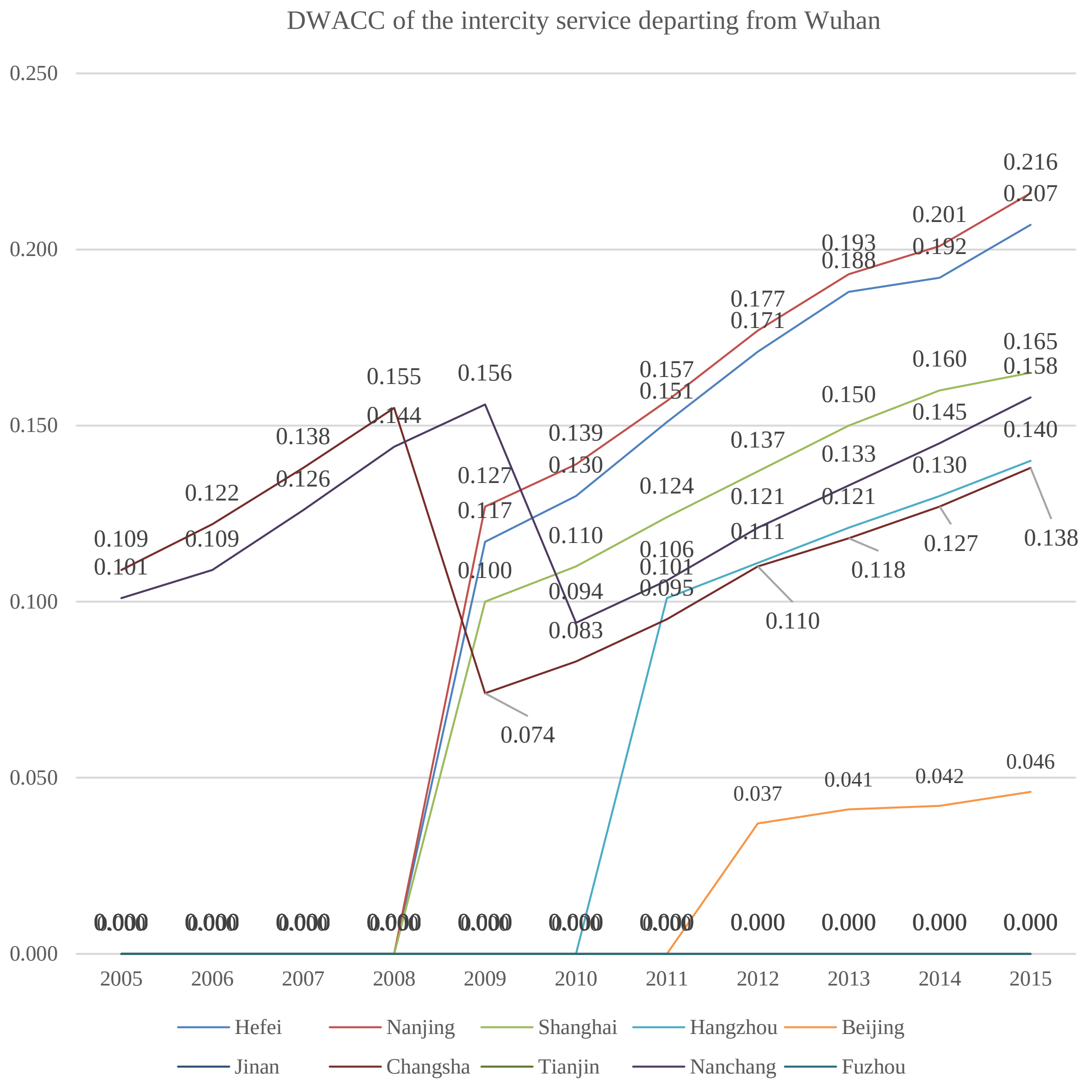
Table 15 – Shanghai DWACC



DWACC	Shanghai to Core					Shanghai to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	0.000	0.122	1.807	0.000	0.231	0.000	0.000	0.000	0.000	0.000	0.000
2006	0.000	0.141	1.821	0.000	0.263	0.000	0.000	0.000	0.000	0.000	0.000
2007	0.000	0.162	1.706	0.000	0.155	0.000	0.000	0.026	0.000	0.042	0.000
2008	0.000	0.084	1.721	0.000	0.172	0.000	0.000	0.029	0.000	0.047	0.000
2009	0.000	0.092	1.774	0.062	0.193	0.000	0.000	0.033	0.000	0.054	0.050
2010	0.078	0.101	1.759	0.070	0.213	0.000	0.000	0.037	0.000	0.060	0.056
2011	0.091	0.114	1.932	0.080	0.241	0.034	0.062	0.042	0.045	0.069	0.064
2012	0.103	0.129	1.953	0.091	0.265	0.039	0.070	0.049	0.052	0.080	0.074
2013	0.113	0.140	1.980	0.099	0.286	0.042	0.076	0.053	0.056	0.086	0.080
2014	0.118	0.149	2.032	0.111	0.312	0.045	0.082	0.058	0.061	0.094	0.087
2015	0.127	0.159	2.036	0.121	0.330	0.049	0.084	0.063	0.066	0.102	0.095

- Wuhan daily work commuting accessibility measurement

Table 16 – Wuhan DWACC



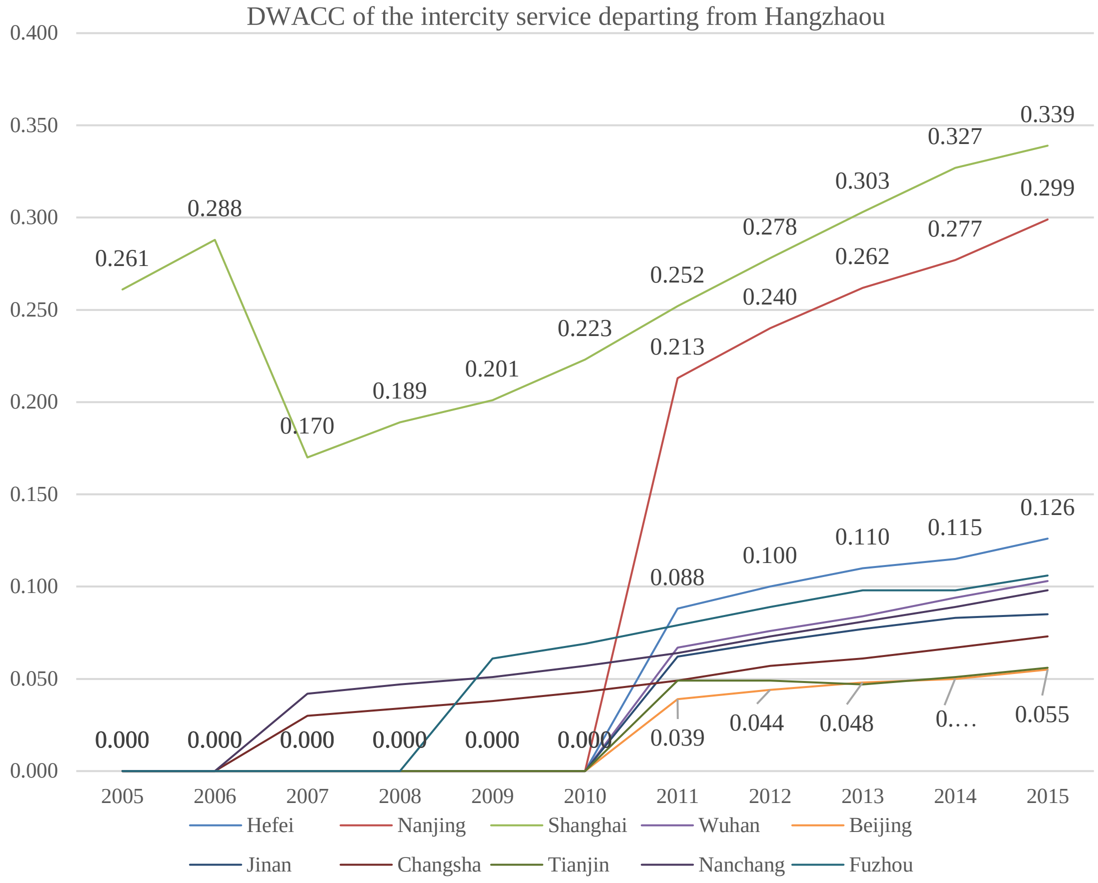
DWACC	Wuhan to Core					Wuhan to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	0.000	0.000	0.000	2.333	0.000	0.000	0.000	0.109	0.000	0.101	0.000
2006	0.000	0.000	0.000	2.244	0.000	0.000	0.000	0.122	0.000	0.109	0.000
2007	0.000	0.000	0.000	2.286	0.000	0.000	0.000	0.138	0.000	0.126	0.000
2008	0.000	0.000	0.000	2.309	0.000	0.000	0.000	0.155	0.000	0.144	0.000
2009	0.117	0.127	0.100	2.439	0.000	0.000	0.000	0.074	0.000	0.156	0.000
2010	0.130	0.139	0.110	2.301	0.000	0.000	0.000	0.083	0.000	0.094	0.000
2011	0.151	0.157	0.124	2.226	0.101	0.000	0.000	0.095	0.000	0.106	0.000
2012	0.171	0.177	0.137	2.021	0.111	0.037	0.000	0.110	0.000	0.121	0.000
2013	0.188	0.193	0.150	2.055	0.121	0.041	0.000	0.118	0.000	0.133	0.000
2014	0.192	0.201	0.160	1.937	0.130	0.042	0.000	0.127	0.000	0.145	0.000
2015	0.207	0.216	0.165	1.918	0.140	0.046	0.000	0.138	0.000	0.158	0.000

Table 16 listed the DWACC calculation results of the service departing from Wuhan, which is located at the west of the high-speed railway network. Compared to its DACC value, the Daily work commuting accessibility reflected a better accessibility level from Wuhan to the other west edge destinations in early time without high speed railway service. The cities of Changsha and Nanchang passed the 8-hour time budget test, supporting long working times at commute destinations. However, the recently opened new high-speed service connecting to the developed area quickly pushed the corresponding commuter's profit level, exceeding the level of the service to the originally round trip available cities, due to higher travel income. The increased accessibility index indicated more reachable and profitable travel and work opportunities for travellers and potential intercity employees.

- Hangzhou daily work commuting accessibility measurement

Table 17 illustrates the DWACC calculation results of the service departing from Hangzhou. Compared to the DACC result, the destinations of normal speed railway service, including Hefei, Nanjing, and Nanchang, were removed from the daily reachable city list, due to overlong time travel time cost causing insufficient work time. With the new high speed service, every destination was available for daily intercity working round trip from Hangzhou.

Table 17 – Hangzhou DWACC



DWACC	Hangzhou to Core					Hangzhou to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	0.000	0.000	0.261	0.000	1.612	0.000	0.000	0.000	0.000	0.000	0.000
2006	0.000	0.000	0.288	0.000	1.579	0.000	0.000	0.000	0.000	0.000	0.000
2007	0.000	0.000	0.170	0.000	1.788	0.000	0.000	0.030	0.000	0.042	0.000
2008	0.000	0.000	0.189	0.000	1.798	0.000	0.000	0.034	0.000	0.047	0.000
2009	0.000	0.000	0.201	0.000	1.787	0.000	0.000	0.038	0.000	0.051	0.061
2010	0.000	0.000	0.223	0.000	1.720	0.000	0.000	0.043	0.000	0.057	0.069
2011	0.088	0.213	0.252	0.067	1.733	0.039	0.062	0.049	0.049	0.064	0.079
2012	0.100	0.240	0.278	0.076	1.994	0.044	0.070	0.057	0.049	0.073	0.089
2013	0.110	0.262	0.303	0.084	2.018	0.048	0.077	0.061	0.047	0.081	0.098
2014	0.115	0.277	0.327	0.094	2.034	0.050	0.083	0.067	0.051	0.089	0.098
2015	0.126	0.299	0.339	0.103	2.115	0.055	0.085	0.073	0.056	0.098	0.106

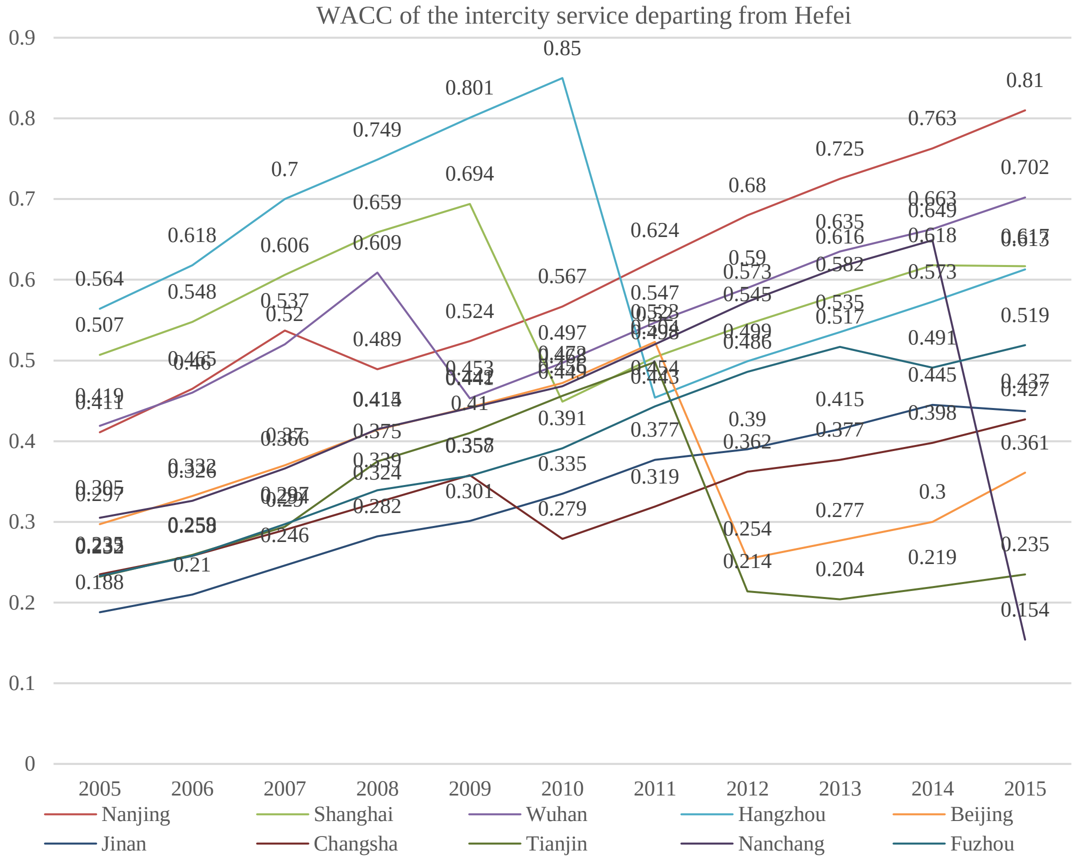
3.3.3 Weekly Return Accessibility (WACC)

This section introduced the weekly return accessibility calculation result. The WACC indicator was designed to assess the intercity commuter's profitability when they travelled between two cities within a week. Compared to any daily return accessibility, the overall level of WACC data showed better results with a higher profit ratio.

- Hefei Weekly Return Accessibility measurement

Table 18 lists the WACC calculations result of the intercity railway service departing from Hefei.

Table 18 – Hefei WACC



WACC	Hefei to Core					Hefei to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	2.032	0.411	0.507	0.419	0.564	0.297	0.188	0.235	0.232	0.305	0.233
2006	2.109	0.465	0.548	0.460	0.618	0.332	0.210	0.258	0.259	0.326	0.258
2007	2.311	0.537	0.606	0.520	0.700	0.370	0.246	0.290	0.294	0.366	0.297
2008	2.172	0.489	0.659	0.609	0.749	0.414	0.282	0.324	0.375	0.415	0.339
2009	2.139	0.524	0.694	0.453	0.801	0.442	0.301	0.358	0.410	0.441	0.357
2010	2.267	0.567	0.449	0.497	0.850	0.472	0.335	0.279	0.456	0.468	0.391
2011	2.227	0.624	0.504	0.547	0.454	0.523	0.377	0.319	0.498	0.520	0.443
2012	1.983	0.680	0.545	0.590	0.499	0.254	0.390	0.362	0.214	0.573	0.486
2013	1.921	0.725	0.582	0.635	0.535	0.277	0.415	0.377	0.204	0.616	0.517
2014	2.087	0.763	0.618	0.663	0.573	0.300	0.445	0.398	0.219	0.649	0.491
2015	2.031	0.810	0.617	0.702	0.613	0.361	0.437	0.427	0.235	0.154	0.519

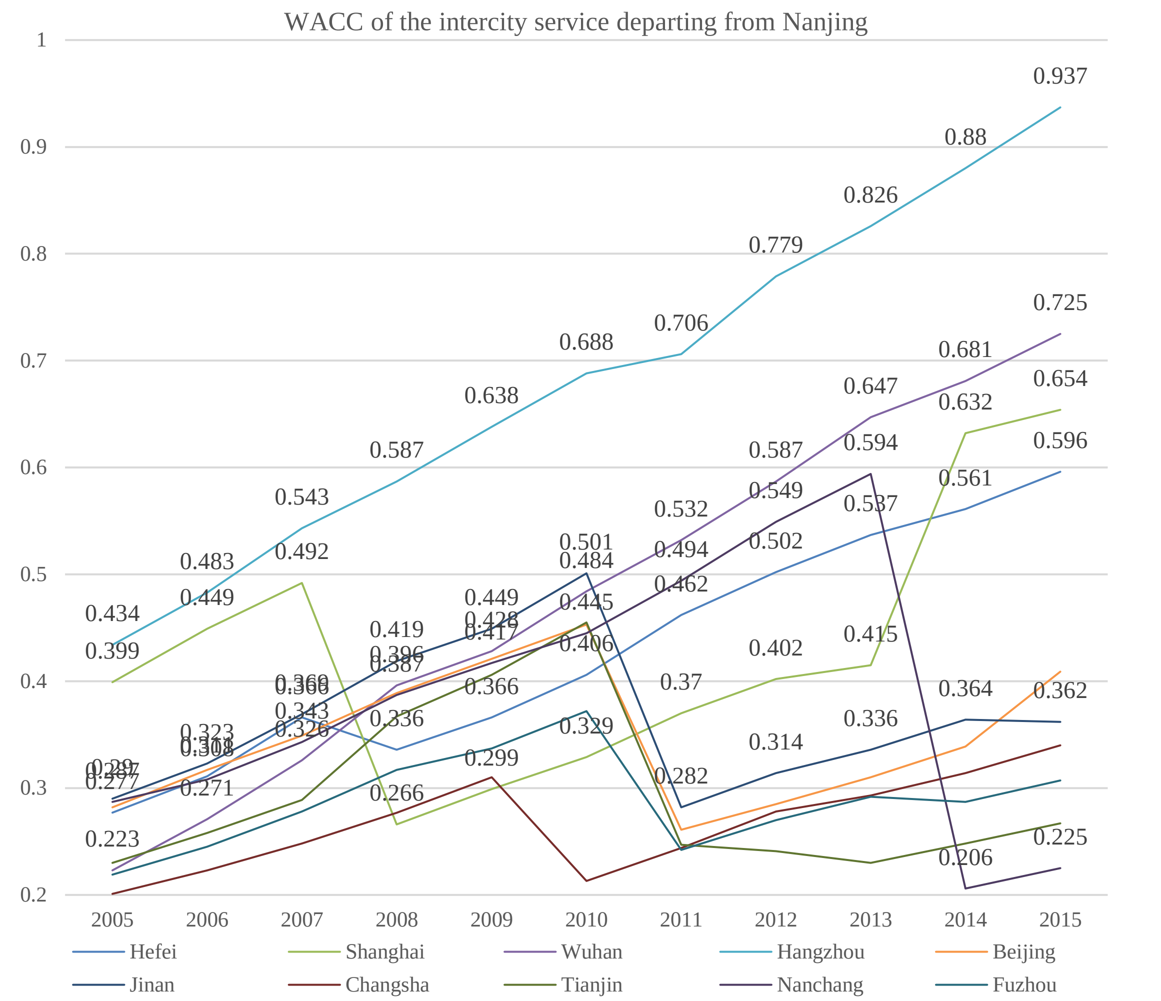
In this case, the traveller spends five days working in the destination city and two days resting in Hefei, receiving the corresponding 5-day work income, spending 5-day's living costs in the destination and 2-day's costs in Hefei. Compared to the DACC calculation result, all accessibility level was increased when the travel frequency was lowered to weekly return.

In the group of the core cities, all weekly accessibility values are above 0.4. Especially the data on the service to Nanjing, the accessibility value reached 0.81 in 2015, which means the profitability of the weekly return intercity life from Hefei to Nanjing is very close to the level which could generate positive net income. By observing the performance in the first year with high speed railway service, the more expensive travel cost reduced the accessibility by 30%

In the group of the service connecting network edge city, the overall weekly accessibility level was also increased. Nearly all values started above 0.2 in 2005, except the service to Jinan. Before the high-speed railway service was opened, in some cases like Beijing, the weekly accessibility reached 0.523 in 2010, achieving high profitability for the long-distance intercity traveller under normal speed railway service. In the same case in the next year, the increased new high-speed service cost cut the Hefei-Beijing weekly accessibility to 0.254 with a 51.4% reduction. The WACC level of the service to Tianjin, which is a city located close to Beijing with a lower income level, was reduced by 57% as well. The other cases' WACC showed better results during the speed change period, with a 3% growth in Jinan and, a 22% decrease in Changsha.

- Nanjing Weekly Return Accessibility measurement

Table 19 – Nanjing WACC

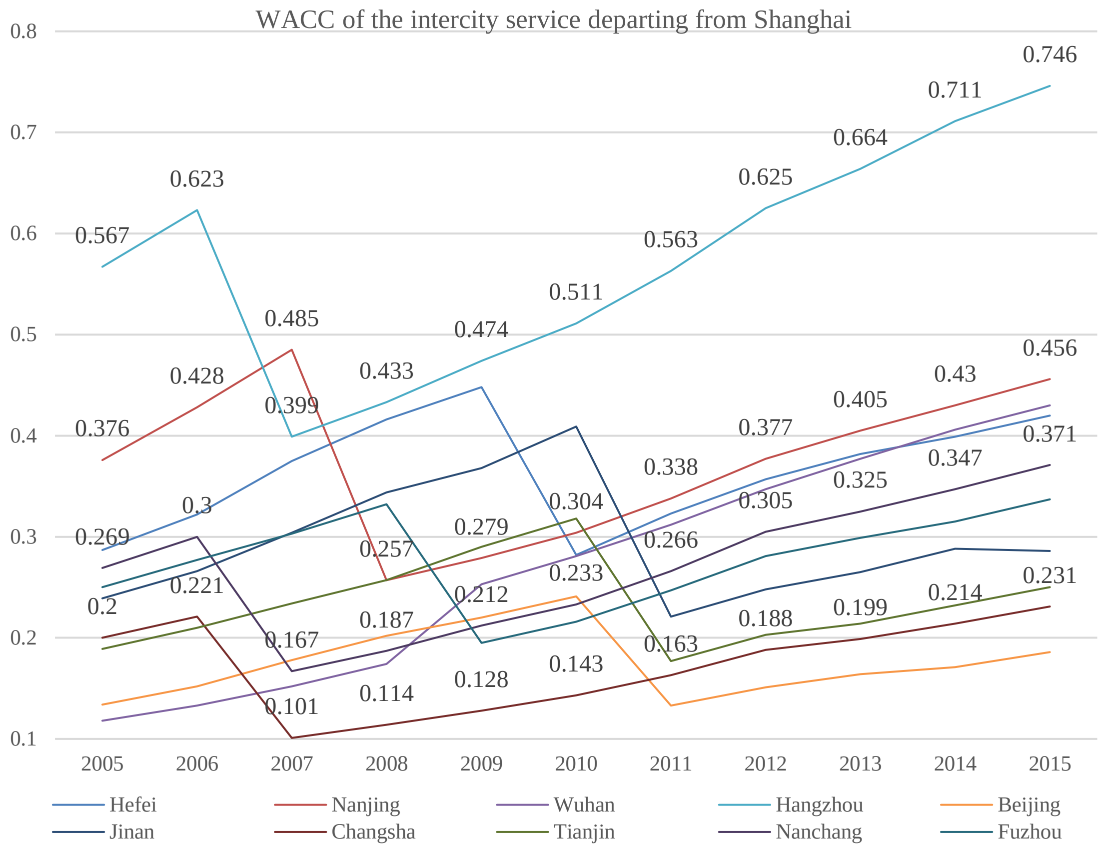


WACC	Nanjing to Core					Nanjing to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	0.277	2.011	0.399	0.223	0.434	0.282	0.290	0.201	0.230	0.287	0.219
2006	0.311	2.098	0.449	0.271	0.483	0.317	0.323	0.223	0.258	0.308	0.245
2007	0.366	2.256	0.492	0.326	0.543	0.349	0.369	0.248	0.289	0.343	0.278
2008	0.336	2.256	0.266	0.396	0.587	0.389	0.419	0.277	0.367	0.387	0.317
2009	0.366	2.240	0.299	0.428	0.638	0.421	0.449	0.310	0.406	0.417	0.337
2010	0.406	2.385	0.329	0.484	0.688	0.453	0.501	0.213	0.455	0.445	0.372
2011	0.462	2.306	0.370	0.532	0.706	0.261	0.282	0.244	0.247	0.494	0.242
2012	0.502	2.357	0.402	0.587	0.779	0.285	0.314	0.278	0.241	0.549	0.270
2013	0.537	2.313	0.415	0.647	0.826	0.310	0.336	0.293	0.230	0.594	0.292
2014	0.561	2.454	0.632	0.681	0.880	0.339	0.364	0.314	0.248	0.206	0.287
2015	0.596	2.549	0.654	0.725	0.937	0.409	0.362	0.340	0.267	0.225	0.307

Table 19 indicates the Weekly Accessibility calculation of the service departing from Nanjing. In this case, the traveller is assumed to stay in the destination for 5 days, with local income and living expenses, and return to Nanjing for the weekend with 2 days' living cost. In the form, the Nanjing single city accessibility data were listed as the reference point. The overall Nanjing WACC level is also higher than the daily accessibility level, due to lower travel frequency. In the group of services to the core cities, the intercity journey from Nanjing to Hangzhou reached the highest accessibility level throughout the research period. In 2010, by travelling through the normal speed railway service, the weekly accessibility from Nanjing to Hangzhou was 0.680. However, in the next year, the weekly accessibility grew up to 0.699 under faster and more expensive high-speed railway service. The new high speed railway reduced the overall track length and increased the service speed, which reduced the travel time from 7.6 hours to 1.9 hours and only raised the ticket price from 72 Yuan to 136.1 Yuan. The whole journey VOT cost was lowered from 153.6 Yuan to 68.33, which means the value of the huge amount of saved time exceeded the growth of the ticket price. The weekly accessibility of Wuhan and Hefei also increased in the first year with new services or quickly recovered. In the edge city group, the intercity commute trip, alongside the Beijing-Shanghai railway line, to Jinan, Beijing and Tianjin has a higher weekly accessibility level under normal-speed service. After the new high speed railway was operated, a WACC level drop also occurred, with an average 40% decrease. On the other direction to the south, Nanchang, the increasing high speed railway cost reduced the accessibility by 65.3%.

- Shanghai Weekly Return Accessibility measurement

Table 20 – Shanghai WACC



WACC	Shanghai to Core					Shanghai to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	0.287	0.376	1.807	0.118	0.567	0.134	0.239	0.200	0.189	0.269	0.250
2006	0.322	0.428	1.821	0.133	0.623	0.152	0.266	0.221	0.210	0.300	0.277
2007	0.375	0.485	1.706	0.152	0.399	0.178	0.304	0.101	0.234	0.167	0.303
2008	0.416	0.257	1.721	0.174	0.433	0.202	0.344	0.114	0.257	0.187	0.332
2009	0.448	0.279	1.774	0.253	0.474	0.220	0.368	0.128	0.290	0.212	0.195
2010	0.282	0.304	1.759	0.281	0.511	0.241	0.409	0.143	0.318	0.233	0.216
2011	0.323	0.338	1.932	0.312	0.563	0.133	0.221	0.163	0.177	0.266	0.247
2012	0.357	0.377	1.953	0.347	0.625	0.151	0.248	0.188	0.203	0.305	0.281
2013	0.382	0.405	1.980	0.377	0.664	0.164	0.265	0.199	0.214	0.325	0.299
2014	0.399	0.430	2.032	0.406	0.711	0.171	0.288	0.214	0.232	0.347	0.315
2015	0.420	0.456	2.036	0.430	0.746	0.186	0.286	0.231	0.250	0.371	0.337

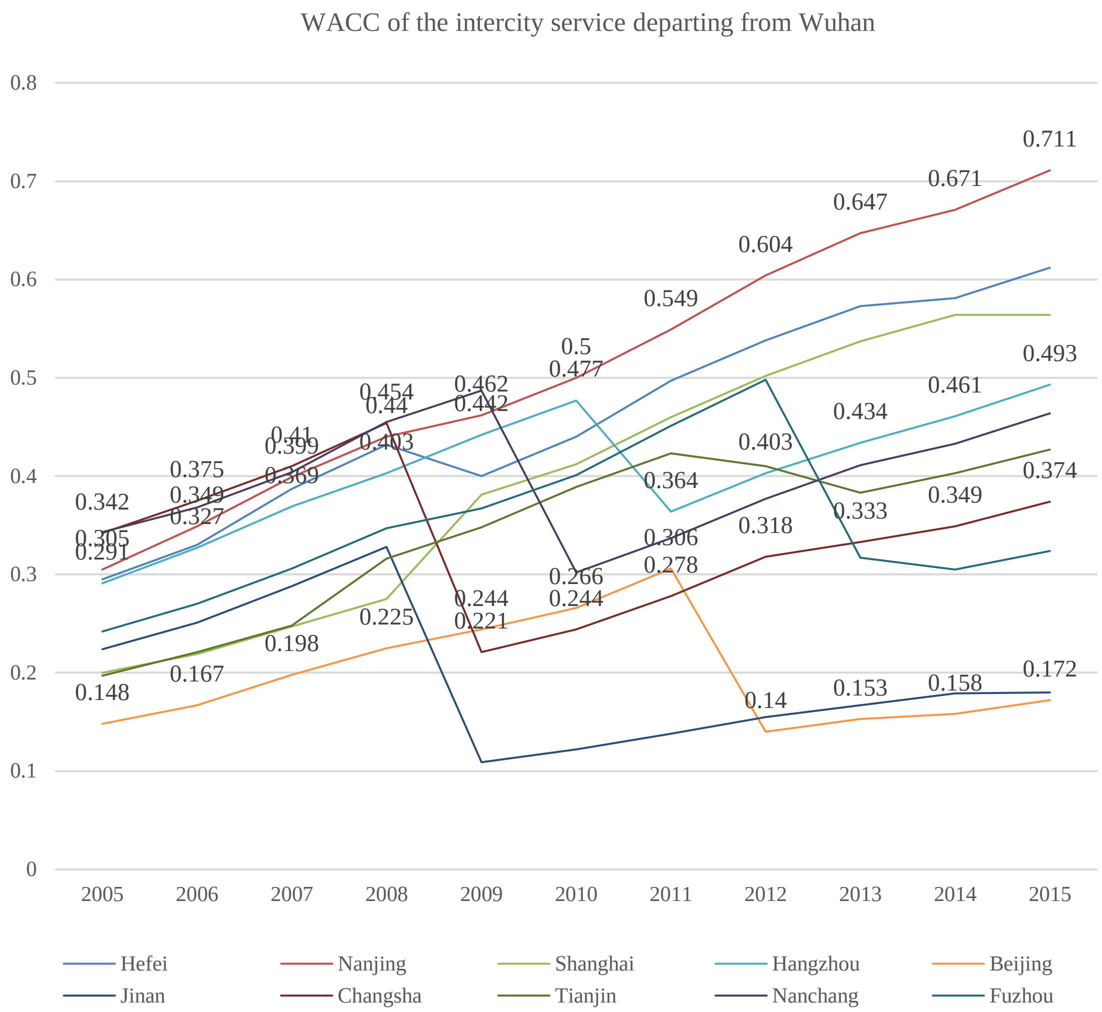
Table 20 lists the WACC calculations result of the intercity railway service departing from Shanghai. Traveller is also assumed to stay in the destination for five days with local income and living expenses, then return to Shanghai for the weekend with two days'

Shanghai living cost. Compared to the other cases, Shanghai is the most developed city, bringing a lower income level in destination, higher weekend expenses and reduced profitability, which could be found in Shanghai DACC analysis. In the WACC calculation result, the weekly intercity travel from Shanghai is still lower than in the other cases.

In the core cities' group, the service to Hangzhou has the highest WACC level throughout the service speed change period. Due to the extremely close distance to Shanghai, the normal speed railway service can support a WACC level of 0.623 in 2006. In the next year, the new high speed service increased the cost and generated the accessibility gap to 0.399 with a 35% decrease. In 2013, the WACC recovered to 0.664. In the group of the service from Shanghai to network edge cities, every case experienced WACC level reduction in the first year with new high speed services. According to the result, the weekly return intercity living strategy to Nanchang achieved the highest profit level. In 2006, the normal speed railway could afford intercity traveller's weekly return trips with an accessibility level of 0.300. After the second year's service speed increase, the accessibility ratio quickly dropped 44% to 0.167. It had recovered until 2012 with a level of 0.305. The accessibility level of the service to further cities like Beijing, Jinan and Changsha showed a worse level below 0.3.

- Wuhan Weekly Return Accessibility measurement

Table 21 – Wuhan WACC



WACC	Wuhan to Core					Wuhan to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	0.295	0.305	0.200	2.333	0.291	0.148	0.224	0.342	0.197	0.343	0.242
2006	0.330	0.349	0.219	2.244	0.327	0.167	0.251	0.375	0.221	0.368	0.270
2007	0.387	0.399	0.247	2.286	0.369	0.198	0.288	0.410	0.248	0.404	0.306
2008	0.432	0.440	0.275	2.309	0.403	0.225	0.328	0.454	0.316	0.455	0.347
2009	0.400	0.462	0.381	2.439	0.442	0.244	0.109	0.221	0.348	0.487	0.367
2010	0.440	0.500	0.412	2.301	0.477	0.266	0.122	0.244	0.389	0.302	0.401
2011	0.497	0.549	0.460	2.226	0.364	0.306	0.138	0.278	0.423	0.337	0.451
2012	0.538	0.604	0.502	2.021	0.403	0.140	0.155	0.318	0.410	0.377	0.498
2013	0.573	0.647	0.537	2.055	0.434	0.153	0.167	0.333	0.383	0.411	0.317
2014	0.581	0.671	0.564	1.937	0.461	0.158	0.179	0.349	0.403	0.433	0.305
2015	0.612	0.711	0.564	1.918	0.493	0.172	0.180	0.374	0.427	0.464	0.324

Table 21 lists the WACC calculations result of the intercity railway service departing from Wuhan. In the Wuhan case study, commuter travellers are assumed to work at their destination for five days a week, earning a local income level and incurring local living expenses, and then return to Wuhan for the weekend with local two-day living costs.

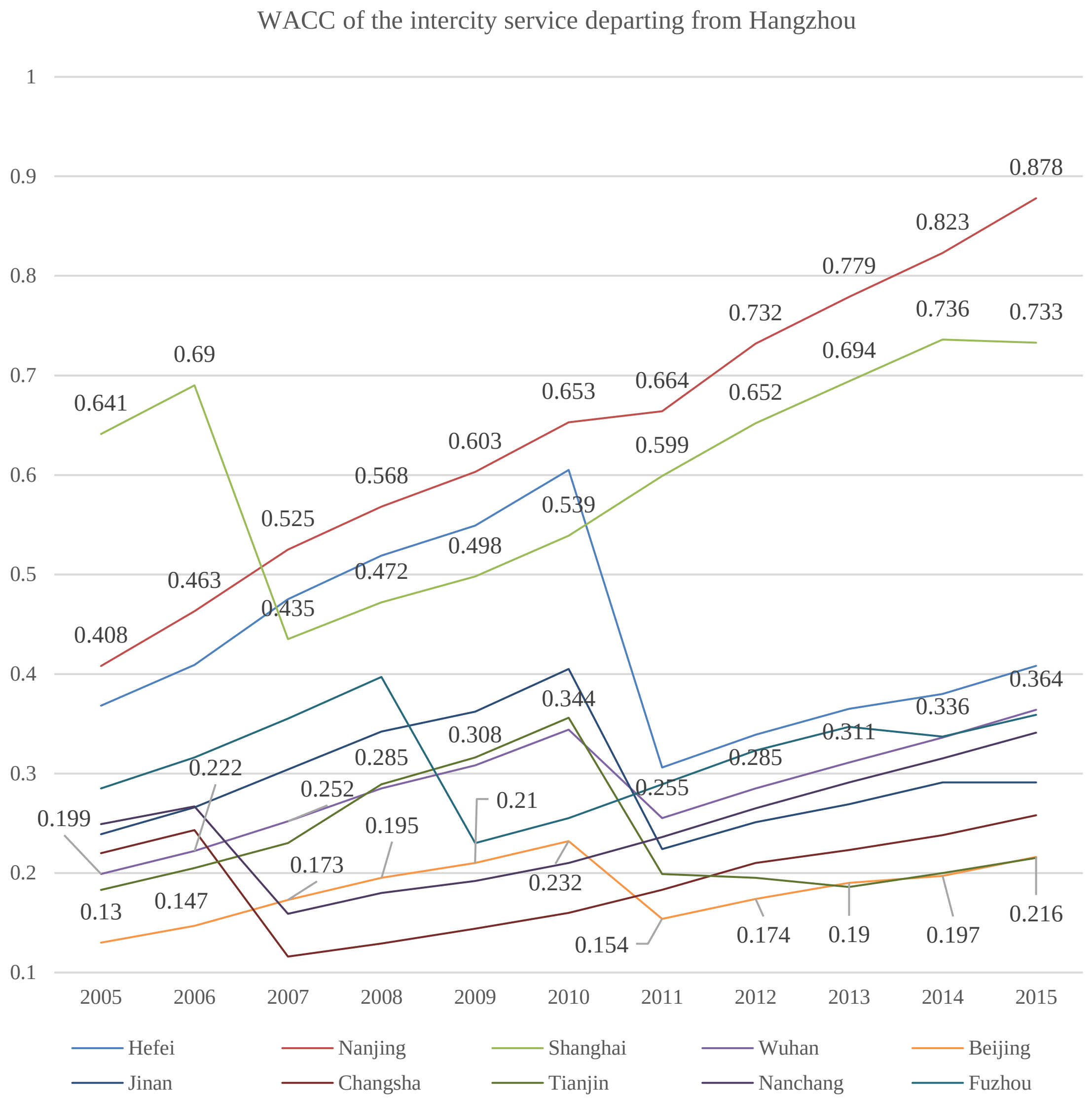
Similar to the statistical results in other case groups, the WACC for individuals travelling from Wuhan has significantly improved compared to DACC and DWACC results. The weekly intercity commuting strategy is more suitable for the general population but still far from generating positive profit. The fourth column in the data table represents the WACC values for Wuhan's intra-city commuting strategy as a reference standard.

Among the cases of commuting from Wuhan to other network core cities, the WACC value for the journey to Nanjing remains relatively high throughout the empirical study period. In 2008, conventional rail transport supported commuters at an average WACC level of 0.440 for weekly commutes. In the following year, 2009, with the introduction of high-speed railway and its associated higher costs, the WACC value continued to grow and reached 0.462, without decrease. In the later years, the weekly commuting profitability increased to 0.647 in 2013 and 0.711 in 2015. The other network core cities also showed substantial growth during the 11 years.

In another group of cases commuting from Wuhan to network edge cities, the weekly intercity commuting to Nanchang had a higher WACC level. As early as 2009, conventional railway service offered a WACC level of 0.487. The following year, with the operation of a more expensive high-speed railway service, the WACC decreased to 0.302, creating a WACC gap of 37.3%. For longer distance intercity travel, such as those to Beijing and Jinan, the WACC showed lower levels and a larger gap emerged with the introduction of high speed railways.

- Hangzhou Weekly Return Accessibility measurement

Table 22 – Hangzhou WACC



WACC	Hangzhou to Core					Hangzhou to Network edge					
Year	Hefei	Nanjing	Shanghai	Wuhan	Hangzhou	Beijing	Jinan	Changsha	Tianjin	Nanchang	Fuzhou
2005	0.368	0.408	0.641	0.199	1.612	0.130	0.239	0.220	0.183	0.249	0.285
2006	0.409	0.463	0.690	0.222	1.579	0.147	0.266	0.243	0.205	0.267	0.316
2007	0.475	0.525	0.435	0.252	1.788	0.173	0.304	0.116	0.230	0.159	0.355
2008	0.519	0.568	0.472	0.285	1.798	0.195	0.342	0.129	0.289	0.180	0.397
2009	0.549	0.603	0.498	0.308	1.787	0.210	0.362	0.144	0.316	0.192	0.230
2010	0.605	0.653	0.539	0.344	1.720	0.232	0.405	0.160	0.356	0.210	0.255
2011	0.306	0.664	0.599	0.255	1.733	0.154	0.224	0.183	0.199	0.236	0.289
2012	0.339	0.732	0.652	0.285	1.994	0.174	0.251	0.210	0.195	0.265	0.323
2013	0.365	0.779	0.694	0.311	2.018	0.190	0.269	0.223	0.186	0.291	0.347
2014	0.380	0.823	0.736	0.336	2.034	0.197	0.291	0.238	0.200	0.315	0.337
2015	0.408	0.878	0.733	0.364	2.115	0.216	0.291	0.258	0.215	0.341	0.359

Table 22 lists the WACC calculation results of the intercity railway service departing from Hangzhou. In the final case WACC analyses with Hangzhou as the departure city, commuters make a round trip to their destination once a week and work in the destination for five days, earning the local average income and covering living expenses, and then spend the weekend in Hangzhou, incurring two days' worth of local living costs.

Compared to the other cases, the service departing from Hangzhou to the core cities has a relatively higher WACC level, according to the calculation result which was shown in the first part. The railway service from Hangzhou to Nanjing brought the highest WACC level. In 2010, weekly intercity commuters travelling from Hangzhou to Nanjing using conventional rail could achieve a WACC level of 0.653. In the following year, the introduction of high-speed railway service directly raised the WACC value to 0.664, bypassing the usual accessibility decline. In 2015, the Hangzhou-Nanjing WACC reached 0.878, which is very close to meeting the point of positive return. The service to Shanghai also has a very high WACC level. In the cases of commute journeys from Hangzhou to network edge cities, due to the longer distance and the lack of direct connections of highspeed lines, the WACC values are significantly lower compared to core city values. After the construction of high-speed railways, Fuzhou in South China became the commuter destination in the edge city group with the highest accessibility value. In 2015, the Fuzhou-Hangzhou WACC value reached 0.347.

3.3.4 Accessibility statistic visualisation and heatmap

The Accessibility statistic visualisation is the project to present the accessibility value visually, which is intended to help traffic managers and governors understand the area’s accessibility change process and promote the policy-making process.

The DWACC values of Hefei are selected and integrated with the high-speed railway construction progress into a group of heat maps. In the figure, the colour from light blue to deep yellow indicates DWACC strength, matching the value from 0 to 1. For the city of Hefei, the yellow colour represents the level of intracity living accessibility ratio, which is the highest level generating positive net profit. The first panel shows the level in 2005 without the high-speed service. The remaining five panels illustrate the DWACC strength change following HSR construction. The intercity living profit ability dramatically improved, and the area covered by the heatmap expanded and became deeper at more places, due to the faster traffic conditions and economic development.

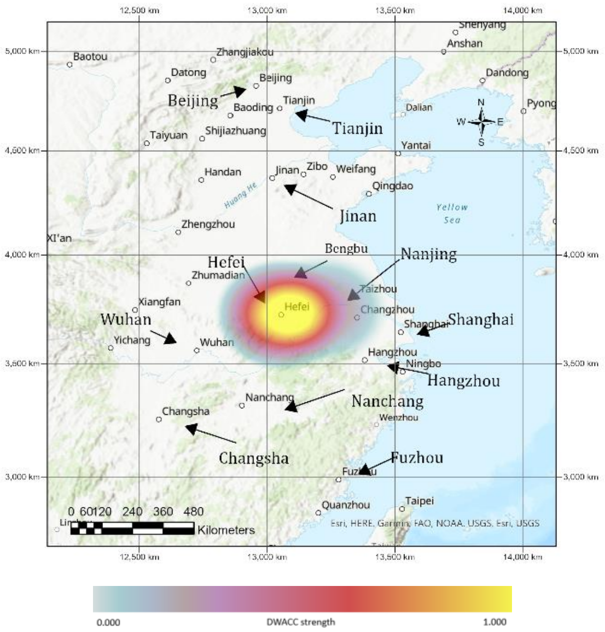


Figure 6 – The DWACC Level and HSR service network from Hefei to the other sample cities in 2005

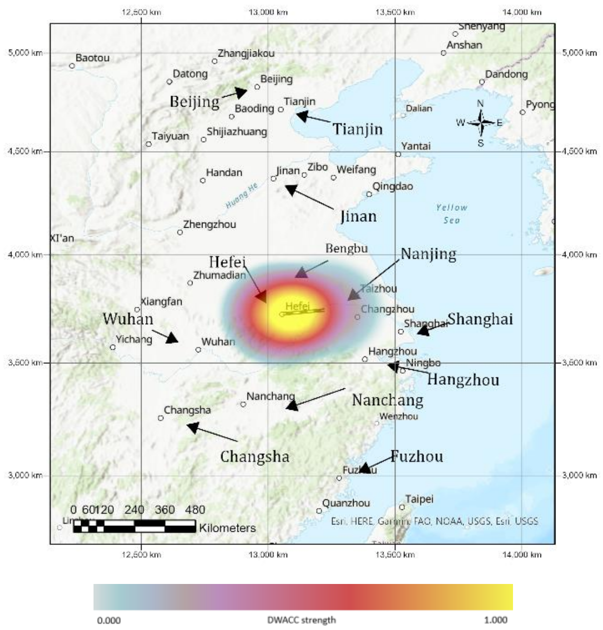


Figure 7 – The DWACC strength and HSR service network from Hefei to the other sample cities in 2008

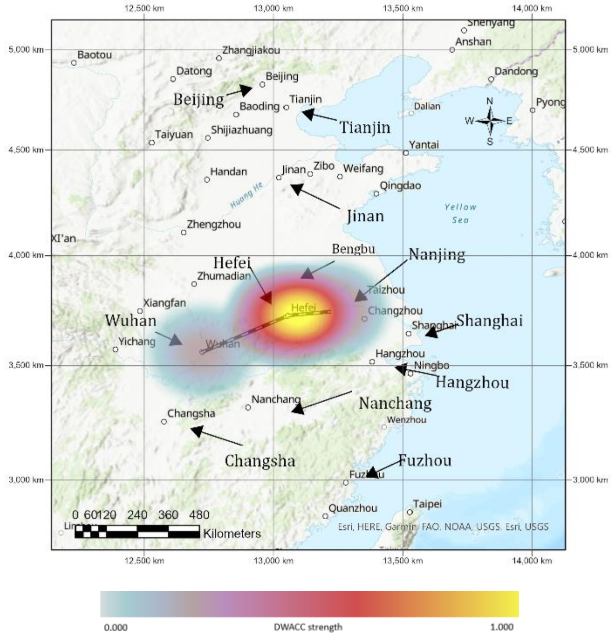


Figure 8 – The DWACC strength and HSR service network from Hefei to the other sample cities in 2009

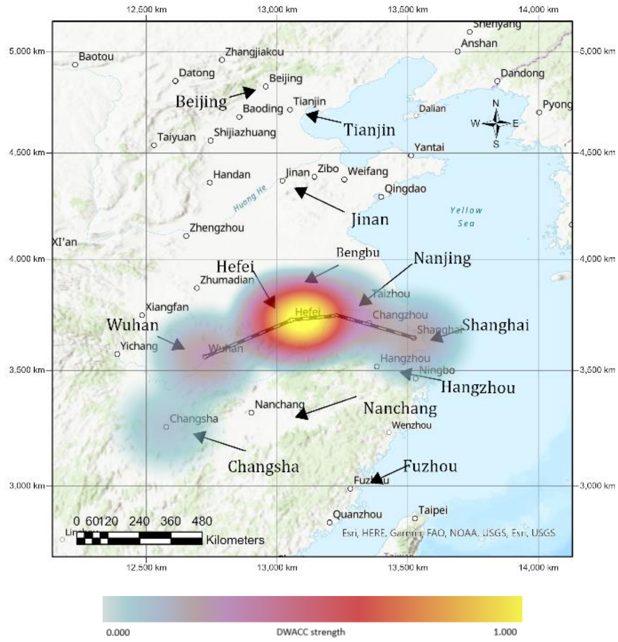


Figure 9 – The DWACC strength and HSR service network from Hefei to the other sample cities in 2010

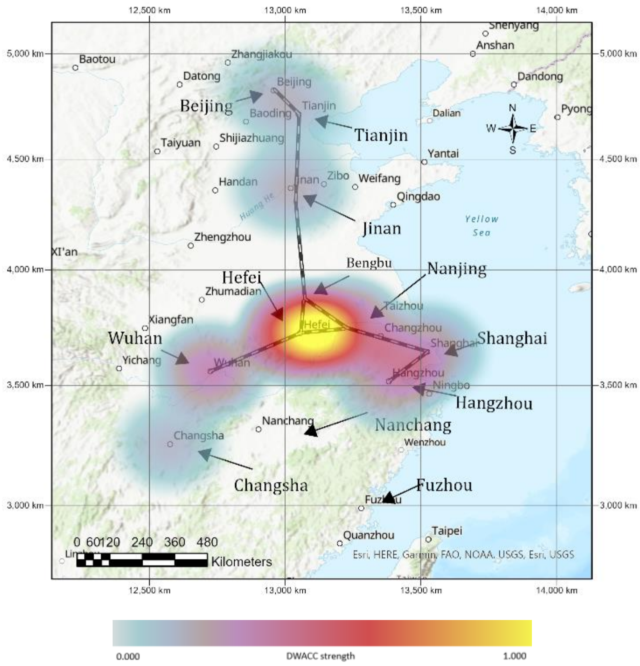


Figure 10 – The DWACC strength and HSR service network from Hefei to the other sample cities in 2012

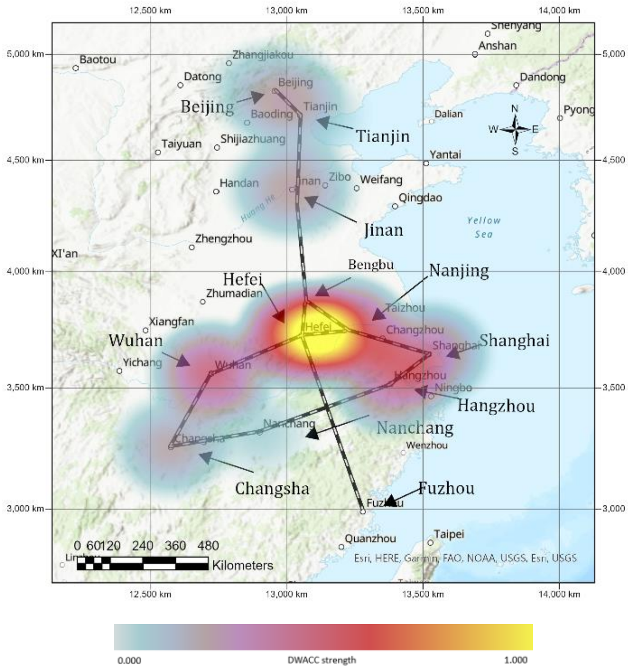


Figure 11 – The DWACC strength and HSR service network from Hefei to the other sample cities in 2015

3.4 Accessibility measurement discussion

The accessibility calculation is a measurement of the attractiveness and fiction level on a certain journey, which is similar to the benefit and cost ratio including travel benefits and all detail costs. In general, people care about the ratio itself. It is easy to understand an investment is profitable if the ratio is over 1. If the value is equal to or lower than 1, the activity is at a loss. In the current transport system, the accessibility value can be assumed as lower than 1 in advance. Because intercity commute travel would be very common for most people if the accessibility value is more than 1. In real life, the high-speed train operational speed and pricing can still be improved. In many countries like Japan and China, the new maglev train is under experiment. It is a possible trend that faster and faster technology can push the accessibility value close to 1. Therefore, the 'dual city life' with a higher commuting frequency of less than one week, is still not worth according to the current accessibility level.

From the vertical time series comparison of each city's data, the most obvious improvement brought by high speed railway service is that the daily intercity return travel was realised. The new high speed service expanded the travel distance in the same time length and more opportunities became achievable. In the case of Hefei, the trip distance between Hefei and Beijing is serviced by an overnight slow speed train with approximately over 1200 kilometres. After 2012, the high-speed railway could even support daily return trips with 8 hours of work, pushing the accessibility value over 0 to 0.068, which is fairly a low value due to the high travel friction but still remarkable progress. At the same time, from the view of the time budget, the current daily return trip is over intensive. The traveller cannot have enough time to have a rest, not to say the result of a fixed 8-hour work schedule. But these data are still useful. Following the increase of traffic modes' speed and economic development, the accessibility of the daily return trip will become much better with higher profit and lower cost. The core cities are all located around the developed area in the east of China. The accessibility between these cities was also dramatically higher than in the case of cities on the edge of the network. Some city governments started to publish the policy for cooperating with the urbanisation process, such as citizen identity mutual recognition, tax system integration and cross-city business process. The integrated accessibility index can guide the governor to make a suitable policy matching the area developing level. By comparing the three levels' data, it can be found that the weekly return commuting has a much better result with an average 0.2 higher than the result of 'daily return' and '8 hours work return'. Travellers spend 5 days in work city and back home during the weekend is a good choice. On the other hand, the high-speed railway service ticket price and intra-city travel costs kept steady in the research period, which are also important factors that can optimise the inter-city transport system utilization. Following rapid economic development, the more expensive cost of faster travel speed will be eliminated and rebalanced by the average income growth, and the accessibility value will be quickly regained, rising to a new level.

3.5 Conclusion

This chapter examined the impact of high-speed rail on accessibility and economic integration using data from eleven cities within the East China high-speed rail network. The analysis of three levels of accessibility—Daily Accessibility (DACC), Daily Work Accessibility (DWACC), and Weekly Accessibility (WACC)—revealed significant improvements in accessibility following the introduction of high-speed rail, particularly in cities such as Hefei, Nanjing, and Shanghai.

For instance, Hefei's DACC increased from 0.097 in 2005 to 0.255 in 2015, highlighting enhanced daily commuting connections with core cities like Nanjing and Shanghai. Similarly, WACC values showed a steady rise over the same period, increasing from 0.277 in 2005 to 0.596 in 2015, reflecting improved weekly commuting feasibility. However, differences in economic integration were noted between larger, more developed cities like Shanghai and smaller ones like Hefei. While Shanghai experienced smaller fluctuations, Hefei's accessibility was more dramatically affected by high-speed rail connectivity, with DACC values peaking in 2011.

The findings also demonstrated how high-speed rail significantly influences regional population distribution. For example, the DACC between Hefei and Nanjing dropped in 2008 after the introduction of high-speed rail but steadily rose to 0.255 by 2015, facilitating increased population movement between the two cities. Similarly, the Shanghai-Hefei line, with a travel speed increase from 50 km/h in 2005 to over 163 km/h in 2010, reduced travel time from 9.4 hours to 2.9 hours, making daily intercity commuting more practical and driving economic integration.

Overall, the analysis demonstrated that high-speed rail has been a key factor in increasing accessibility between cities, with smaller cities benefitting more in terms of population mobility and economic integration compared to larger metropolitan areas. The fluctuations in DACC and WACC over the years underscore the dynamic nature of accessibility as infrastructure develops, particularly in the context of rapidly growing urban economies in East China.

Chapter 4. Empirical Economy-Accessibility validation and analysis

4.1 Introduction

In this chapter, several empirical analyses are conducted to validate the accessibility indicators developed in earlier sections. The analyses aim to evaluate the relationship between high-speed rail (HSR) services and various economic and demographic factors. First, an optimal intercity traffic service speed is analysed in relation to passenger accessibility and profitability under different service speeds. This is followed by an econometric analysis investigating the impact of accessibility on regional population dynamics, exploring how variations in city traffic conditions influence local demographics. Additionally, the chapter discusses the role of HSR in promoting urbanisation and the necessity of ultra-high-speed services for enhancing regional connectivity. Finally, the influence of HSR on the development of primary, secondary, and tertiary industries is assessed, offering insights into which sectors benefit most from improvements in intercity accessibility.

4.2 Optimal Intercity traffic service speed analysis

Following the development of the new railway technology, travel speed is becoming faster and faster. In an experiment in France, the test highspeed rolling stock achieved over 570km/h in 1990. And in China, the highspeed train, CRH380A, was tested with the speed of 486.1 km/h in 2014 and operated with the speed of 350 km/h in daily service.

Although the current highspeed railway system has dramatically expanded the travellers' moving ability, the conventional wheel-rail mode started to meet its maximum performance limitation. The balance between economic benefits and the more expense brought by either speed increase or the maintenance, would not be even and efficient.

The new technology started to shift from wheel-rail interactions to the other. Maglev has been discovered for many decades and its technical feasibility has been proved. However, not many commercial services were built due to the high cost and weak networking capability. In recent years, following the strong economic development in the east of Asia, the new Maglev train experiment pushed the speed up to a new level. The Japanese Maglev, JR-Maglev, reached 603 km/h in the test in 2011. In China, the CRRC 600 Maglev was released with speed of 600 km/h in design. Another form is the Hyperloop in the US, which is one evacuated tube transport system and achieved 172 km/h in a test in 2020. Its future project aims to increase the speed to over 1000 km/h and promote it to more countries.

What could be brought to the passenger and economic development by the faster travel speed is always under discussion along with the progressed technology. In this research, the improved accessibility measurement estimated the passengers' profit level, according to the collected traffic information and economic data. On the other hand, the three levels of the accessibility indicators could also be used to measure and simulate the travel benefit and cost level based on the parameter of the transport system in the period of design, which is called Optimal Speed Analysis (OSA) in this research. The optimal speed analysis established the cost-speed function, to estimate expense growth due to the faster speed transport system, and an Accessibility-speed gradient through the research periods, which support a clear view and forecast of the highspeed railway passengers' travel benefits following the speed increase and overall economic growth.

4.2.1 Service speed and traveller's cost function

According to the accessibility value calculation methods, the intercity travel cost and time are necessary for estimation. At the same time, the actual price and travel time data are unknown for the assumed intercity transport system. The basic relation between them is negative. Following the speed growth, the cost of technical development and customers would increase much higher than the margin of the speed. Therefore, a power function model, time-cost function (TCF), was introduced to simulate the cost and travel time relationship on a certain intercity transport service.

$$y = a * x^{-b}, (x \leq Slow\ service\ time) \quad 4\text{-}1$$

In this function, x is the travel cost, and y is the corresponding travel time. Both of them were collected from the service data of highspeed railways and normal speed railways in history. Through two groups of samples, the parameters a and b could be calculated. Three HSR services are selected for the case study, including the lines between Hefei-Nanjing, Hefei and Shanghai and Shanghai-Nanjing. These three cities are the main hubs of the East China Highspeed railway network and are connected by the highspeed line from Hefei to Nanjing and a part of the tracks from Shanghai to Beijing, with a length of 480 km.

Table 23 – Time and cost function

Service	Slow speed train time(h)	Slow speed train cost(¥)	High speed train time(h)	High speed train cost(¥)	a	b	Speed-cost function
Hefei-Nanjing	1.76	41.50	0.97	67.00	65.38	0.80	$y = 65.38 * x^{-0.8}$
Hefei-Shanghai	9.45	71.25	2.93	210.00	566.45	0.92	$y = 556.45 * x^{-0.92}$
Nanjing-Shanghai	3.12	59.50	1.84	135.00	350.95	1.56	$y = 350.95 * x^{-1.56}$

The TCF function parameters are shown in Table 23. The curve of the estimated inverse function will go through the two sample points and extend to the left side with a shorter travel time. The lowest point of the function was set to be the slow service time because it is unlikely and unnecessary to open a new service which is slower than the current slowest service. On the other hand, the fastest journey was assumed to travel by a 600km/h highspeed system, which is close to the new Maglev speed level.

- The TCF curve is discontinued in real life because the different service times and costs are the few time and cost combinations. The traffic service is also not possible to adjust their operating strategy flexibly in a short period. Therefore, in this case study, establishing a smooth curve by assuming a differentiable service gradient would help to find possible better points for analysis.
- On the other hand, a TCF, which integrated all lines' data, could be regressed as a single model to reflect the relationship between journey time and passengers' cost change. However, each line has its ticket pricing process according to the different maintenance costs and local economic development levels. Mixing the different services may cause higher errors. It would be worse when using the over-

mixed TCF on a single line's accessibility analysis. Therefore, the TCF would be estimated and applied in the corresponding accessibility case.

- To indicate the travel speed and time clearly, the line length data was collected and used to calculate the curve that illustrates the gradient of time and speed.

Table 24 – Railway track length and speed data

Service	Route length (km)	NSR Average speed (km/h)	HSR Average speed (km/h)
Hefei-Nanjing	156	88.64	160.82
Hefei-Shanghai	473	50.05	161.43
Nanjing-Shanghai	307	98.50	166.48

The TCF figures for three cases are shown below. In the first figure of the railway service from Hefei to Nanjing, Figure 12, the blue line is the TCF curve and the red one is the service speed curve. Both of them started from the shortest travel time on the left side with about 600 km/h service speed to the current normal speed service. In normal speed service, the passenger needs took 1.76 hours from Hefei to Nanjing with a ticket price of 41.5 Yuan. The high-speed railway service decreased travel time to 0.97 hours with an average speed of 160.82 km/h and increased the cost to 67 Yuan. The predicted fastest service with an average speed of 624 km/h would raise the cost to 198 Yuan and lower the journey time to 0.25 hours.

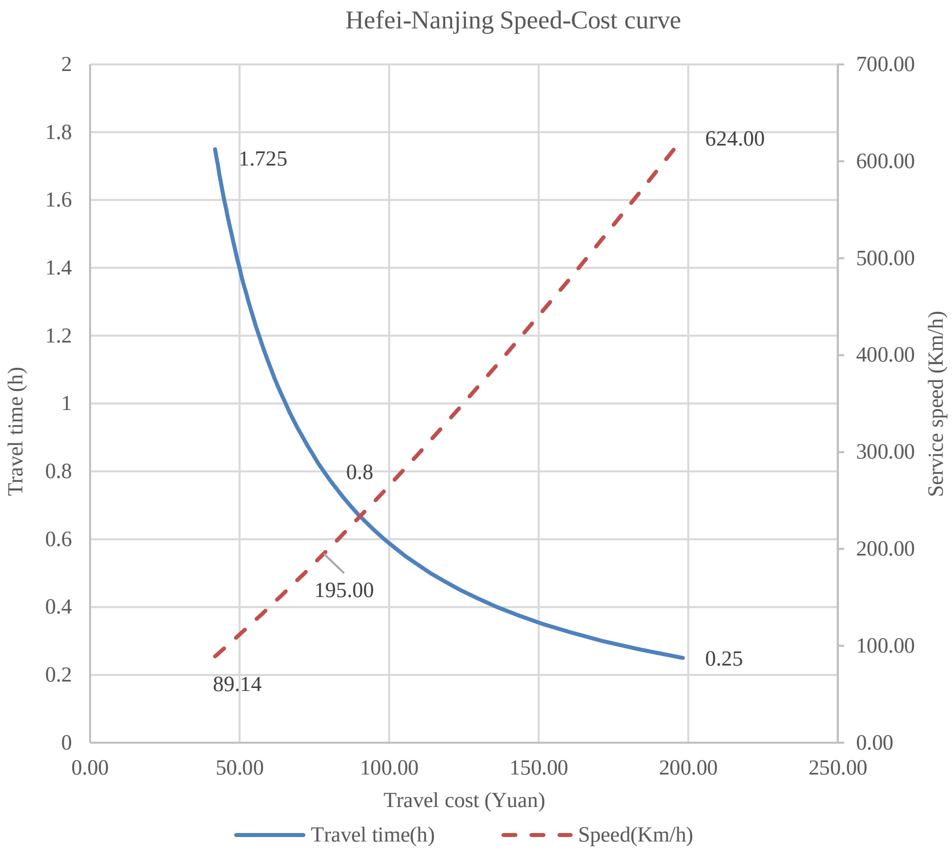


Figure 12 – Hefei-Nanjing Railway travel time and ticket cost curve

The second figure, Figure 13, is the railway service from Hefei to Shanghai. The blue curve is the TCF curve and the red one is the corresponding train speed curve. In normal speed service, the passenger needs to take 9.45 hours from Hefei to Nanjing with the ticket price of 71.25 Yuan. The high-speed railway service reduced the travel time to 2.93 hours with an average speed of 161.43 km/h but increased the cost to 210 Yuan. The predicted fastest service with an average speed of 675.71 km/h would raise the cost to 786.45 Yuan and lower the journey time to 0.7 hours.

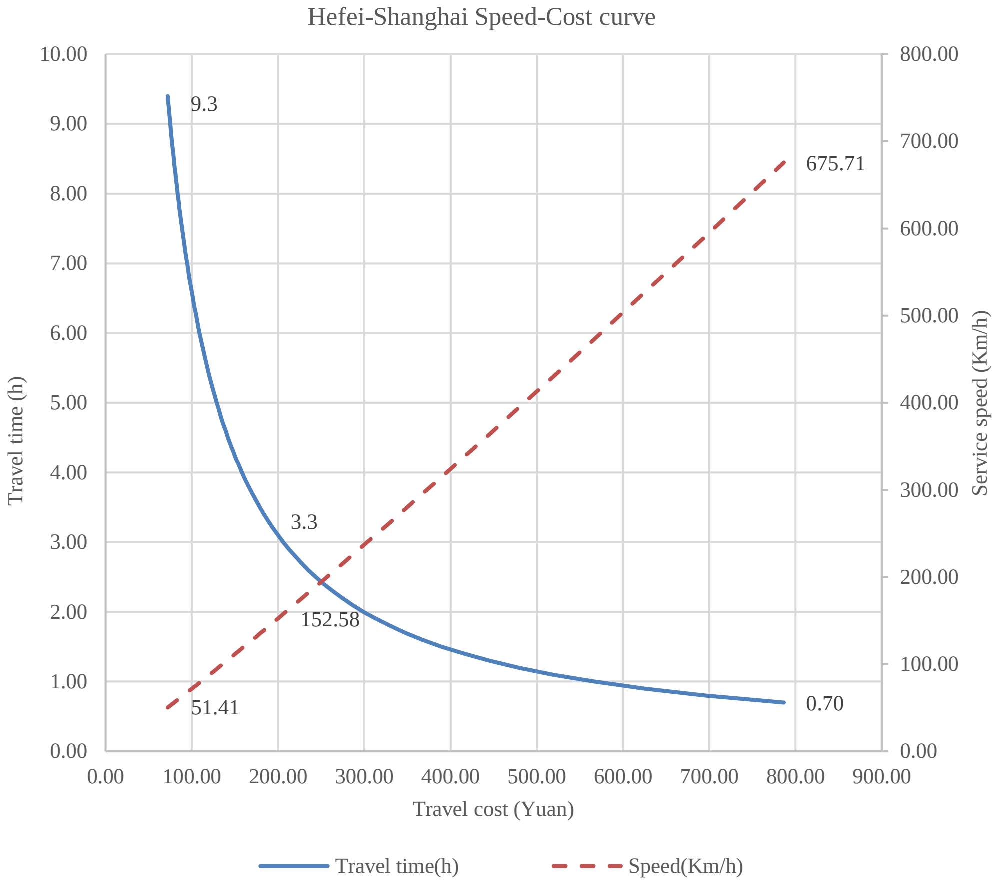


Figure 13 – Hefei-Shanghai Railway travel time and ticket cost curve

Figure 14 shows the railway service from Nanjing to Shanghai. In normal speed service, the passenger need took 3.12 hours from Nanjing to Shanghai with a ticket price of 59.5 Yuan. The high-speed railway service decreased travel time to 1.84 hours with an average speed of 166.48 km/h and increased the cost to 135 Yuan. The forecast of the fastest service with an average speed of 614 Km/h would raise the cost to 1034 Yuan and lower the journey time to 0.5 hours.

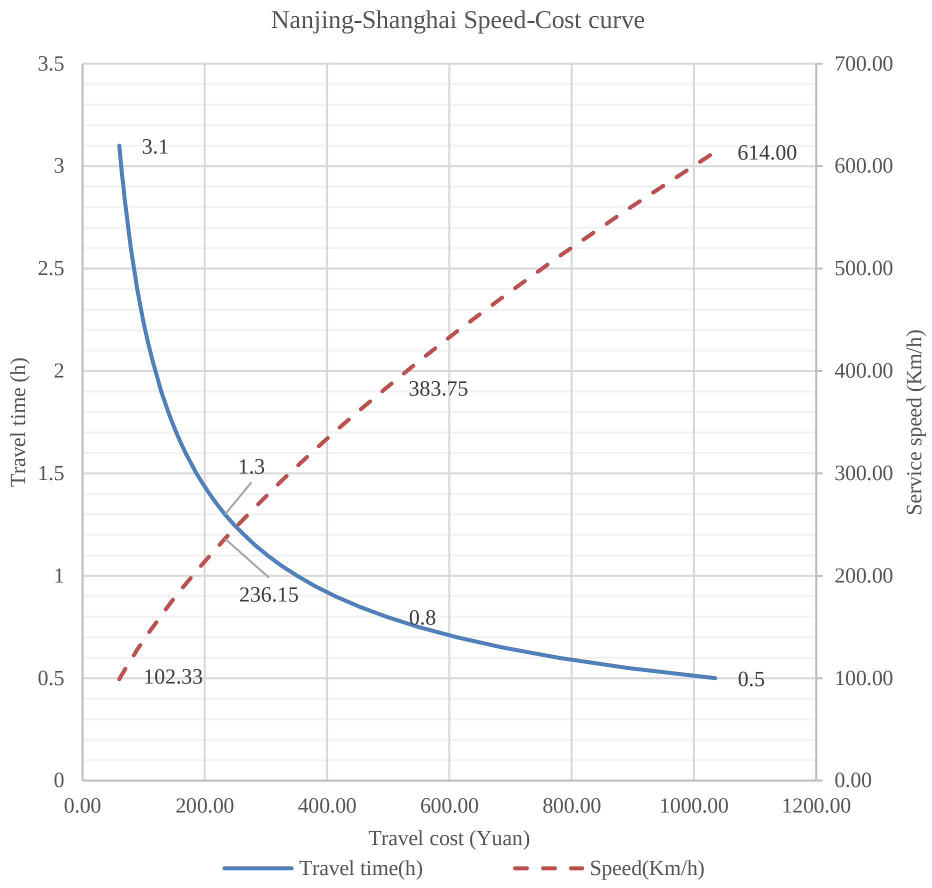


Figure 14 – Nanjing-Shanghai Railway travel time and ticket cost curve

4.2.2 Accessibility value gradient and inter-city travel speed analysis

After generating the TCF and speed curve, the accessibility analysis under different speed levels could be applied to each case. The TCF-Accessibility analysis calculates the DACC value based on the forecast of the speed and cost gradient. Traveller is still assumed to live the intercity life and commute through the intercity system. The sample points which are the different service cost and time combinations, would be introduced into the accessibility measurement model throughout the 11 years' research period. The accessibility curve based on the predicted service options could bring an overview of how the change for the service will affect the local travellers' benefit and cost level and if the faster speed intercity service could be feasible following the economic development year by year.

The TCF-DACC calculation is listed below:

The DACC of TCF-Accessibility analysis: Passengers' accessibility level of travelling to the destination and back in one day through the predicted intercity commute options.

Travel time with return: $2 \times \left(T_{ai} + T_{ij}^{TCF} + T_{aj}\right)$; 4-2

Travel monetary cost: $2 \times C_{ij} = 2 \times \left(C_{ai} + C_{ij}^{TCF} + C_{aj}\right)$; 4-3

Living cost: $C_{li} = R_i + C_{fi}$; 4-4

Monetary time cost: $Vot = f\left(T_{ij}^{TCF}\right) = \left|\frac{C_{ij}^{TCF} - C_{normal\,speed\,railway}}{T_{ij}^{TCF} - T_{normal\,speed\,railway}}\right| \times T_{ij}^{TCF}$; 4-5

Total cost: $TC_{ij}^{TCF} = 2 \times f\left(T_{ij}^{TCF}\right) + 2 \times C_{ij} + C_{li}$; 4-6

DACC: $DACC = \frac{OPP_j}{f\left(T_{ij}^{TCF}\right) + C_{ij} + C_{li}} \left(T_{ij}^{TCF} \leq 24h\right)$ *or* $DACC = 0 \ (T_{ij}^{TCF} > 24)$. 4-7

Compared to the original procedure, the TCF-DACC calculation replaced the travel price cost and time cost term with the estimated data, T_{ij}^{TCF} and C_{ij}^{TCF}. The access journey, between the station and home or destination, was unchanged with the same condition, and the living cost was also kept the same. In the Monetary time cost evaluation, the faster intercity traffic service is the simulated combination of the time and cost on the curve of the TCF. The relatively slower service is set to be the current normal speed railway service for calculating the passengers' value of the time. The time budget is 24 hours without a working time requirement according to the definition of DACC.

The six figures below indicated the DACC variation based on the TCF predicted service in the 11-year research period.

4.2.2.1 Hefei-Nanjing TCF-DACC

The first group of the figures is the TCF-DACC value of the intercity railway service from Hefei to Nanjing. The data is shown in Table 32 in the Appendix. The test traveller lived in Hefei with a local cost level of food and accommodation and received travel benefits in the city of Nanjing. The Speed curve indicated the service speed predicted by the TCF, from normal speed railway service to over 600 km/h high speed railway service. All accessibility values at any speed level are lower than value 1, which means the intercity lifestyle is still not profitable for most people. By observing the overall trend, the accessibility value is increased following the decrease of the service speed in eleven years. The slower traffic service is more economical to the travellers, and the faster service is still too expensive. The accessibility value curve is moving up year by year due to the stable ticket cost and economic growth.

In 2005, passengers, who took the normal speed railway with an average speed of 89.14 km/h and 1.75 hours journey time, could achieve 0.172 DACC level for the daily return trip between Hefei and Nanjing. According to the TCF curve, if the current high speed railway data was applied in 2005, passengers need to spend 0.97 hours on the trip with an average speed of 160 km/h and DACC level of 0.123. The fastest TCF service with an average speed of 624 km/h and 0.25 hours journey time, could lower the DACC value to 0.048. To the traveller, the ultrafast service reduced by 85% journey time but dropped profitability by 72%. The profit loss and travel time reduction ratio is 0.847, which is an inefficient improvement, although the profitability is already at a very low level.

In 2008 when the current high-speed railway service was opened, passengers who took the same normal speed railway service with 1.75 hours of travel time, could reach DACC with 0.235. The traveller, who used high speed railway service with an average speed of

160 km/h and 0.97 hours' travel time, had a DACC level of 0.168. The predicted ultrafast intercity service with 624 km/h and 0.25 hours would decrease the DACC to 0.065. The high-speed railway service was reduced by 44.6% travel time and decreased the DACC level by 28.5%. The ratio between DACC reduction and travel time saving is 0.639. Compared to the high-speed railway service, the ultrafast service could shorten the travel time by 74% and cut the profitability by 61%. The DACC reduction and time-saving ratio is 0.823. The speed improvement to over 600 km/h for travellers is still too expensive and damages the traveller's benefit excessively. However, the speed increase from the normal speed level to the current highspeed service is suitable for most people with less reduction of the profit and considerable speed level.

In the final year of 2015, the accessibility curve moved to the top. The traveller's DACC value at any speed level was increased. The normal speed railway service reached the value of 0.372. The highspeed and ultra-highspeed railways achieved 0.269 and 0.107 respectively

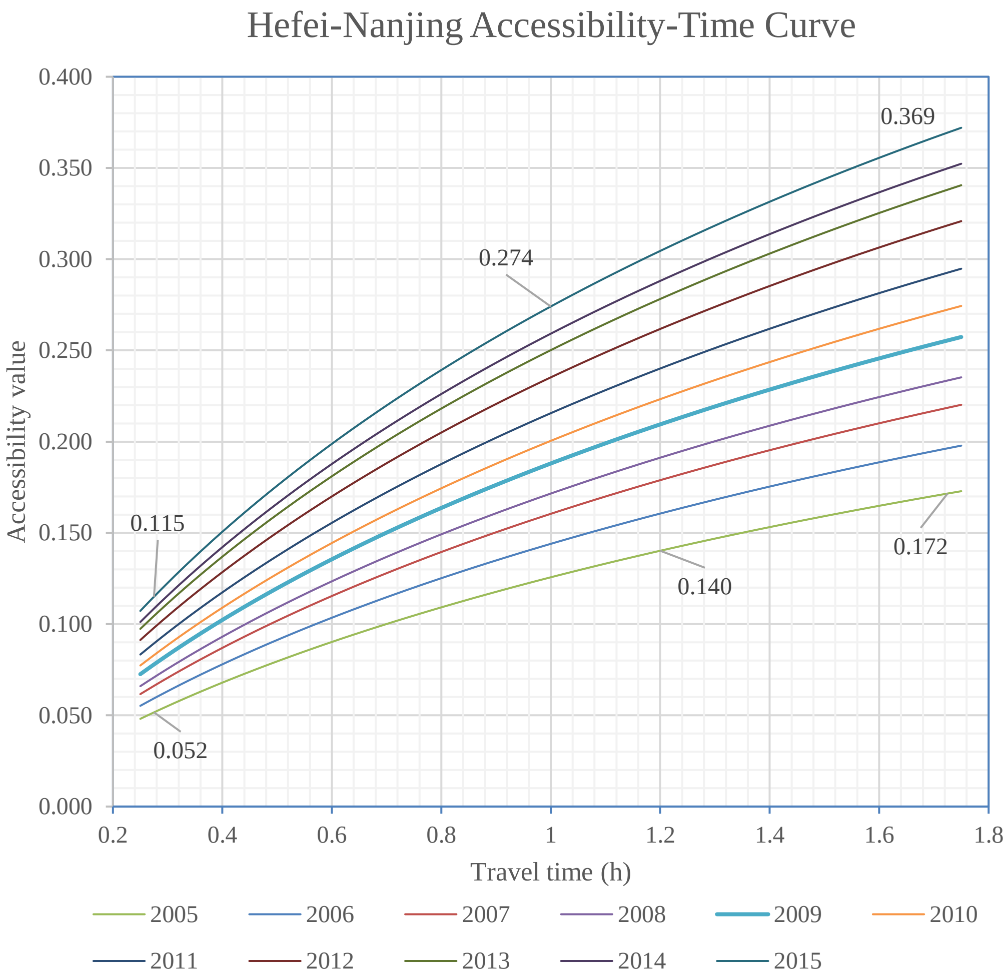


Figure 15 – Hefei-Nanjing Railway Accessibility and Time Analysis

On the other hand, the same accessibility value could be satisfied by higher travel speed with higher costs during economic development. In 2008, the DACC level of high speed service could support faster travel speed in the following years. Passengers could travel at higher speeds by affording more expense but achieving the same profit level. In 2008. The high-speed railway DACC base level is 0.168 with 0.975 hours of travel time and 160 km/h average speed. In 2009, the journey with the same DACC level of around 0.163 had a time of 0.8 hours and a speed of 195 km/h. In 2010, the travel speed could be increased to 215.17 km/h and the time could be lower to 0.725 Hours. In the last year

2015, the service speed increased to 328.42 km/h and the journey time was reduced to 0.47 hours, which means that nearly half of the time was saved compared to the current high speed railway service but the maintained same passenger earing ability. Throughout the 11-year research period, the speed growth volume each year remained relatively stable at around 20 to 30 km/h per year. The speed change under the same DACC level is shown in Figure 16.

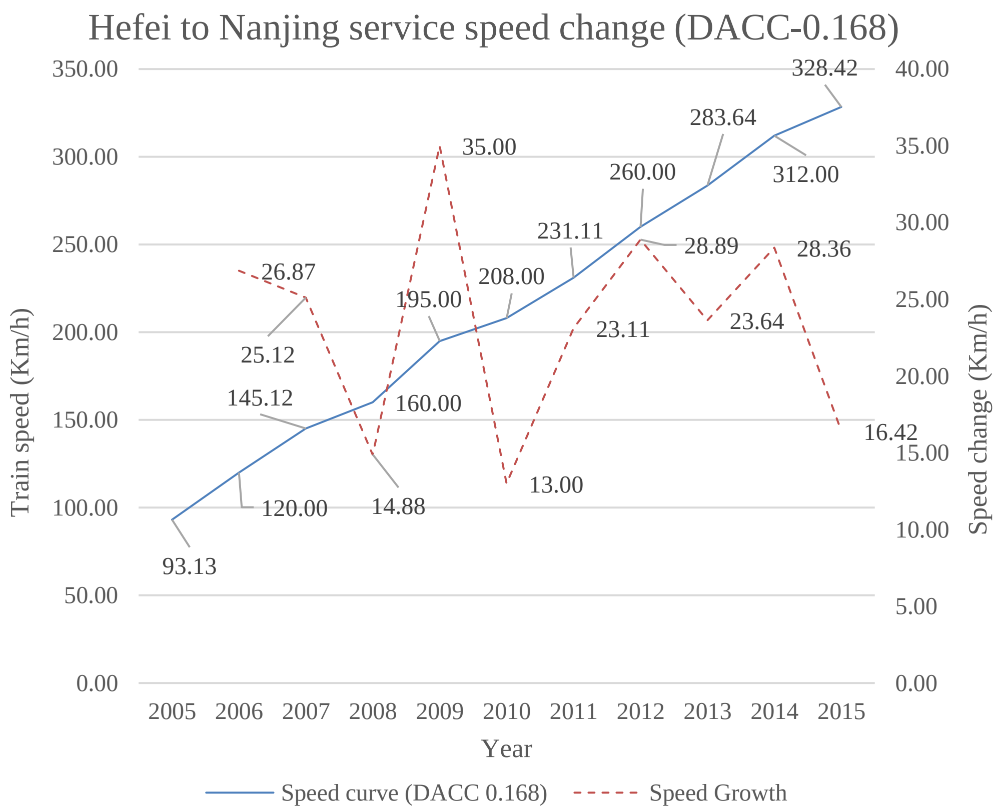


Figure 16 – Hefei-Nanjing Railway speed curve DACC-0.168

4.2.2.2 Nanjing-Hefei TCF-DACC

The second group of figures is the TCF-DACC value of the intercity railway service from Nanjing to Hefei, which is shown in Table 33 in the Appendix.

In this case, the test traveller lived in Nanjing with a local cost level of food and accommodation and received the travel benefit in the city of Hefei. The TCF-DACC curve illustrated the predicted service speed and relative accessibility value from normal speed railway service to ultra high speed railway within 11 years period. The intercity life in the direction from Nanjing to Hefei is still not profitable for most people, because all accessibility value with any service option is much lower than 1. Due to the TCF function being the same on both service directions between two points, the DACC value difference is mainly caused by the different living and income conditions between them. The DACC value is also increased following the decrease of the service speed. And the value curve is raised year by year due to the stable ticket cost and economic growth.

In 2005, passengers, who took the normal speed railway with an average speed of 89.14 km/h and 1.75 hours journey time, could achieve 0.111 DACC level for the daily return trip between Nanjing and Hefei. According to the TCF curve, the assumed high-speed railway passengers need to spend 0.97 hours on the trip with an average speed of 160 km/h and a DACC level of 0.079. The fastest TCF service with an average speed of 624 km/h and 0.25 hours journey time, lower the DACC value to 0.031. To the Nanjing-Hefei commuters, the ultrafast service reduced 85% journey time by decreasing 72% of profitability, which is also as inefficient as the direction from Hefei to Nanjing.

In the year of 2008 with the Hefei-Nanjing high speed railway service opened, the commuter who took the high speed railway had a DACC level of 0.112.and the normal speed railway service user's level was increased to 0.155. The TCF predicted ultrafast intercity railway service would decrease the DACC to 0.044. The high speed railway service reduced 44.6% travel time and decreased the DACC level by 27.8%. The ratio between DACC reduction and travel time saving is 0.623. By comparing the ultrafast railway service and high-speed railway service, the ultrafast service could shorten the travel time by 74% but cut the DACC level by 60.7%. The DACC reduction and time-saving ratio is 0.82. The ultrafast speed improvement is still expensive with an excessive cost on the traveller's benefit. However, the speed increase from the normal speed level to the current high-speed service is suitable for most people with less reduction of the profit and considerable speed level. Compared to the result in 2005, the DACC value of normal speed, current high-speed and ultrahigh speed service was increased by 39.6%,.41.7% and 41.9%, which indicated that the passenger profit level under the three different service speeds had experienced similar growth through economy development, due to unchanged travel cost and increased personal income data. At the same time, the intercity living strategy of the commute direction from Nanjing to Hefei showed higher growth in travellers' profitability, by comparing the result of the Hefei to Nanjing service. In 2015, the DACC curve reached the top level with the highest value on any speed level. The value of the normal speed railway service is 0.266. And high speed and ultrahigh speed railway services reached the DACC level of 0.193 and 0.076.

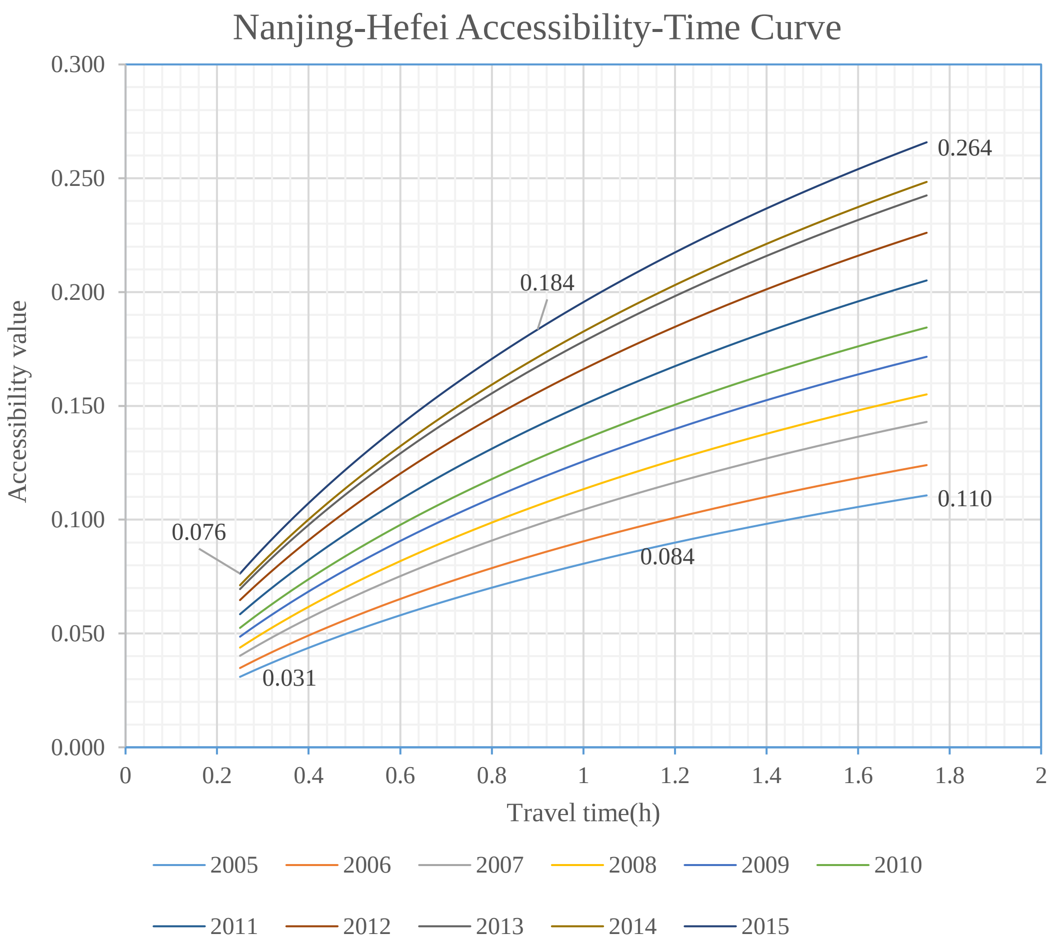


Figure 17 – Nanjing-Hefei Railway Accessibility and Time analysis

For comparing the affordable speed increase under the same DACC, the value of high-speed service with 0.97 hours journey in 2008 is set as the reference point, which is 0.112. In 2005, the DACC-0.112 matched the service of a normal speed railway. Passengers who commuted through the normal speed railway service would have the same profit level as the passenger who travelled by high speed railway in 2008. The economic development in the three years supports people to travel at a faster speed and maintain revenue. In the year after 2008, the service speed of DACC-0.112 kept increasing year by year. In 2010, the corresponding average service speed reached 200 km/h. In 2013, the TCF service speed broke 300 km/h and the journey time could be reduced to half an hour. In 2015, the

DACC-0.112 could be satisfied by the cost of the service speed of 367.06 km/h, which reduced the travel time to 0.425 hours. The service speed under the same passenger accessibility level increased steadily throughout the 11 years' time, with fluctuations around 20 km/h to 40 km/h.

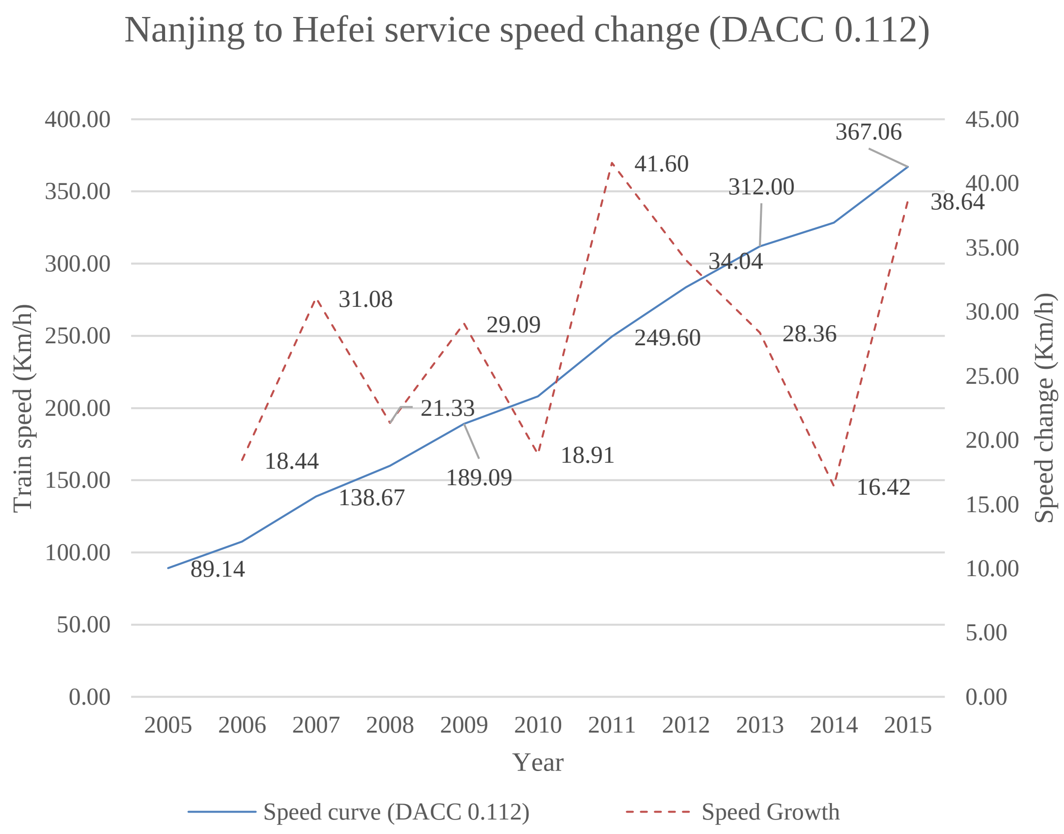


Figure 18 – Nanjing-Hefei Railway speed curve: DACC-0.112

4.2.2.3 Hefei-Shanghai TCF-DACC

The third group of the figures shown in Figure 19 and Table 34 in the Appendix are the TCF-DACC value of the intercity railway service from Hefei to Shanghai.

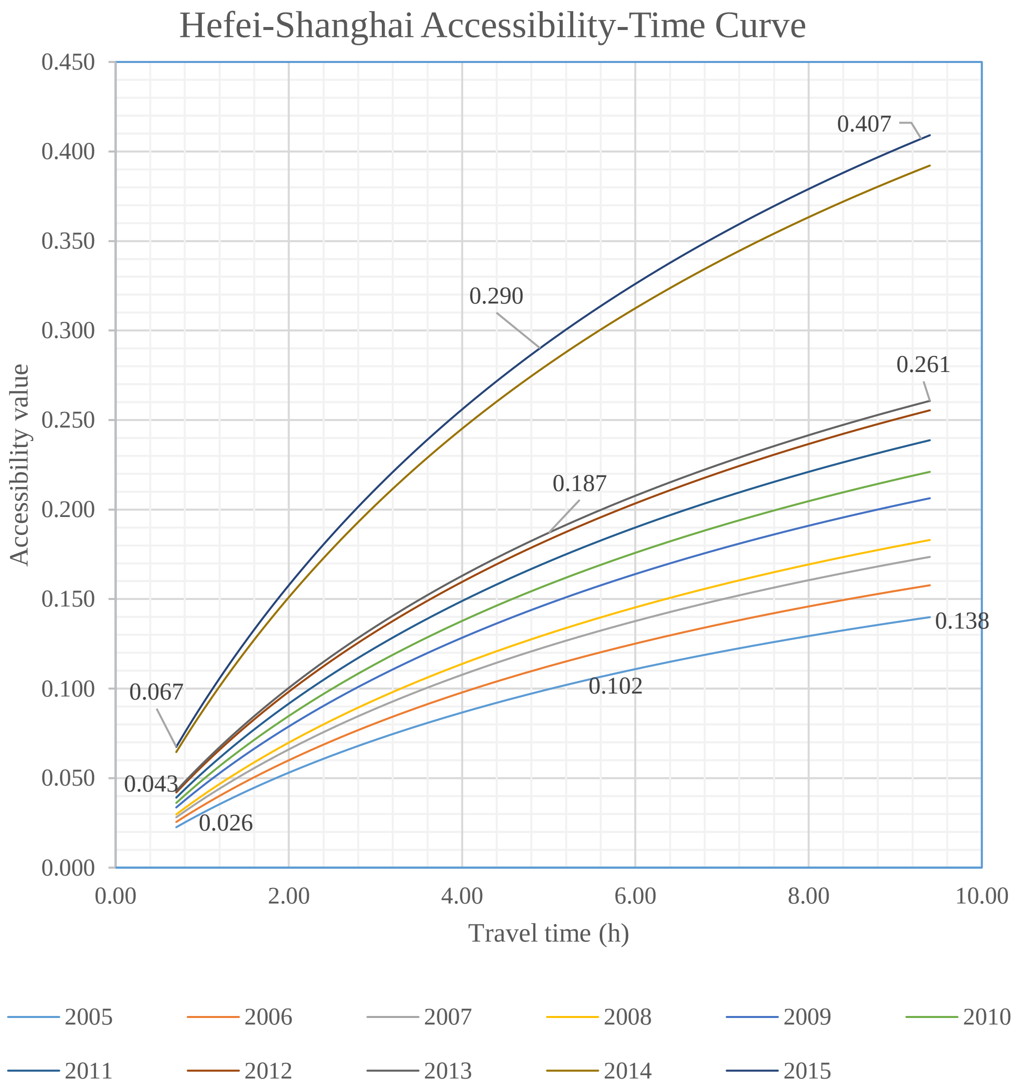


Figure 19 –Hefei-Shanghai Railway Accessibility and Time analysis

The intercity commuter lives in Hefei with a local level of living cost and working in Shanghai to receive the travel benefits. The speed-cost curve indicates the service speed and cost gradient from normal speed railway to ultrahigh speed railway which is simulated by TCF. Due to the inability to fix data errors caused by statistic standard modification after 2014 in Shanghai, the TCF and speed curve showed an unusual increase at the top of the figure. The accessibility value increased sharply but the trend still illustrated that the profit level kept growing following the economic development.

On the other hand, the normal speed railway service from Hefei to Shanghai used a longer route for connecting more cities, rather than just having a slower speed. Because the normal speed railway service journey time was collected from the history timetable, the longer track length may cause the calculation result of the average travel speed far less than the other normal speed service. For integrating the route length information of different services, the current high speed line length was assumed to be the same at any speed level.

By observing the DACC datasheet, all the Hefei-Shanghai accessibility values are still lower than 1 under any TCF service configurations. Through all DACC data, the accessibility level has also increased following the decrease in the service speed in eleven years. The slower traffic service is more economical to the travellers, and the faster service is still too expensive. And the entire commute profit level is slightly lower, compared to the case of Hefei to Nanjing. The highest DACC value is 0.409, which is the level of the slow speed railway commute in 2015.

In 2005, passengers, who took the normal speed railway with an average speed of 50.32 km/h and 9.40 hours journey time, could achieve 0.140 DACC level for the daily return trip between Hefei and Nanjing. According to the TCF curve, if the current high-speed railway data was applied in 2005, passengers need to spend 2.9 hours on the trip with an average speed of 163 km/h and a DACC level of 0.07. The fastest TCF service with an average speed of 675 Km/h and 0.7 hours of journey time, could lower the DACC value to 0.023. To the traveller, the ultrafast service reduced 75% journey time but dropped profitability by 67%. The profit loss and travel time reduction elastic is 0.893, which is an efficient improvement but meaningless. The profit level is already at an extremely low level.

In 2010, due to the new high-speed railway service from Hefei to Shanghai was also opened, the passenger who travelled through the normal speed railway would have a DACC of 0.221 and passengers who took high speed train could reach 0.111 with 2.9 hours of travel time and 163 km/h average speeds. The TCF predicted ultrahigh speed railway service with 675.71 km/h speed, 0.7 hours travel time and 0.036 DACC value. The high-speed service reduced the travel time by 0.69% about 6.5 hours and lowered the DACC value by 49.7%. In the year 2013 under the same statistical criteria, the traveller of normal speed railway service, normal high speed railway service and TCF ultra high speed service could achieve the DACC level of 0.261, 0.131 and 0.043 respectively. Compared to the year 2010, three profit values were increased by 18%, 18% and 19.4%, due to the income growth and steady ticket price. But for the daily commuters, the trip from Hefei to Shanghai was still too expensive in 2013.

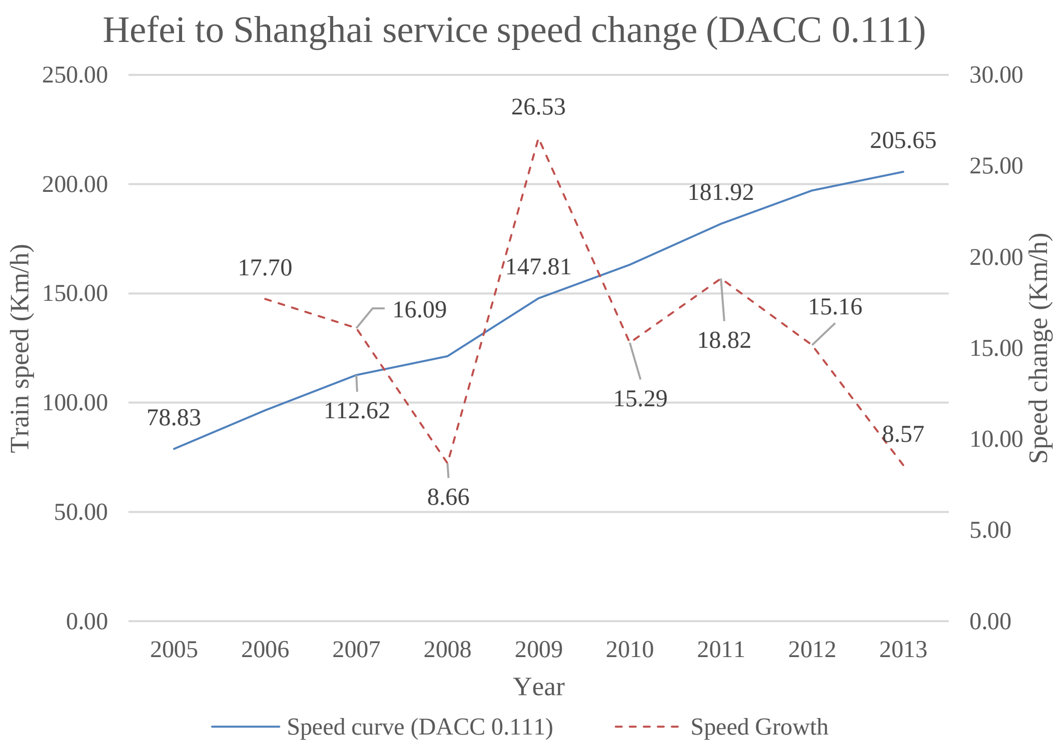


Figure 20 – Hefei-Shanghai Railway speed curve: DACC 0.111

The affordable service speed change with the same DACC level is also discussed in the service between Hefei and Shanghai. The reference DACC value is set to be 0.111 which is the level of the intercity commute trip through a normal high speed railway in the opening year of 2010. In 2005, DACC-0.111 supported a speed of 78.83 Km/h for intercity travellers with the same performance as the normal high speed railway service user in 2010 with a speed of 163.10 km/h. In 2008, the DACC-0.111 speed reached 112.62 Km/h with 4.2 hours of travel time. In 2013, DACC-0.111 speed achieved 205 km/h and shortened trip duration to 2.3 hours but with the same benefit and cost level. The speed in 2013 was about 2.6 times faster than it was in the year of 2005. Although the data contained errors in the final two years, It can be seen that the speed of DACC-0.111 kept its growing trend following the economic development.

4.2.2.4 Shanghai-Hefei TCF-DACC

The fourth group indicated the TCF-DACC analysis result of the intercity traffic service from Shanghai to Hefei, which is the reverse direction of the third group. The DACC value table is listed in Table 35 in the Appendix.

In this case, the test traveller lives in Shanghai and works in Hefei. Shanghai is the economic centre city of the East China area, but Hefei is a developing city with a smaller size. Due to the high economic difference between the development of these two cities, intercity living hardly happened. In the calculation result, all DACC data, throughout the research period and various speed and cost service configurations, is far smaller than the data of the service direction from Hefei to Shanghai, and remarkably close to 0. It illustrated the poor profitability of the intercity living strategy on this trip. In the year 2015 which has the highest DACC value in most cases, the TCF-DACC value of the inter-city travel from Shanghai to Hefei is 0.188. It is a very low level which would not be considered by real travellers. The TCF-DACC analysis discussed how economic growth and different levels of service speed affect profitability.

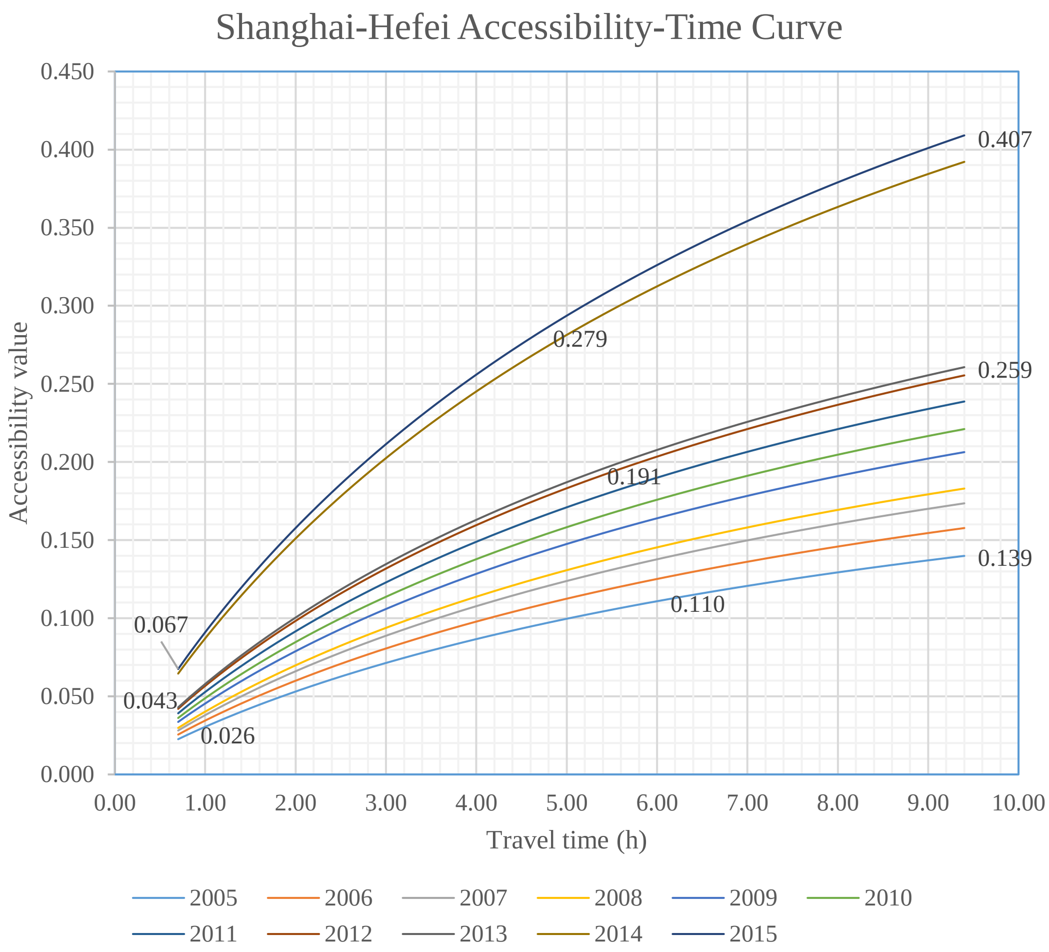


Figure 21 – Shanghai-Hefei Railway Accessibility and Time analysis

In 2005, the only normal railway service from Shanghai to Hefei needed to take 9.40 hours. Because of the longer distance, the average speed only reached 50.3 km/h. The corresponding DACC value only has 0.08. In 2010, the normal high speed railway service was opened, and it shortened the travel time to 2.9 hours with an average speed of 163 km/h. Passengers who travel through the normal high speed railway for intercity living strategy would have a DACC level of 0.07. In the same year, the normal speed railway user has a DACC level of 0.134 with a 67.6% improvement. But both options only achieved half of the profit level on the direction from Hefei to Shanghai at the same time. The ultra-high speed service estimated by TCF achieved a DACC value of 0.02, with a speed of 675 km/h and 0.7 hours of travel time. In 2013, the final year with the same statistical criteria, the normal speed railway traveller had a DACC level of 0.177. The high-speed railway user has 0.09 and the ultra high speed user has 0.03. Compared to 2010, the DACC of normal speed service, normal high speed high service and ultra high speed service was increased by 32%, 28.6% and 7%.

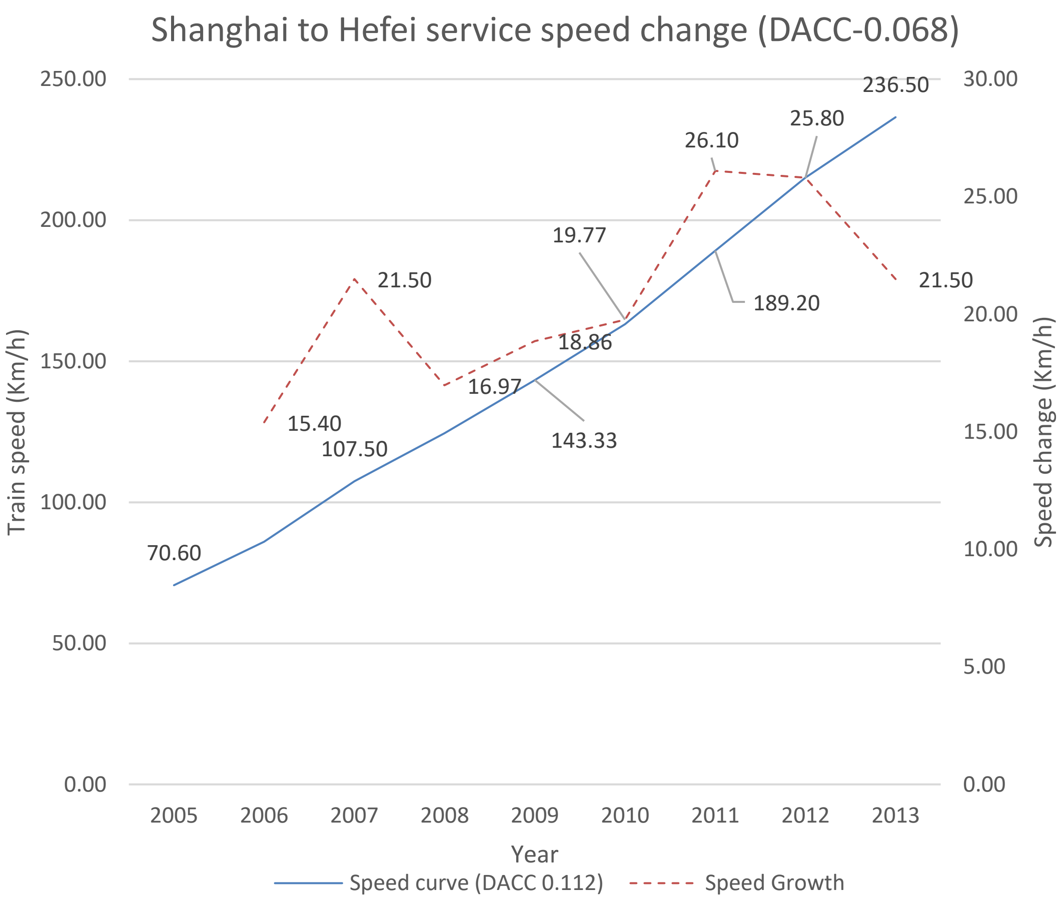


Figure 22 – Shanghai-Hefei Railway speed curve: DACC-0.068

In the analysis of the service speed change under the same travellers' profitability, the DACC level of the normal high speed railway traveller in 2010, which is 0.068, is set as the reference point. In 2005, DACC-0.068 supported the travel speed of 70.6 km/h with 6.7 hours of travel time. In 2007, the speed of DACC-0.068 increased to 107.50 km/h and decreased the travel time to 4.40 hours. In 2012, 0.068 level could support a travel speed of over 215 km/h and the travel time was also reduced to 2.2 hours. Following the development of the local economy, the affordable service speed was increased 3 times in ten years, although the intercity strategy is extremely unprofitable from Shanghai to Hefei. By comparing two directions of data, the service speed under the reference point from Hefei to Shanghai shows a faster growth rate than the direction from Shanghai to Hefei after 2010. It indicated that the smaller city experienced a fast development time and improved the travel benefit, increasing the service speed under the same traveller profit level.

4.2.2.5 Nanjing-Shanghai TCF-DACC

The fifth group is the intercity railway service connecting Nanjing and Shanghai. The data sheet is listed in Table 36 in the Appendix. Compared to the case between Shanghai and Hefei, Nanjing is more developed than Hefei but smaller than Shanghai. The high speed railway between these two cities was constructed in 2010. It is also the east section of the service from Hefei to Shanghai. The test traveller would live in Nanjing with local living costs and take a commute trip to Shanghai for working income. By observing the figure, the overall DACC level is still very low. The intercity strategy is not ideal at that moment. Due to the data statistical error of Shanghai in 2014 and 2015, the TCF-DACC curve showed the highest growth speed in the final two years, located at the top of the figure. The trend is still clear that intercity commuters achieved higher DACC levels following the economy growth year by year.

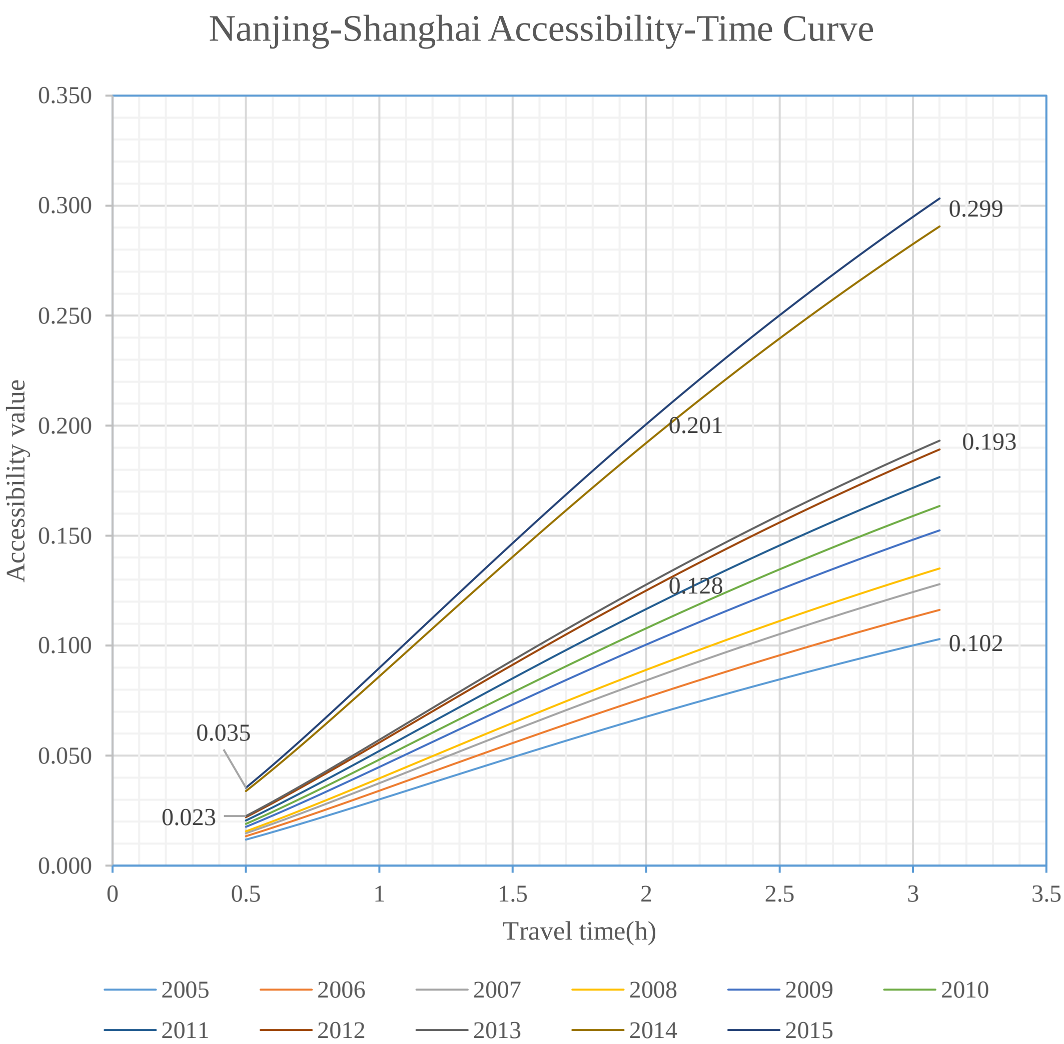


Figure 23 – Nanjing-Shanghai Railway Accessibility and Time analysis

However, the overall daily accessibility level is very low. In 2005, the only normal speed railway service from Nanjing to Shanghai took 3 hours with an average speed of 99.03 km/h. Intercity commuters could have a DACC level of 0.102. In 2010 with the opening of normal high speed railway service, the DACC level of Nanjing-Shanghai intercity commuter could reach 0.099. In the same year, the normal speed railway user has a value of 0.163 with an average speed of 165.9 km/h. Compared to normal speed railway, the high speed railway speed was increased by 67.5%, with a 64% decrease in the intercity living profitability. According to the TCF result, the ultrahigh speed railway with a 614 km/h average travel speed could achieve a DACC value of 0.019 in 2010. By comparing the result of the ultrahigh speed service to the real common high-speed service, the average travel speed would be increased by 2.6 times and could shorten the travel time by 71.3%. The intercity commuter's profitability dropped further to 0.018. It is only 18% of the level of highspeed railway service users and 11% of normal speed railway users. In 2013, the DACC index of the user commuting through normal speed, high-speed and TCF ultrahigh speed service reached 0.193, 0.117 and 0.022. Compared to the year 2010, commutes' DACC of different speed levels increased by 18.4%, 18.2% and 22.2%, which indicated better intercity commute profit ability following development.

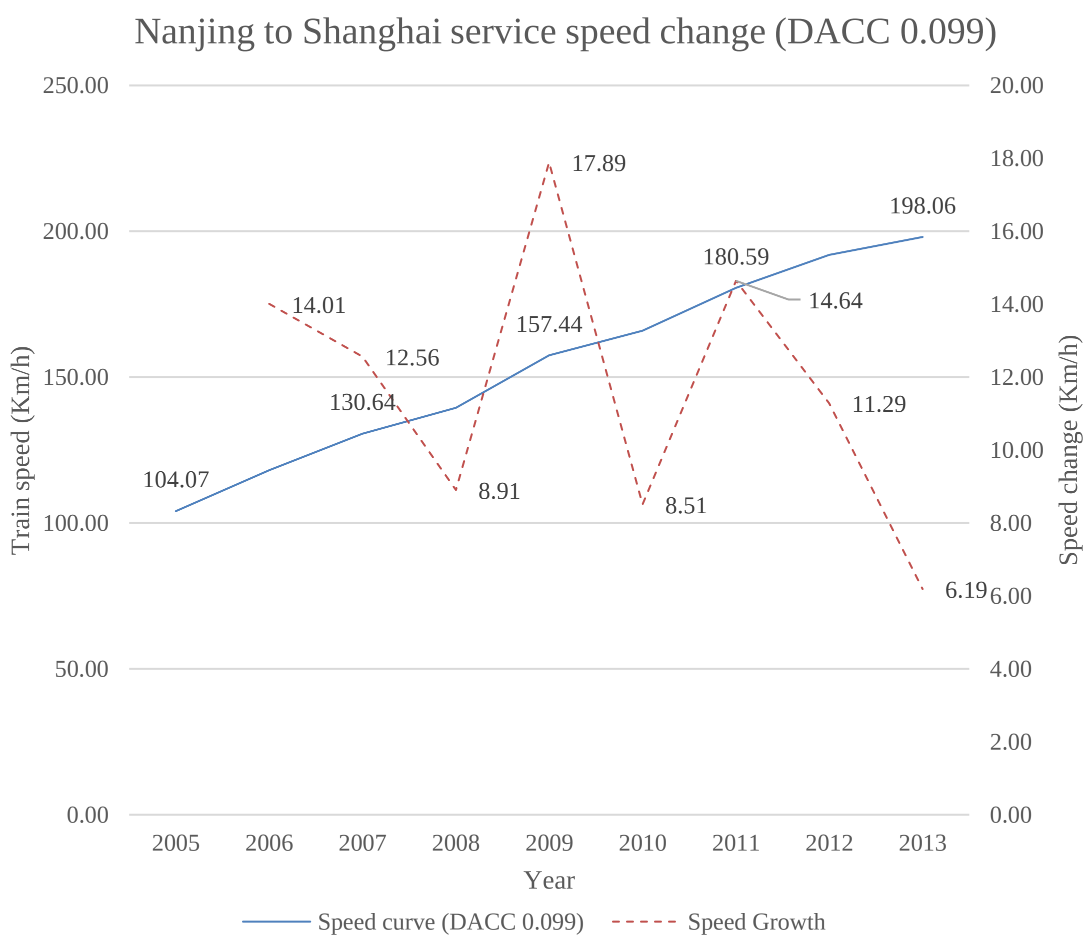


Figure 24 – Nanjing-Shanghai Railway speed curve: DACC-0.099

In the analysis of the service speed change under the same travellers' profitability, the DACC level of the normal high speed railway traveller from Nanjing to Shanghai in 2010 is set as the reference point, which is 0.099. In 2005, DACC-0.099 supported the travel speed of 104.7 km/h with 2.95 hours of travel time. In 2007, the speed of DACC-0.099 increased to 130.64 km/h and decreased the travel time to 2.35 hours. In 2012, 0.096 level could support a travel speed of over 191.88 km/h and the travel time was also reduced to 1.6 hours. In the final year of 2013 maintaining the same statistical criteria on accommodation and food expenses, the DACC-0.099 could support intercity travel with a speed of 198.06 km/h and 1.55 hours of journey time. Through 8 years, the service speed with a DACC level of 0.099 was increased by 90%, nearly breaking 200 km/h. In 2014 and 2015, the service speed estimation even exceeds 300 km/h. Considering the statistical data deviation, the result would not be discussed deeper. On the other hand, the passengers' benefit level under the same service speed was also increased. Since the normal high speed railway was opened, the intercity commuter DACC value has increased by 25% from 2010 to 2013. Factors like passenger incoming growth, steady travel cost and economic growth positively pushed the service speed hike and kept it within affordable range. More and more people would benefit from the intercity travel.

4.2.2.6 Shanghai-Nanjing TCF-DACC

The final group of the optimised speed analysis is the commuting service from Shanghai to Nanjing. The data sheet is listed in Table 37 in the Appendix. According to the assumed condition, the intercity commuter lived in Shanghai with local food, intracity traffic and accommodation costs, and worked in Nanjing to receive the benefit. The intracity travel cost in Nanjing was also taken into account as the travel friction part. In this case, the relationship between these two cities is similar to the case of Shanghai to Hefei. Compared to the city of Shanghai, Nanjing has a smaller population size and economic scale. In the test scenario, intercity commuters live in the city of Shanghai with a higher living cost level and work in a city with a lower income level. Due to the extremely low profit, the intercity living strategy from Shanghai to Nanjing is unlikely to be selected. However, the analysis result still helped to discover how the different speeds of the intercity transport system and the growing economy affect the passenger travel benefit.

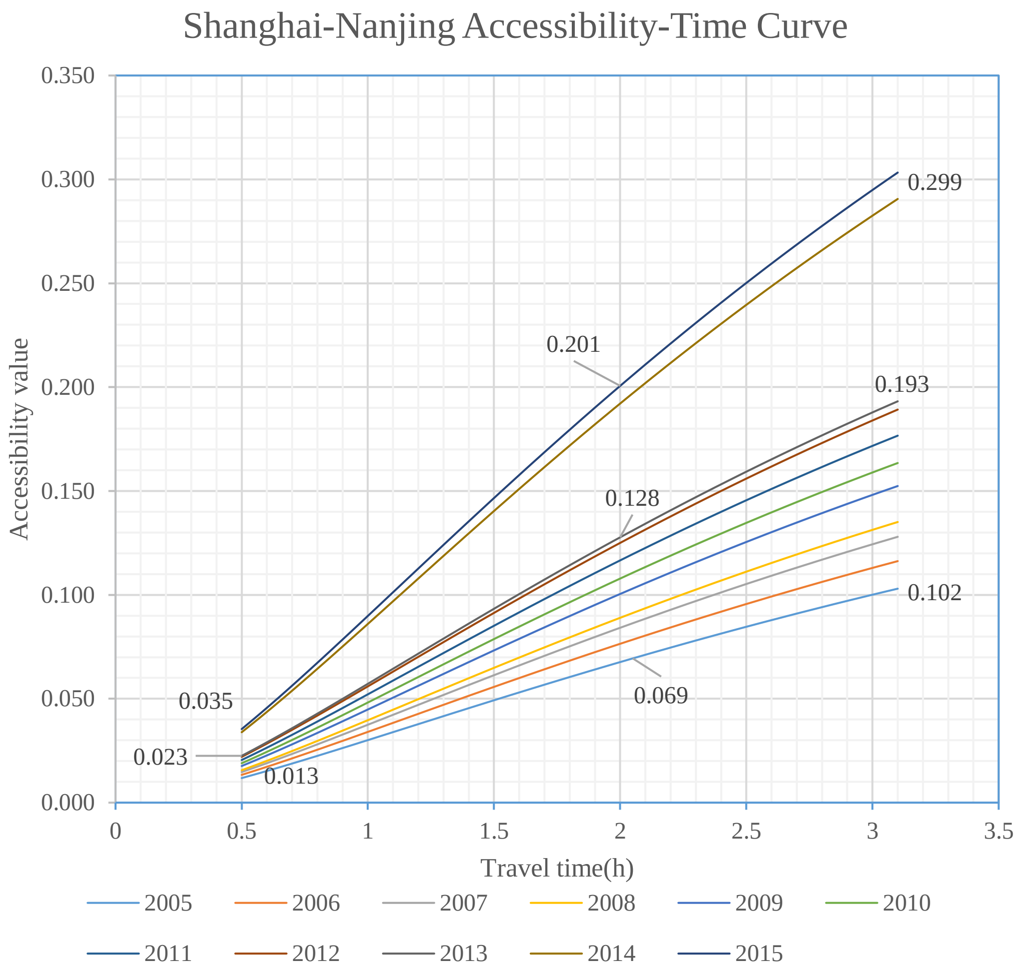


Figure 25 – Shanghai-Nanjing Railway Accessibility and Time analysis

Throughout the 11 years, the Nanjing-Shanghai accessibility-speed curve moved up year by year, indicating that the traveller's commute benefit level was increased continually. The figure structure and result are close to the other cases. The curve of 2014 and 2015 are also affected by inevitable errors in Shanghai statistic data, far exceeding the result in previous years. In 2005, the normal speed railway service user needed to speed 3.1 hours for a single trip with an average speed of 99 km/h. The Shanghai-Nanjing intercity living strategy only has a DACC level of 0.092. It is an extremely low level which is just slightly higher than the level of the Shanghai-Hefei case in the same year. In 2010, the normal speed railway commuter's DACC value was increased by 56.7% to 0.147. Also in 2010, the new high-speed railway commuter could reach the same DACC-0.09 level with faster speed and higher ticket prices. However, it was achieved by cheap normal speed railway service in 2005. In 2010, the normal speed railway commuter had a DACC value of 0.147. The new high speed service reduced 40.3% of travel time by cutting 38.7% of intercity commute profitability. The ultrahigh speed railway service was estimated through TCF with an average speed of 614 km/h and 0.5 hours of travel time from Shanghai to Nanjing. And the theoretical ultra high speed railway service commute could reach the DACC level of 0.017, reducing 72% of the travel time with a loss of 81% profit ratio in the year 2010. Following economic development, the DACC value of normal speed railway service, high speed railway service and forecasted ultrahigh speed railway service achieved DACC levels of 0.184, 0.113 and 0.022. Compared to the result in 2010, the profit of these three different intercity travel speed configurations increased by 25%, 25.6% and 29%.

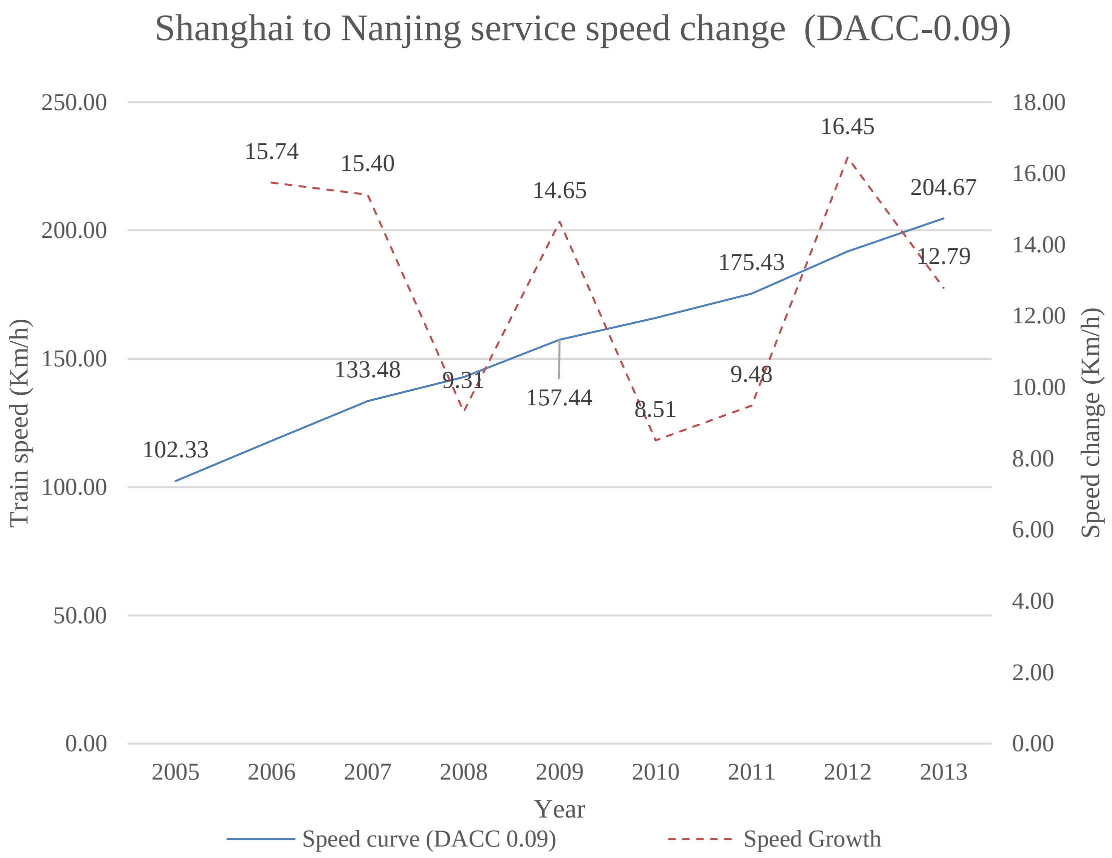


Figure 26 – Shanghai-Nanjing Railway speed curve: DACC 0.09

In the analysis of the service speed change under the same travellers' profitability, the DACC level of the normal high speed railway traveller from Shanghai to Nanjing in 2010 is set as the reference point, which is 0.090. In 2005, DACC-0.09 supported the travel speed of 102.33 km/h with 3 hours of travel time. In 2007, the speed of DACC-0.099 increased to 133.48 km/h and decreased the travel time to 2.3 hours. In 2012, 0.09 level could support a travel speed of over 191.88 km/h and the travel time was also reduced to 1.6 hours. In the final year of 2013 maintaining the same statistical criteria on accommodation and food expenses, the DACC-0.09 could support intercity travel with a speed of 204.67 km/h and 1.5 hours journey time. Since the year 2005, the service speed of DACC-0.09 has increased by 94.4%. In the following years under different statistical standards, the DACC-0.09 speed also rose but slower. Although the service speed and timetable are not adjusted regularly the traveller’s profit ability kept increasing under same speed level. Through the research period, the DACC value of the normal speed service user was doubled from 2005 to 2013 and the value of the high speed service increased by 25.6% from 2010 to 2013.

4.2.3 Result discussion

The profitability of travellers under different service speeds and directions was examined across six groups, revealing that the passenger travel benefit levels have consistently increased year over year. This increase is linked to economic growth and stable ticket prices. For example, the DACC value of normal speed railway service for the Hefei-Nanjing route increased by 39.6% between 2005 and 2015, reaching a value of 0.266. Meanwhile, the highspeed service DACC improved by 41.7%, while the ultrahigh speed service saw a 41.9% rise in DACC during the same period. Despite this overall positive trend, the extreme low income level below DACC ratio of 0.12 indicated that the ultrahigh-speed service remains unaffordable for most passengers, with a DACC reduction of 60.7% and a time-saving ratio of 0.82 compared to normal-speed services .

However, despite this positive trend, the introduction of ultrahigh speed services such as Maglev trains remains unaffordable for the average intercity commuter at current income levels. For example, while conventional high-speed trains can offer a cost-benefit ratio that fits most commuters' needs, the faster service speeds of Maglev trains do not provide a commensurate increase in economic accessibility at the same cost. The cost-function analysis demonstrated that service speeds over 300 km/h do not significantly improve commuter affordability or benefit levels, suggesting that ultrahigh-speed railway is not yet viable for widespread daily commuting, and generate huge financial burden.

Furthermore, this section's findings underline the limitations of accessibility improvements. While there is clear evidence of increased daily commuter access in cities like Hefei and Nanjing, the steep cost of advanced technologies like Maglev systems makes them impractical for the broader population under current economic conditions. This raises questions about the future of ultrahigh speed rail and its role in shaping regional economic development.

4.3 Population and Accessibility

The three accessibility indicators, DACC, DWACC and WACC, are also validated in other practical problems. A series of econometrical panel data models were built and applied to different economy sections. The first part of the econometrical analysis is to discover how the local population fluctuation is affected by the accessibility index change.

4.3.1 Two population types and modelling indicators RPD and LTPD

There are main two types of population statistics commonly used in China, Registered residents and Long-term residents.

- Registered resident

The registered resident is the citizen who is registered by the resident's administration office. Normally, they are considered as living and working in a fixed area around the registered address and included in the local service, like education, tax etc.

- Long term resident

The long-term resident is the population who live in a certain address for a long term, over 6 months, including the people who may be registered residents at other addresses in other cities. The number of long-term residents is equal to registered residents plus non-registered long-term residents. The Long-term resident is mainly distinguished by living time. The city development plan would prefer to design facilities and service capacity according to the long-term resident volume.

The registered resident and long-term resident are two levels of the population statistic from lower volatility to higher. In the empirical research, it is assumed that following the growing trend of the accessibility level, both types of registered residents and long-term residents will increase in turn as a wave. Because the improvement of traffic accessibility makes further commutes possible and profitable, the departing city will also become more attractive for intercity travellers to settle in and work in a developed city. The three levels of the accessibility indicator are directional from departing place to destination with both cities' data. Therefore, the single city registered residents and long-term residents were also transited into the different values of the two cities, RPD and LTPD.

- RPD

RPD is the registered resident population difference. In this study, RPD calculated the registered resident difference between the service start city and the destination city.

- LTPD

Similar to the RPD, LTPD is the long-term resident population difference between the service start city and destination.

4.3.2 RPD and LTPD econometrical panel data model structure

The RPD and LTPD as explained variables are researched in two Fixed Effect models respectively. Each model in these two groups contained the same explanatory variables structure which are Daily Commuting Accessibility(DACC), Daily Work Commuting Accessibility (DWACC), Weekly Return Accessibility (WACC) and Single city accessibility difference (SACCD). In each group, four different econometrical data panels representing four different levels of sample scale and research objectives were introduced to discuss the overall relationship between accessibility change and population flow difference. The panels are the All cities panel, Hefei panel, Nanjing panel and Shanghai panel, covering all 11 years of research time from 2005 to 2015.

- All-cities panel contained all the accessibility measurement cases including 5 core cities, 6 network edge cities with a total of 50 intercity trips and 5 core cities' intracity data. It aims to discuss the overall effects of traffic conditions change on the population;
- Hefei panel contained data on the 10 intercity trips departing from Hefei, and its intracity traffic data;
- Nanjing panel contained data on the 10 intercity trips departing from Nanjing, and its intracity traffic data;
- Shanghai panel contained data of the 10 intercity trips departing from Shanghai, and its intracity traffic data;

The All-cities panel measured overall traffic condition change impact on population differences, involving and mixing all types of cities. The other three panels, Hefei, Nanjing and Shanghai were introduced to analyse and compare the effect under different economy sizes. Shanghai is the most developed city in the research area with the largest population and highest GDP. Hefei is the smallest with a smaller population and lower economic size. And Nanjing is in the middle between them.

4.3.3 Modelling result

Two groups of the fixed effects panel data regression analysis results of RPD and LTPD were listed in Table 25 and Table 26. In the analysis result sheet, the coefficient values were indicated in three colours, red, yellow and green, which represented the three robust check levels from weak to strong. The three p-value threshold levels are 0 to 0.05, 0.05 to 0.35 and more than 0.35, distinguishing the reliability of the coefficient from high to low.

4.3.3.1 RPD Fixed effect regression

Table 25 – RPD Fixed Effects Panel Test Result

All-Cities Fixed Effects Panel Test Result; Service: 50; Years: 11; Samples: 550; Within R-sq: 0.1676;		
Registered population difference (RPD)	Coefficient	p-value
Daily ACC (DACC)	-1.281	0.000
Daily work ACC (DWACC)	0.0818	0.641
Weekly work ACC (WACC)	0.3839	0.000
ACC Difference between start and destination (SACCD)	0.2709	0.000
Constant	0.1725	0.000
Hefei fixed effects panel test result; Service: 10; Years: 11; Samples:110; Within R-sq: 0.1983;		
Registered population difference (RPD)	Coefficient	p-value
Daily ACC (DACC)	-1.287	0.003
Daily work ACC (DWACC)	0.0545	0.819
Weekly work ACC (WACC)	0.6707	0.000
ACC Difference between start and destination (SACCD)	0.1637	0.021
Constant	-3.446	0.000
Nanjing fixed effects panel test result; Service: 10; Years: 11; Samples: 110; Within R-sq: 0.1190;		
Registered population difference (RPD)	Coefficient	p-value
Daily ACC (DACC)	-1.333	0.018
Daily work ACC (DWACC)	0.0055	0.988
Weekly work ACC (WACC)	0.5159	0.004
ACC Difference between start and destination (SACCD)	0.0928	0.182
Constant	-1.871	0.000
Shanghai fixed effects panel test result; Service: 10; Years: 11; Samples: 110; Within R-sq: 0.2940;		
Registered population difference (RPD)	Coefficient	p-value
Daily ACC (DACC)	-0.307	0.75
Daily work ACC (DWACC)	1.6244	0.055
Weekly work ACC (WACC)	0.4056	0.113
ACC Difference between start and destination (SACCD)	0.1294	0.11
Constant	6.5923	0.000
Wuhan fixed effects panel test result; Service: 10; Years: 11; Samples: 110; Within R-sq: 0.4533;		
Registered population difference (RPD)	Coefficient	p-value
Daily ACC (DACC)	-1.731	0.061
Daily work ACC (DWACC)	0.3751	0.679
Weekly work ACC (WACC)	-0.074	0.797
ACC Difference between start and destination (SACCD)	0.444	0.000
Constant	0.4575	0.000
Hangzhou fixed effects panel test result; Service: 10; Years: 11; Samples: 110; Within R-sq: 0.0396;		
Registered population difference (RPD)	Coefficient	p-value
Daily ACC (DACC)	-0.377	0.551
Daily work ACC (DWACC)	0.3592	0.351
Weekly work ACC (WACC)	0.0307	0.901
ACC Difference between start and destination (SACCD)	0.0826	0.218
Constant	-1.086	0.000

- DACC and WACC

The population difference regression fitted well on the All-cities, Hefei, and Nanjing panels. The p-value indicated the high significance of DACC and WACC, over 95%. DACC measures the benefit level of an HSR user and WACC represents that of a normal-speed railway user. By comparing both variables' parameters, it can be found that DACC has a negative impact on RPD, but WACC shows a positive, which means the HSR could help to eliminate the population gap between the departure city and destination city, but the normal speed service could enlarge it. By observing the parameters, the RPD DACC value showed 3 to 4 times greater strength than WACC, which indicates that the high-speed service has a heavier weight in reducing the population gap and it is also strong enough to counteract the opposite effect brought by the slow-speed service in the research period. In the Shanghai panel, DACC is not as significant as in the other cases, but DWACC ($p < 0.06$) and WACC ($p < 0.12$) could affect the explained variables effectively. Shanghai, as the megacity in the east network, has the largest population, which far exceeds that of the other case cities with a positive population difference value. The DACC parameter is insignificant in the Shanghai panel regression, which means that the highspeed service started from Shanghai to the other cities did not have a dramatic effect on decreasing the population gap.

In the Wuhan case, the DACC value exhibits strong significance at -1.7309, with the coefficient itself having a relatively large absolute value and a p-value of 0.061. The WACC value representing the yield of conventional rail travel is -0.074, demonstrating very weak significance at 0.797. Similar to other groups, the negative value of DACC indicates that the daily commuting yield from Wuhan to surrounding cities contributes to narrowing the population gap and achieving balance between Wuhan and nearby destination cities. Differing from other groups, in this case, WACC is negative, demonstrating a similar directional impact as DACC. However, the level of significance in the hypothesis test is considered only as a reference. In the final case of Hangzhou, neither the DACC nor WACC variables show significance. This implies that changes in intercity commuting conditions between Hangzhou and surrounding cities do not have a significant impact on RPD.

- DWACC

DWACC, with an additional 8 hours working time budget, reflects an extremely frequent commute travel scenario. The p-value for DWACC in the regression for the All-cities, Hefei, Nanjing, Wuhan and Hangzhou panels, is insignificant. However, in the case of Shanghai, the p-value is less than 0.06 and the parameter reached 1.624, which indicates that DWACC can significantly affect the population gap between Shanghai and the other destinations. Following the increasing DWACC value, the population gap would be enlarged. Due to Shanghai's population advantage, if more services can satisfy the 8-hour working time budget, more people may expect to move to Shanghai and take HSR to other cities for work. Compared to the other cities with a smaller economy, travellers from the top-level cities have different intercity travel preferences.

- SACCD

SACCD as a control variable measured the difference in single-city living benefit level between the departure city and destination city, representing fluctuations affected by the attraction of the city itself rather than the travel service. In the analysis, SACCD has a significant impact on the population difference with the positive parameter passing the robustness check ($p < 0.05$) in the All-cities, Hefei and Wuhan panels and returning a p-value lower than 0.25 in the other cases, which corresponds to the motivation for population migration in reality. Living conditions and income level can be regarded as important factors affecting the population difference. Whereas, compared to DACC, DWACC, and WACC, SACCD did not have the same strength, which was only approximately one-sixth that of DACC. The major power of population migration is more related to traffic conditions.

4.3.3.2 LTPD Fixed effect regression

- DACC and WACC

LTPD represents a population group with stronger mobility. In the fixed effects panel data regression model, DACC and WACC showed different test results compared to RPD. Additionally, even within the LTPD group, there were variations among different cases. In the ALL-Cities case, DACC was -1.0545, but it did not pass the significance test. The WACC value was 0.7907 with a p-value of 0.203. Looking solely at the direction of impact, the travel benefits rate of high-speed railway represented by DACC and that of conventional rail represented by WACC are similar to the RPD case. Improved high-speed rail services can reduce differences in mobile populations between regions, while conventional rail services, representing weekly travel commuters, tend to increase these differences. In sub-cases, both DACC and WACC in Hefei and Nanjing passed the 95% significance test. Compared to the RPD group's regression results, these two cities showed strong DACC coefficient weights. In RPD, the coefficients for Hefei and Nanjing were -1.2873 and -1.3325, respectively, which increased to -7.2179 and -8.0053 in LTPD. The WACC coefficients also rose from 0.6707 and 0.5159 to 2.7648 and 2.3613, respectively. The comparison of coefficients confirms that mobile populations are more sensitive to changes in transportation conditions than registered populations. Compared to Shanghai, Hefei and Nanjing are relatively smaller cities. In Shanghai, a top-tier large city, LTPD is not significant for DACC and WACC. Conversely, DWACC shows a strong correlation with LTPD. In other cases, Wuhan and Hangzhou, as remote railway hubs, showed different regression results from the first three sub-cases. In the Wuhan case, DACC was not significant. WACC was relatively significant, with a coefficient of -3.1657, passing the 95% significance test. The direction of the mobile population difference in Wuhan, unlike the previous cases, is negative. This indicates that the travel benefit efficiency of conventional railway is negatively correlated with the mobile population difference in Wuhan compared to other cities, suggesting that improved conventional rail services can reduce mobile population differences in the region. In the Hangzhou case, DACC was significant at -7.087. However the WACC parameter with 0.2583 did not pass, indicating that the mobile population in the eastern network region of Hangzhou is more sensitive to high-speed railway services, with a travel population structure different from that in western Wuhan.

- DWACC

In the LTPD analysis, DWACC for measuring the travel profit under extremely frequent commute conditions, showed different results to the RPD's. In All Cities cases, which includes all scenarios, the DWACC coefficient is -1.152 with a p-value of 0.286. The regression result was not highly significant, failing to reach the 95% threshold. However, the coefficients indicate that the DWACC level has a negative correlation with the LTPD differences between the two cities, suggesting that higher travel benefits help to reduce regional differences in long-term resident populations with higher volatility. In the sub-panel model, The DWACC coefficient of Hefei and Shanghai cases, passed the 95% robust check, with values of -5.192 and 22.6382 respectively. In the case of Hangzhou, the DWACC coefficient was 2.7905 with a p-value of 0.199, indicating weaker significance. Shanghai and Hangzhou, as the two most developed cities, similarly situated on the easternmost side of the railway network, both have positive DWACC coefficients, which is contrary to the results found in the All Cities case. Moreover, the DWACC coefficient of Shanghai reached 22.6, significantly higher than in other cases, indicating that for highly developed cities or regions, the LTPD difference between them and neighbouring cities is positively correlated with the level of accessibility to these neighbouring cities. A better inter-city commuting benefit rate could enlarge the gap in transient populations between cities. The Shanghai case exemplifies the population suction effect of super-developed cities. In the remaining Nanjing and Wuhan cases, the regression results for the DWACC coefficients were not significant.

- SACCD

In LTPD analysis, as a reference variable, all the SACCD coefficients in different groups can't pass the 95% robust check. In the All Cities case, the SACCD showed a small value of 0.2846 and weak significance with 0.128 p-values, which indicated that the intra-city living accessibility difference could enlarge the long-term resident population with positive correlations. In the sub-cases, most of the SACCD coefficients were not effective, except in the case of Hangzhou with a coefficient of -0.4925 and p-value of 0.192. Due to the smaller parameter value and robust check result, it can be summarized that the variations of the intracity accessibility difference between cities didn't impact its transient population differences, compared to the result of DACC DWACC and WACC.

Table 26 – LTPD Fixed Effects Panel Test Result

All-Cities Fixed Effects Panel Test Result; Service: 50; Years: 11; Samples: 550; Within R-sq: 0.0113;		
Long-term resident population difference (LTPD)	Coefficient	p-value
Daily ACC (DACC)	-1.0545	0.515
Daily work ACC (DWACC)	-1.152	0.286
Weekly work ACC (WACC)	0.7907	0.203
ACC Difference between start and destination (SACCD)	0.2846	0.128
Constant	0.528	0.005
Hefei fixed effects panel test result; Service: 10; Years: 11; Samples:110; Within R-sq: 0.2897;		
Long-term resident population difference (LTPD)	Coefficient	p-value
Daily ACC (DACC)	-7.2179	0.004
Daily work ACC (DWACC)	-5.192	0.000
Weekly work ACC (WACC)	2.7648	0.007
ACC Difference between start and destination (SACCD)	0.0841	0.832
Constant	-5.3296	0.000
Nanjing fixed effects panel test result; Service: 10; Years: 11; Samples: 110; Within R-sq: 0.1804;		
Long-term resident population difference (LTPD)	Coefficient	p-value
Daily ACC (DACC)	-8.0053	0.013
Daily work ACC (DWACC)	-0.3697	0.862
Weekly work ACC (WACC)	2.3613	0.02
ACC Difference between start and destination (SACCD)	-0.2788	0.478
Constant	-2.6145	0.000
Shanghai fixed effects panel test result; Service: 10; Years: 11; Samples: 110; Within R-sq: 0.4543;		
Long-term resident population difference (LTPD)	Coefficient	p-value
Daily ACC (DACC)	3.8399	0.583
Daily work ACC (DWACC)	22.6382	0
Weekly work ACC (WACC)	-0.2687	0.884
ACC Difference between start and destination (SACCD)	-0.563	0.335
Constant	11.5313	0.000
Wuhan fixed effects panel test result; Service: 10; Years: 11; Samples: 110; Within R-sq: 0.0785;		
Long-term resident population difference (LTPD)	Coefficient	p-value
Daily ACC (DACC)	0.9446	0.808
Daily work ACC (DWACC)	2.4919	0.519
Weekly work ACC (WACC)	-3.1657	0.011
ACC Difference between start and destination (SACCD)	0.2476	0.537
Constant	0.3323	0.411
Hangzhou fixed effects panel test result; Service: 10; Years: 11; Samples: 110; Within R-sq: 0.0910;		
Long-term resident population difference (LTPD)	Coefficient	p-value
Daily ACC (DACC)	-7.087	0.048
Daily work ACC (DWACC)	2.7905	0.199
Weekly work ACC (WACC)	0.2583	0.852
ACC Difference between start and destination (SACCD)	-0.4925	0.192
Constant	-1.6772	0.000

4.3.4 High speed Railway and Urbanization Progress and Hypothesis

The accessibility index was calculated based on the collected average income and travel cost data, which indicated the profit level of a common commuter. Through the distribution of national income, the size of the population which could achieve a higher profit level from intercity travel can be evaluated. By adjusting the OPP value and the travel friction, the accessibility index can classify the variable travel profit into several tiers with different commuter incomes and investigate the urbanisation process. Figure 27, Figure 28 and Figure 29 indicate the urbanisation process and corresponding accessibility index in three stages. If the national income followed an ideal normal distribution, the faster service speed and suitable journey cost would push the better profit area to the left, eliminating the gap between single-city life and dual-city life, and making more people benefit from intercity trips. Combining the indicators of the average-income traveller's accessibility value and local national income distribution could reflect the progress of the urban integration process.

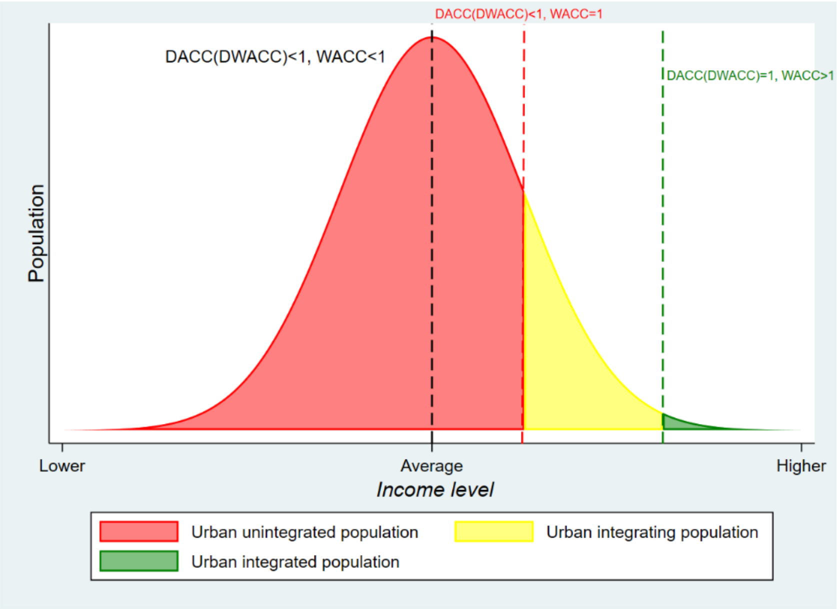


Figure 27– Accessibility and Urbanisation Process Stage 1

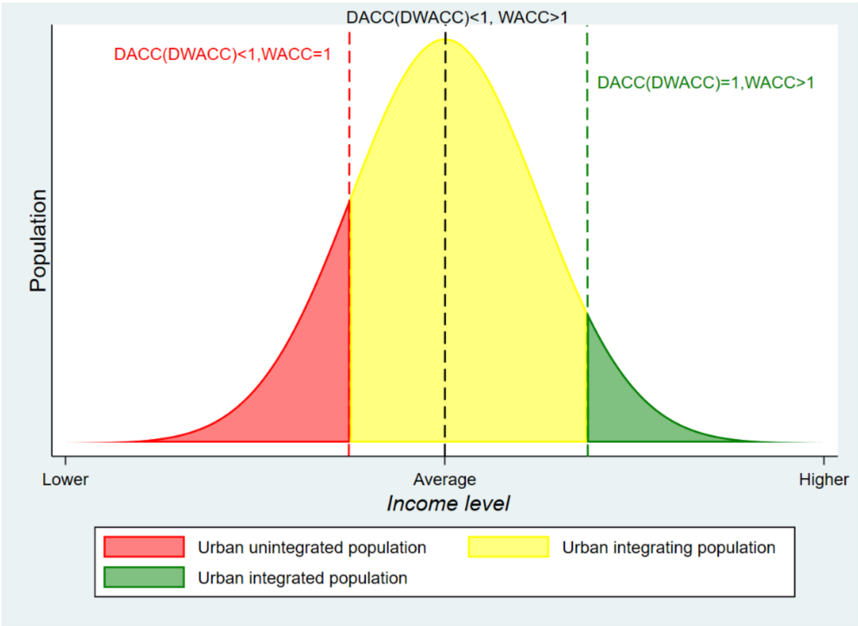


Figure 28– Accessibility and Urbanisation Process Stage 2

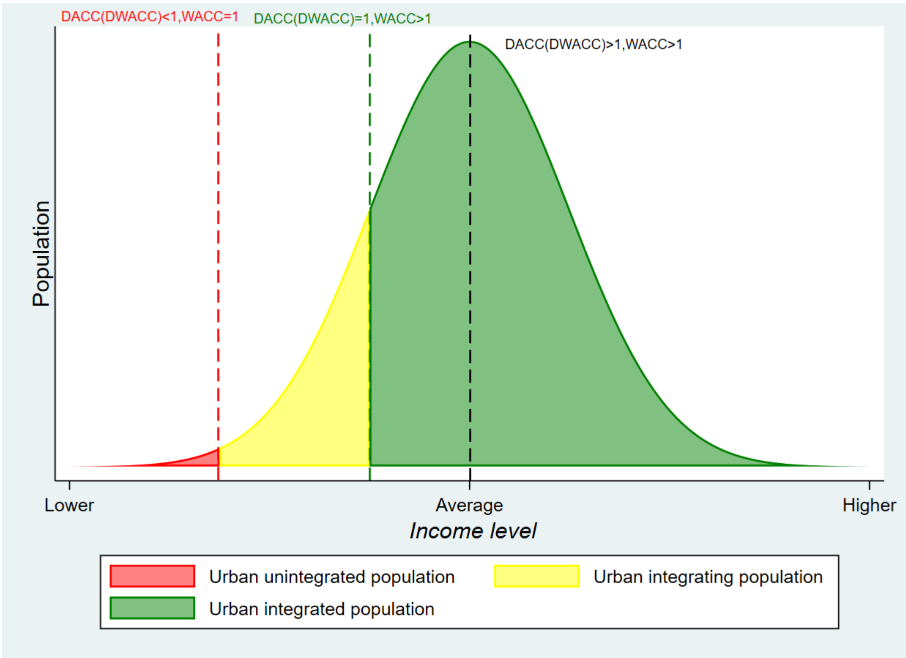


Figure 29– Accessibility and Urbanisation Process Stage 3

4.4 Dynamic Population and Accessibility Effectiveness analysis

In the previous regression analysis, DACC, DWACC, WACC, and SACCD were introduced into the model as explanatory variables, with transient population differences between cities serving as the dependent variable. The model used all eleven years' data as the regression panel and validated the efficacy of the designed accessibility indicator.

In this section, the same econometric model structure is maintained. However, the regression panels were integrated and simulated at different fixed intervals. This analysis is termed Dynamic Population-Accessibility Effectiveness Analysis, which aims to observe the dynamic changes of corresponding accessibility coefficients and test the fluctuating impact of population migration changes following the construction and operation of a new high-speed railway service.

4.4.1 Cases and variables

In the case design, All Cities, Hefei, Nanjing, and Shanghai groups were retained to describe four different sample size levels. All Cities case contained 11 cities' data. Hefei, Nanjing and Shanghai case represented three levels of the economy from the smaller developing city to the most developed city, within the East China highspeed rail network.

The model variables remain the same as in previous analyses. Since the primary goal is to discuss the impact of the high-speed railway on socio-economics, the results focus on the DACC variable, representing highspeed and high-frequency daily intercity commuting accessibility, and the WACC variable, representing lower frequency, slower weekly commuting by train. The RPD is selected to be the dependent variable.

4.4.2 Analysis period

The sampling times for the accessibility panel data are divided into four tiers, generating the panel data every 3, 4, 5, or 6 years. Due to the ample sample size in the All Cities case, all sampling frequencies were tested. In the sub-cases, due to insufficient panel data volume caused by sampling every 3 and 4 years, leading to poor regression model performance, only the data with 5 years and 6 years intervals were used for regression analysis.

4.4.3 All case panel modelling result

Table 27 indicates the All Cities case regression test result, with different sampling frequencies. In the coefficient sheet, the regression result validity kept decreasing following the reduction of the sample volume and the increasing sampling frequency in each regression.

Table 27 – Dynamic All Cities Fixed Effects Panel Test Result

All Cities Fixed Effects Panel Test Result; Service: 50; Sampling frequency: Every 6 years; Samples: 300 in each test;

Year		Coefficient					P-value					
From	To	DACC	DWACC	WACC	ACCD	CONS	P(DACC)	P(DWACC)	P(WACC)	P(ACCD)	P(CONS)	Within R-sq
2005	2010	0.940	-0.232	-0.237	-0.040	0.260	0.001	0.315	0.010	0.266	0.000	0.0517
2006	2011	0.376	-0.103	-0.192	0.019	0.277	0.156	0.578	0.063	0.683	0.000	0.0159
2007	2012	-0.362	0.049	0.152	0.242	0.202	0.157	0.777	0.158	0.000	0.000	0.1144
2008	2013	-0.945	0.071	0.402	0.270	0.148	0.000	0.667	0.000	0.000	0.000	0.2169
2009	2014	-1.282	-0.026	0.442	0.234	0.155	0.000	0.882	0.000	0.000	0.000	0.2665
2010	2015	-1.352	-0.087	0.368	0.191	0.185	0.000	0.652	0.000	0.000	0.000	0.2722

All Cities Fixed Effects Panel Test Result; Service: 50; Sampling frequency: Every 5 years; Samples: 250 in each test

Year		Coefficient					P-value					
From	TO	DACC	DWACC	WACC	ACCD	CONS	P(DACC)	P(DWACC)	P(WACC)	P(ACCD)	P(CONS)	Within R-sq
2005	2009	0.816	-0.234	-0.157	0.001	0.243	0.015	0.421	0.105	0.969	0.000	0.0352
2006	2010	0.812	-0.172	-0.272	-0.088	0.280	0.004	0.437	0.006	0.022	0.000	0.0737
2007	2011	0.123	-0.072	-0.093	0.083	0.260	0.634	0.691	0.402	0.145	0.000	0.0153
2008	2012	-0.481	0.051	0.199	0.265	0.195	0.046	0.759	0.058	0.000	0.000	0.1798
2009	2013	-0.981	0.037	0.400	0.263	0.149	0.000	0.831	0.000	0.000	0.000	0.2852
2010	2014	-1.233	-0.061	0.365	0.169	0.179	0.000	0.762	0.000	0.000	0.000	0.2316
2011	2015	-1.125	-0.236	0.224	0.100	0.230	0.005	0.545	0.024	0.000	0.000	0.1598

All Cities Fixed Effects Panel Test Result; Service: 50; Sampling frequency: Every 4 years; Samples: 200 in each test

Year		Coefficient					P-value					
From	TO	DACC	DWACC	WACC	ACCD	CONS	P(DACC)	P(DWACC)	P(WACC)	P(ACCD)	P(CONS)	Within R-sq
2005	2008	0.677	-0.283	-0.015	0.005	0.205	0.138	0.537	0.895	0.887	0.000	0.0285
2006	2009	0.716	-0.138	-0.229	-0.051	0.271	0.030	0.618	0.024	0.179	0.000	0.0549
2007	2010	0.579	-0.160	-0.242	-0.122	0.288	0.041	0.452	0.030	0.014	0.000	0.0691
2008	2011	-0.052	-0.063	-0.025	0.119	0.250	0.832	0.720	0.822	0.041	0.000	0.0303
2009	2012	-0.520	0.056	0.231	0.277	0.181	0.035	0.749	0.027	0.000	0.000	0.2834
2010	2013	-0.978	0.007	0.353	0.203	0.163	0.000	0.974	0.001	0.000	0.001	0.2651
2011	2014	-1.565	0.227	0.223	0.053	0.238	0.007	0.690	0.044	0.083	0.000	0.1381
2012	2015	-0.260	-0.469	-0.051	0.028	0.258	0.519	0.273	0.650	0.354	0.000	0.0482

All Cities Fixed Effects Panel Test Result; Service: 50; Sampling frequency: Every 3 years; Samples: 150 in each test

Year		Coefficient					P-value					
From	TO	DACC	DWACC	WACC	ACCD	CONS	P(DACC)	P(DWACC)	P(WACC)	P(ACCD)	P(CONS)	Within R-sq
2005	2007	0.523	-0.416	0.051	0.026	0.196	0.371	0.447	0.711	0.389	0.000	0.0332
2006	2008	0.766	-0.257	-0.126	-0.031	0.237	0.120	0.586	0.279	0.339	0.000	0.0415
2007	2009	0.515	-0.098	-0.262	-0.104	0.297	0.126	0.717	0.036	0.064	0.000	0.0644
2008	2010	0.353	-0.109	-0.152	-0.112	0.269	0.165	0.576	0.184	0.015	0.000	0.0791
2009	2011	-0.174	-0.075	0.035	0.207	0.236	0.509	0.710	0.772	0.001	0.000	0.1277
2010	2012	-0.537	0.058	0.212	0.242	0.183	0.051	0.781	0.060	0.000	0.000	0.2970
2011	2013	-1.372	0.169	0.255	0.087	0.220	0.023	0.764	0.052	0.012	0.001	0.1854
2012	2014	-1.372	1.047	-0.106	-0.084	0.252	0.075	0.254	0.434	0.020	0.000	0.1219
2013	2015	0.185	-0.828	-0.130	0.069	0.266	0.629	0.032	0.246	0.014	0.000	0.1271

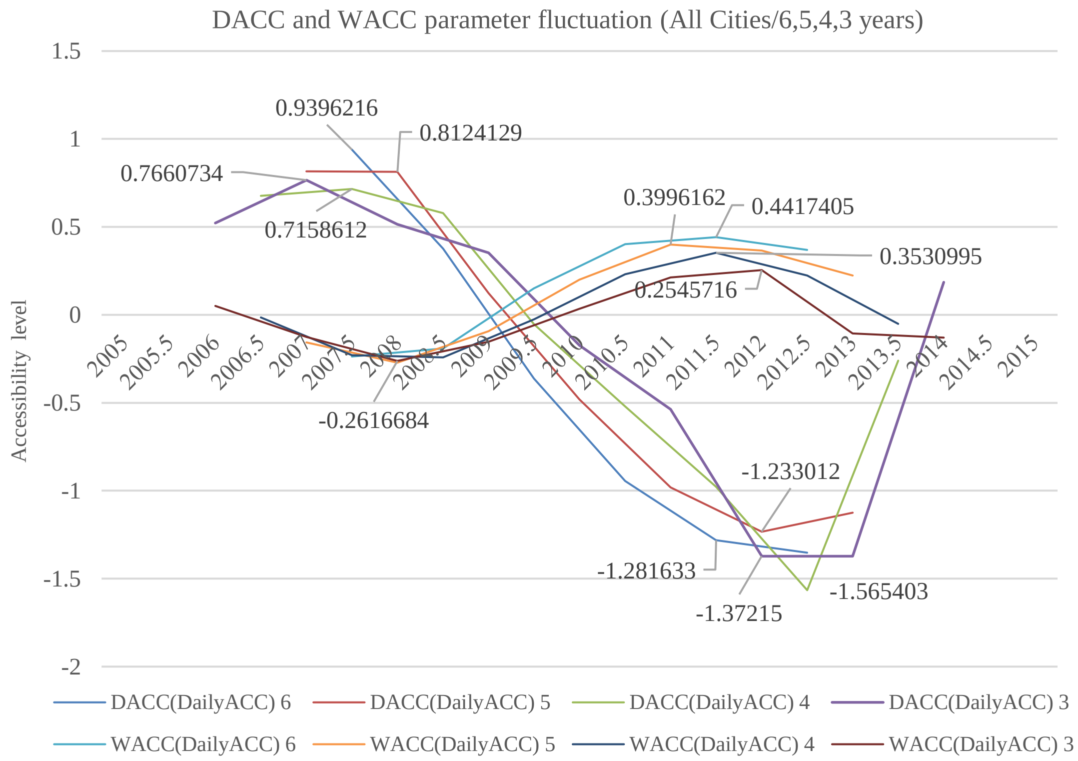


Figure 30– All Cities DACC and WACC parameter fluctuation

Figure 35 illustrates the temporal dynamics of the DACC and WACC against the backdrop of high-speed railway development in East China. The DACC curve begins with positive values, peaks in 2007, then gradually declines, crossing into negative territory by 2010, and reaching its lowest point in 2013 before recovering. Conversely, the WACC curve exhibits an inverse pattern; it starts near zero in 2006, dips to its lowest in 2008, ascends past the neutral mark in 2009, peaks in 2011, and subsequently declines. The initiation of the East China high-speed railway network in 2007 and its substantial completion by 2012 coincide with these fluctuations, mirroring changes in resident travel patterns and lifestyles influenced by high-speed railway connectivity. From 2007 onwards, the expansion of high-speed services profoundly affected DACC, signifying enhanced daily commuting benefits to and from surrounding cities. Over the following six to seven years, this effect intensified, leading to a pronounced negative impact on the

RPD, which reached a nadir of -1.5 before beginning a recovery. Meanwhile, WACC, indicative of less frequent commuting accessibility, exhibited some counter fluctuations for approximately six to seven years post-launch, but its absolute values remained modest, approximately 0.3 to 0.4, only about a third of the impact observed with DACC. The data suggest that before the operation of high-speed railway, improvements to conventional railway coverage positively affected the balancing of transient populations among regional cities. However, as high-speed railway service coverage expanded, encompassing more cities within a feasible daily travel range, it rapidly overshadowed the role of conventional rail, becoming the dominant factor in shaping transient population disparities between cities. This shift underscores the transformative impact of highspeed railway on regional accessibility and demographic distribution.

4.4.4 Sub-panel data modelling result: Hefei, Nanjing and Shanghai

- Hefei panel data modelling result

Hefei's dynamic Population-Accessibility regression results are shown in Table 28. The DACC and WACC test results are illustrated in Figure 31.

Table 28 – Hefei Dynamic Fixed Effects Panel Test Result

Hefei Fixed Effects Panel Test Result; Service: 10; Sampling frequency: Every 6 years; Samples: 60 in each test;												
Year		Coefficient					P-value					
From	TO	DACC	DWACC	WACC	ACCD	CONS	P(DACC)	P(DWACC)	P(WACC)	P(ACCD)	P(CONS)	Within R-sq
2005	2010	1.207	-0.077	-0.229	0.013	-3.277	0.031	0.813	0.294	0.850	0.000	0.1138
2006	2011	1.341	0.016	-0.419	-0.044	-3.198	0.014	0.953	0.065	0.583	0.000	0.1288
2007	2012	-0.195	0.361	0.400	0.078	-3.441	0.641	0.236	0.047	0.349	0.000	0.0958
2008	2013	-0.648	0.378	0.596	0.147	-3.496	0.070	0.173	0.001	0.060	0.000	0.2511
2009	2014	-0.837	-0.071	0.556	0.085	-3.439	0.027	0.814	0.001	0.227	0.000	0.2676
2010	2015	-1.170	-0.348	0.439	0.089	-3.325	0.006	0.339	0.009	0.155	0.000	0.3030
Hefei Fixed Effects Panel Test Result; Service: 10; Sampling frequency: Every 5 years; Samples: 50 in each test;												
Year		Coefficient					P-value					
From	TO	DACC	DWACC	WACC	ACCD	CONS	P(DACC)	P(DWACC)	P(WACC)	P(ACCD)	P(CONS)	Within R-sq
2005	2009	1.030	0.423	-0.172	0.090	-3.296	0.161	0.399	0.520	0.209	0.000	0.1253
2006	2010	1.086	-0.120	-0.327	-0.057	-3.206	0.058	0.707	0.169	0.415	0.000	0.1100
2007	2011	1.156	-0.061	-0.434	-0.091	-3.160	0.038	0.841	0.102	0.328	0.000	0.1262
2008	2012	-0.282	0.331	0.414	0.056	-3.439	0.459	0.269	0.032	0.492	0.000	0.1322
2009	2013	-0.476	0.432	0.553	0.158	-3.510	0.158	0.184	0.001	0.032	0.000	0.3111
2010	2014	-0.927	-0.156	0.447	0.055	-3.369	0.031	0.689	0.013	0.431	0.000	0.2540
2011	2015	-1.011	-0.797	0.219	0.021	-3.186	0.085	0.141	0.226	0.740	0.000	0.2846

Due to the smaller sample size, data were only collected every five and six years for inclusion in the model analysis. The data reveal that since the inauguration of the high-speed railway from Hefei to surrounding cities in 2008, the DACC has had an increasingly negative impact on the RPD. This trend suggests that as daily accessibility to surrounding cities from Hefei improved, facilitating more frequent inter-city commuting, the high-speed railway service significantly contributed to population distribution equity, with noticeable fluctuations occurring over five to six-year periods. In contrast, the WACC exhibited inverse fluctuations. A comparison of the absolute values of the DACC and WACC coefficients further indicates that the enhancements in daily inter-city travel accessibility offered by high-speed railway services are more pronounced, suggesting a reduction in overall population disparities. The benefits of daily inter-city travel have had a more substantial impact, effectively supplanting the population balancing role traditionally held by slower rail services.

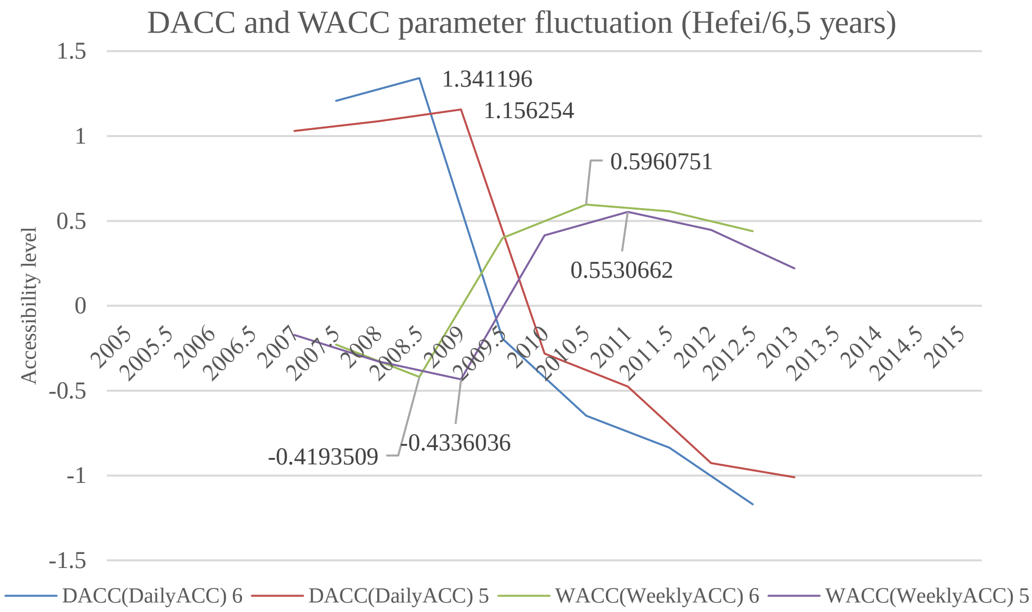


Figure 31– Hefei DACC and WACC parameter fluctuation

- Nanjing 5 and 6 years' panel modelling

Table 29 and Figure 32 illustrate the dynamic population-accessibility analysis result and accessibility indicators' coefficient of Nanjing.

Table 29 – Nanjing Dynamic Fixed Effects Panel Test Result

Nanjing Fixed Effects Panel Test Result; Service: 10; Sampling frequency: Every 6 years; Samples: 60 in each test;												
Year		Coefficient					P-value					
From	TO	DACC	DWACC	WACC	ACCD	CONS	P(DACC)	P(DWACC)	P(WACC)	P(ACCD)	P(CONS)	Within R-sq
2005	2010	2.403	-1.651	-0.208	-0.003	-1.754	0.003	0.033	0.298	0.958	0.000	0.2102
2006	2011	-0.135	-0.075	0.427	-0.121	-1.866	0.784	0.832	0.026	0.166	0.000	0.1162
2007	2012	-0.507	-0.095	0.464	-0.021	-1.879	0.295	0.763	0.017	0.847	0.000	0.1327
2008	2013	-1.017	-0.080	0.484	0.108	-1.884	0.036	0.783	0.009	0.246	0.000	0.2207
2009	2014	-1.329	-0.098	0.350	0.092	-1.801	0.009	0.734	0.022	0.209	0.000	0.2612
2010	2015	-0.999	-0.084	0.167	0.085	-1.770	0.063	0.81	0.254	0.167	0.000	0.1567
Nanjing Fixed Effects Panel Test Result; Service: 10; Sampling frequency: Every 5 years; Samples: 50 in each test;												
Year		Coefficient					P-value					
From	TO	DACC	DWACC	WACC	ACCD	CONS	P(DACC)	P(DWACC)	P(WACC)	P(ACCD)	P(CONS)	Within R-sq
2005	2009	2.937	-2.090	-0.224	0.114	-1.770	0.001	0.014	0.269	0.095	0.000	0.3374
2006	2010	1.883	-1.142	-0.134	-0.063	-1.754	0.04	0.191	0.532	0.366	0.000	0.1861
2007	2011	-0.209	-0.052	0.410	-0.172	-1.845	0.648	0.872	0.033	0.123	0.000	0.1473
2008	2012	-0.695	-0.092	0.347	0.039	-1.835	0.141	0.748	0.069	0.711	0.000	0.1703
2009	2013	-1.325	-0.082	0.429	0.144	-1.843	0.007	0.75	0.012	0.08	0.000	0.3518
2010	2014	-0.997	-0.099	0.239	0.063	-1.787	0.071	0.764	0.132	0.398	0.000	0.1785
2011	2015	-7.637	7.344	-0.155	0.052	-1.670	0.138	0.148	0.322	0.406	0.000	0.1129

The analysis of Nanjing, similar to the Hefei case, incorporated data collected every five and six years. Post-2008, the charts for DACC and WACC in Nanjing reveal substantial fluctuations in population differences between cities. These shifts are attributable to changes in daily and weekly accessibility, enhanced by the expansion of high-speed railway services. As a medium-developed city and a pivotal high-speed rail hub among the three cities studied, Nanjing exhibited more pronounced changes in its accessibility coefficients. Specifically, the DACC coefficient showed a marked decline from 2.5 in 2007 to approximately -1.25 by 2011. Concurrently, the WACC coefficient transitioned from negative to positive, reaching a peak of around 0.5. The duration of these fluctuations for both DACC and WACC spanned about five to six years.

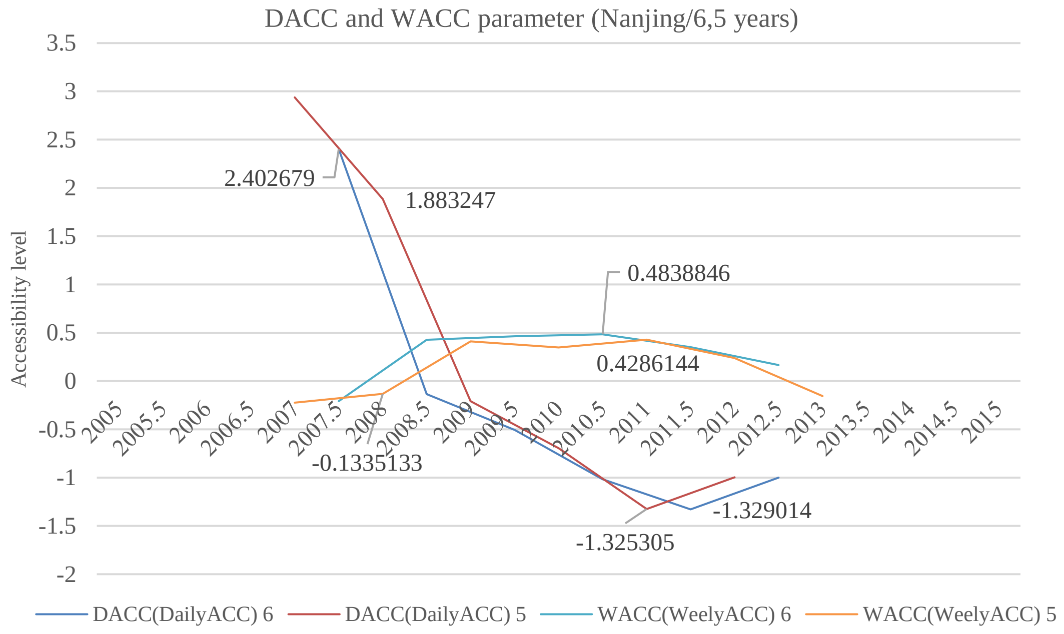


Figure 32– Nanjing DACC and WACC parameter fluctuation

- Shanghai panel modelling result

Table 30 and Figure 33 illustrate the dynamic population-accessibility analysis result and accessibility indicators' coefficient of Shanghai.

Table 30 – Shanghai Dynamic Fixed Effects Panel Test Result

Shanghai Fixed Effects Panel Test Result; Service: 10; Sampling frequency: Every 6 years; Samples: 60 in each test;												
Year		Coefficient					P-value					
From	TO	DACC	DWACC	WACC	ACCD	CONS	P(DACC)	P(DWACC)	P(WACC)	P(ACCD)	P(CONS)	Within R-sq
2005	2010	0.644	1.220	-0.279	-0.195	6.631	0.567	0.210	0.277	0.107	0.000	0.1611
2006	2011	0.432	1.739	-0.030	-0.113	6.593	0.662	0.044	0.908	0.402	0.000	0.2362
2007	2012	0.006	1.738	0.419	0.124	6.595	0.994	0.025	0.092	0.292	0.000	0.3869
2008	2013	-0.449	1.682	0.680	0.127	6.564	0.560	0.018	0.004	0.150	0.000	0.4368
2009	2014	-1.134	1.298	0.621	0.127	6.660	0.232	0.121	0.013	0.096	0.000	0.2648
2010	2015	-0.824	0 (omitted)	0.509	0.146	6.787	0.201	0 (omitted)	0.045	0.018	0.000	0.1841
Shanghai Fixed Effects Panel Test Result; Service: 10; Sampling frequency: Every 5 years; Samples: 50 in each test;												
Year		Coefficient					P-value					
From	TO	DACC	DWACC	WACC	ACCD	CONS	P(DACC)	P(DWACC)	P(WACC)	P(ACCD)	P(CONS)	Within R-sq
2005	2009	1.934	-0.887	-0.377	-0.107	6.689	0.318	0.653	0.114	0.346	0.000	0.1048
2006	2010	0.762	1.215	-0.265	-0.241	6.608	0.511	0.205	0.348	0.091	0.000	0.1955
2007	2011	-0.064	1.824	0.291	0.060	6.605	0.942	0.021	0.266	0.670	0.000	0.3192
2008	2012	-0.152	1.926	0.650	0.109	6.537	0.828	0.005	0.005	0.281	0.000	0.5075
2009	2013	-0.740	1.366	0.657	0.168	6.631	0.393	0.084	0.009	0.057	0.000	0.3664
2010	2014	-0.253	0 (omitted)	0.520	0.103	6.732	0.721	0 (omitted)	0.049	0.163	0.000	0.1675
2011	2015	1.375	0 (omitted)	-0.557	0.090	6.906	0.716	0 (omitted)	0.717	0.157	0.000	0.0577

The analysis of Shanghai, the final group studied, similarly utilized data panels sampled every five and six years. Notable changes in statistical calibres after 2013 and a smaller panel data size for Shanghai resulted in less effective analysis of the DWACC in regression results. The coefficient statistics chart indicated that DACC and WACC continued to display opposing fluctuation trends. Compared to the previous cases of Hefei and Nanjing, Shanghai, the largest and most economically developed of the three cities, experienced shorter fluctuation durations and larger swings in DACC effect coefficients, but with smaller minimum absolute values and lower significance in regression coefficients. This suggests that in a highly developed city within the railway network, the proliferation of high-speed railways has a limited effect and duration on balancing regional populations and is not a primary factor influencing its population composition.

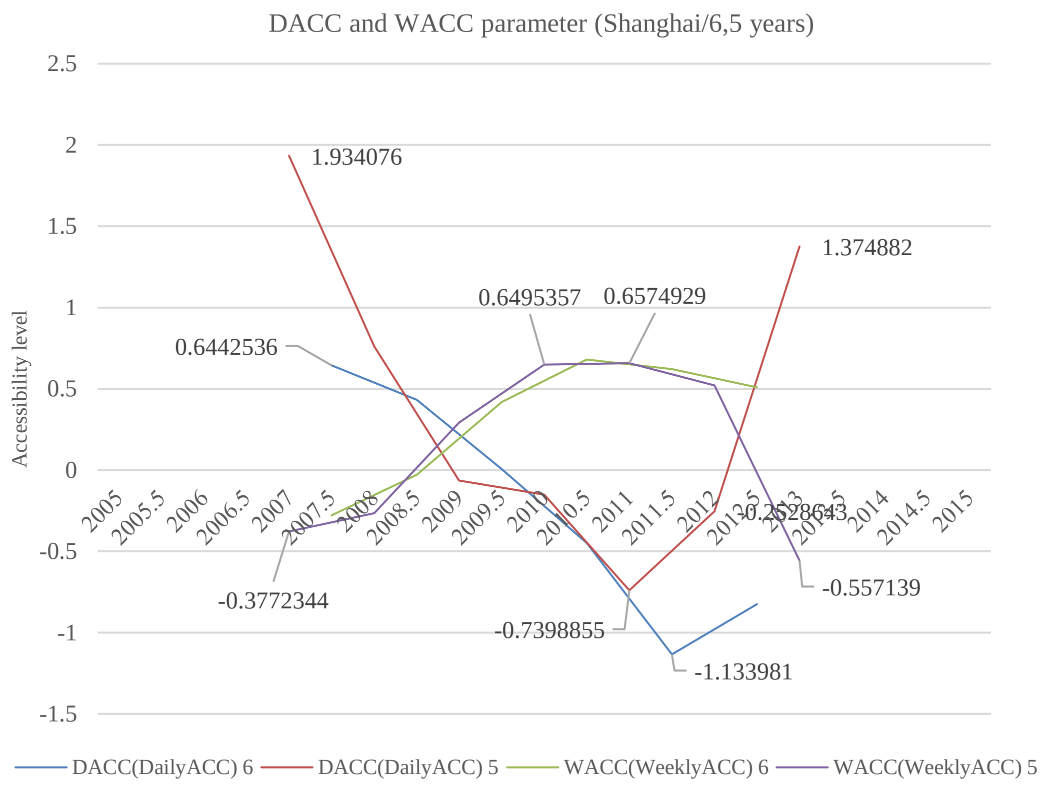


Figure 33– Shanghai DACC and WACC parameter fluctuation

4.4.5 Result discussion

The results from testing four groups demonstrate observable fluctuations in railway effectiveness on population migration. Following the commencement of new high-speed railway services, there is a gradual replacement of conventional, normal-speed railway services. This transition and the associated accessibility fluctuations typically persist for four to five years, serving as a useful reference period for analysing other cases. Unlike conventional railway services, which tend to disperse populations, the new high-speed railway services have the opposite effect, contributing to population concentration. Furthermore, compared to the most developed city in the region, smaller and developing cities experience more significant impacts and benefits from the new high-speed railway network.

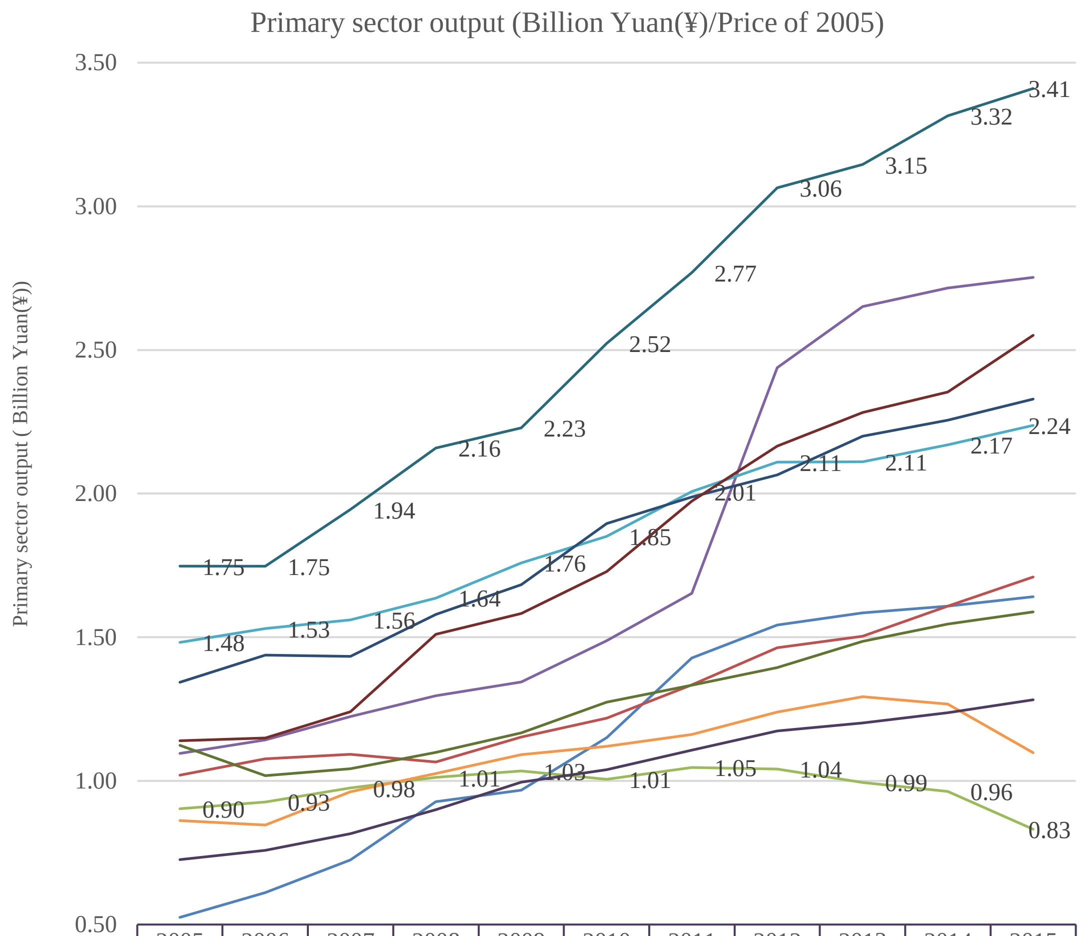
4.5 Accessibility and industry development analysis

To broaden the application scope of the accessibility index and test its practicality, economic data from the three industries were also used as dependent variables in regression analysis alongside accessibility data.

4.5.1 Three levels of industry sectors and statistics result

- Primary sector

The primary sector involves the direct extraction and production of raw materials and natural resources, including agriculture, forestry, fishing, and mining. This sector is closely linked to the exploitation and utilisation of natural resources and forms the foundation of the economy in many countries. Due to the high correlation between the primary sector and the distribution of natural resources, there is a significant disparity in the level of the primary sector across different cities. Moreover, the output of the primary sector, compared to the subsequent secondary and tertiary sectors, does not constitute a major portion of the overall GDP. Figure 34 displays the primary industry output of eleven sample cities from 2005 to 2015. All statistical data are deflated to the price level of 2005, adjusted according to the annual CPI increase. The graph reveals that the primary sector in most cities maintained an expansion trend over the eleven years. In all cases, the primary industry data of Beijing and Shanghai, which are the two cities with the largest economic scales, stayed at very low level and showed a decline after 2014. This indicates that the primary sector is not the pillar industry in the capital Beijing and Shanghai, and following the economic development, the relatively lower-end industries gradually contract. Among other cities, the southern coastal city of Fuzhou maintains the highest scale and growth rate of the primary sector.

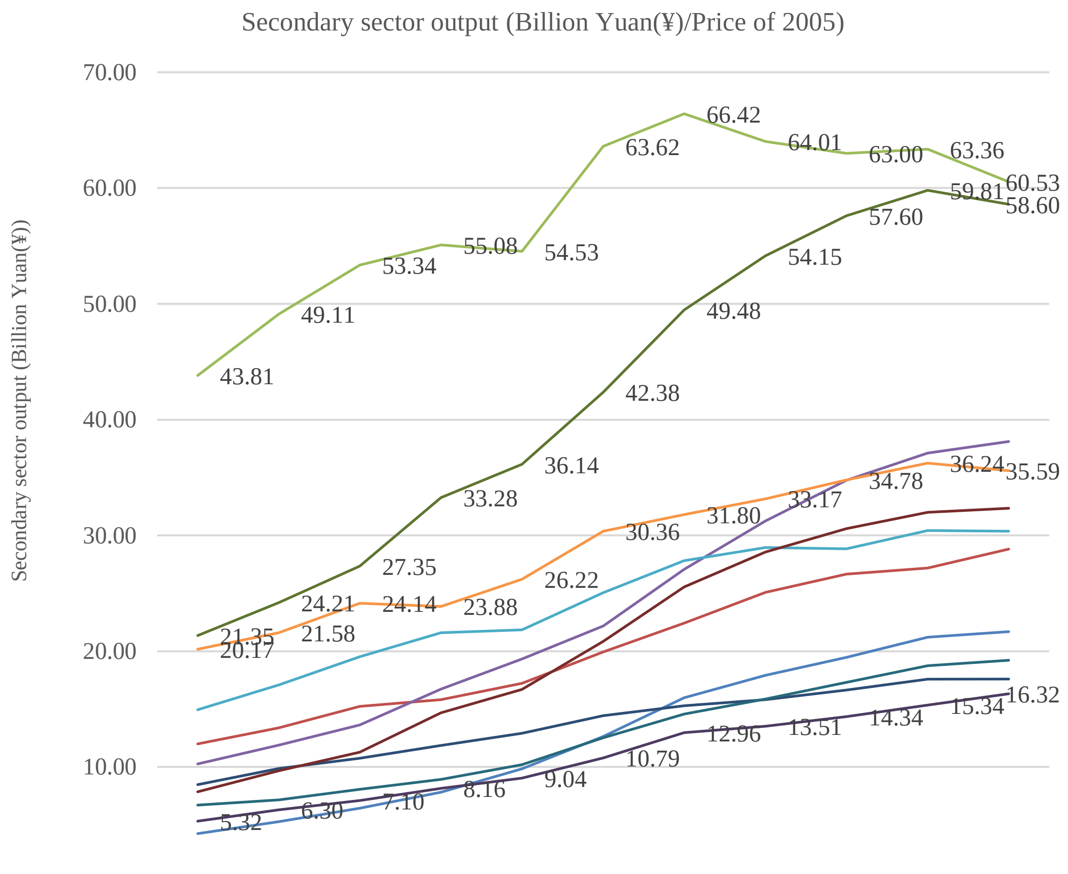


	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Hefei	0.53	0.61	0.73	0.93	0.97	1.15	1.43	1.54	1.59	1.61	1.64
Nanjing	1.02	1.08	1.09	1.07	1.15	1.22	1.33	1.46	1.50	1.61	1.71
Shanghai	0.90	0.93	0.98	1.01	1.03	1.01	1.05	1.04	0.99	0.96	0.83
Wuhan	1.10	1.14	1.22	1.30	1.34	1.49	1.65	2.44	2.65	2.72	2.75
Hangzhou	1.48	1.53	1.56	1.64	1.76	1.85	2.01	2.11	2.11	2.17	2.24
Beijing	0.86	0.85	0.96	1.03	1.09	1.12	1.16	1.24	1.29	1.27	1.10
Jinan	1.34	1.44	1.43	1.58	1.68	1.90	1.99	2.07	2.20	2.26	2.33
Changsha	1.14	1.15	1.24	1.51	1.58	1.73	1.97	2.17	2.28	2.35	2.55
Tianjing	1.12	1.02	1.04	1.10	1.17	1.27	1.33	1.39	1.49	1.55	1.59
Nanchang	0.73	0.76	0.82	0.90	1.00	1.04	1.11	1.17	1.20	1.24	1.28
Fuzhou	1.75	1.75	1.94	2.16	2.23	2.52	2.77	3.06	3.15	3.32	3.41

Figure 34– The Primary sector output

- Secondary sector

The secondary sector pertains to the transformation of raw materials which was produced in the primary sector into finished products. Especially in China's economy, manufacturing and construction took the main part. Associated with industrialisation and the development of manufacturing, this sector is the backbone of industrialised nations. It covers everything from simple handcrafted goods production to highly automated and technologically advanced manufacturing processes. Figure 35 displays the secondary industry output of eleven cities over eleven years, with the statistical data similarly deflated to the 2005 base year. The secondary sector in most cities maintained rapid growth during this period. Among all the data, the figures for Shanghai and Tianjin are particularly striking. Throughout the entire statistical period, Shanghai had the highest secondary industry output, which began to gradually decline after 2011 as the economy transitioned towards the tertiary sector, which offers higher added value and profit. This transition is evident in the subsequent statistics for the tertiary sector. Tianjin achieved a very high growth rate in the secondary sector over the eleven-year statistical period, gradually approaching Shanghai's output around 2014. Tianjin's convenient transportation conditions, including its excellent international deep-water port and the developed Beijing-Shanghai and Beijing-Tianjin high-speed railway networks, have played a significant role in the rapid development of its manufacturing industry. In other cities, those that were initially relatively backwards in the secondary sector, such as Hefei and Wuhan, also achieved very high growth rates in later years.

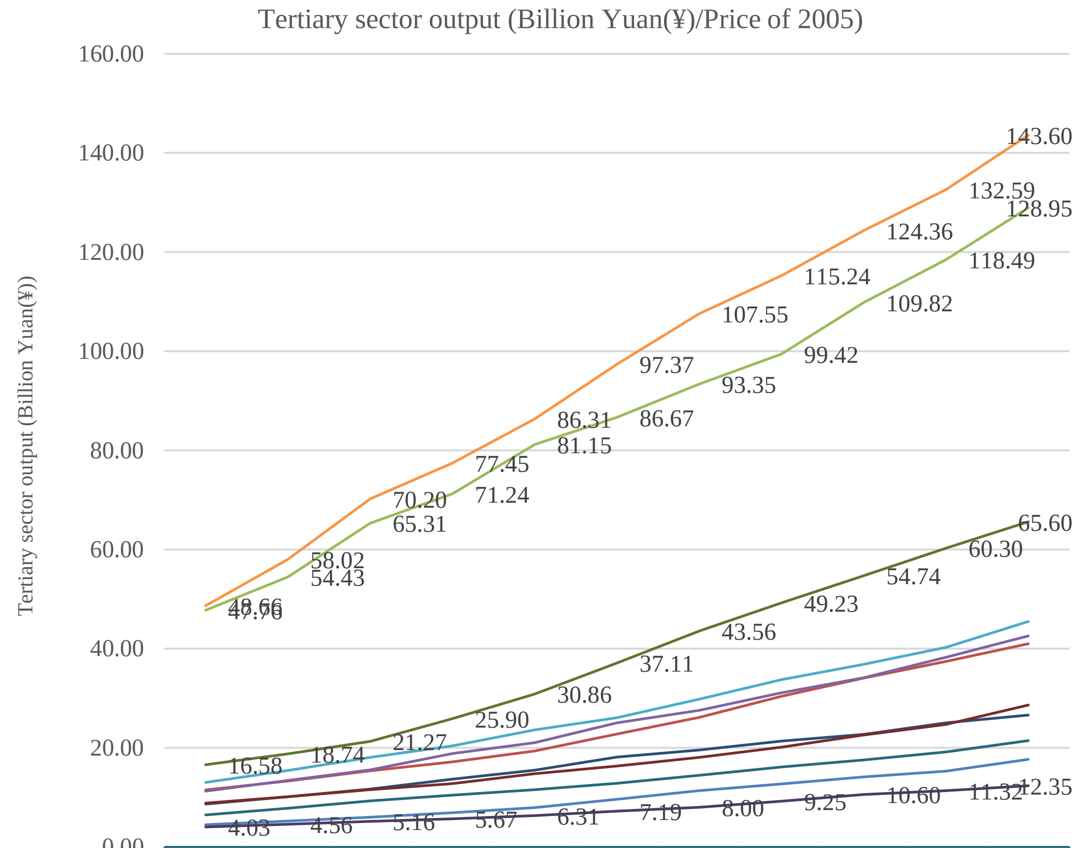


	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Hefei	4.25	5.28	6.43	7.83	9.84	12.62	15.98	17.93	19.48	21.21	21.69
Nanjing	11.99	13.37	15.24	15.81	17.22	19.93	22.42	25.07	26.66	27.19	28.82
Shanghai	43.81	49.11	53.34	55.08	54.53	63.62	66.42	64.01	63.00	63.36	60.53
Wuhan	10.26	11.89	13.64	16.74	19.32	22.17	27.08	31.24	34.75	37.13	38.11
Hangzhou	14.94	17.08	19.53	21.59	21.84	25.05	27.81	28.95	28.84	30.42	30.38
Beijing	20.17	21.58	24.14	23.88	26.22	30.36	31.80	33.17	34.78	36.24	35.59
Jinan	8.47	9.88	10.77	11.85	12.90	14.43	15.29	15.82	16.64	17.58	17.59
Changsha	7.86	9.67	11.28	14.69	16.71	20.85	25.56	28.57	30.59	32.01	32.35
Tianjing	21.35	24.21	27.35	33.28	36.14	42.38	49.48	54.15	57.60	59.81	58.60
Nanchang	5.32	6.30	7.10	8.16	9.04	10.79	12.96	13.51	14.34	15.34	16.32
Fuzhou	6.71	7.15	8.07	8.92	10.21	12.51	14.57	15.88	17.32	18.75	19.22

Figure 35– The Secondary sector output

- Tertiary sector

The tertiary sector, also known as the service industry, provides intangible goods or services. It includes a wide range of activities such as retail, education, health, finance, consulting, tourism, and hospitality services. As economies evolve, the service sector becomes the dominant industry in many countries, reflecting a shift towards more advanced economic forms. Figure 36 shows the tertiary industry output statistics for eleven cities over eleven years, with 2005 also taken as the base year and the data deflated according to the CPI. Observing the graph reveals that the scale of the tertiary sector in all cities maintained rapid growth during the study period, and the more developed the economy, the larger the scale of its tertiary sector. In detail, it is apparent that Beijing and Shanghai's tertiary industry output far exceeds that of other sample cities and maintains rapid growth. This demonstrates the attractiveness of Beijing and Shanghai as regional core megacities for the service industry and high-tech manufacturing. Moreover, comparing the output of these two cities in the secondary and primary sectors, it can be seen that developed cities are transitioning to more high-end industries in their development process, phasing out relatively low-end manufacturing and the primary sector. Among the remaining cities, Tianjin's tertiary sector, like its secondary sector, maintained a trend of rapid development. Hangzhou, Wuhan, and Nanjing also maintained relatively fast growth rates.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Hefei	4.49	5.23	6.00	6.92	7.91	9.64	11.33	12.68	14.10	15.30	17.67
Nanjing	11.50	13.31	15.34	17.18	19.36	22.77	26.15	30.41	34.05	37.40	40.99
Shanghai	47.76	54.43	65.31	71.24	81.15	86.67	93.35	99.42	109.82	118.49	128.95
Wuhan	11.25	13.39	15.54	18.85	21.01	25.06	27.54	31.11	34.15	38.27	42.57
Hangzhou	13.01	15.42	18.09	20.36	23.59	26.10	29.84	33.73	36.82	40.23	45.48
Beijing	48.66	58.02	70.20	77.45	86.31	97.37	107.55	115.24	124.36	132.59	143.60
Jinan	8.64	10.10	11.65	13.71	15.48	18.13	19.56	21.33	22.70	25.01	26.60
Changsha	8.84	10.13	11.57	12.77	14.75	16.33	18.04	20.16	22.57	24.69	28.62
Tianjing	16.58	18.74	21.27	25.90	30.86	37.11	43.56	49.23	54.74	60.30	65.60
Nanchang	4.03	4.56	5.16	5.67	6.31	7.19	8.00	9.25	10.60	11.32	12.35
Fuzhou	6.46	7.83	9.31	10.42	11.55	12.84	14.48	16.15	17.55	19.14	21.45

Figure 36– The Tertiary sector output

4.5.2 Analysis model structure, variables, cases and period

The empirical study in this chapter utilises the same sample as the previous experiments, selecting All cities within the East China Railway Network. The intercity traffic service destination includes five core cities Hefei, Nanjing, Shanghai, Wuhan, and Hangzhou as well as six peripheral cities: Beijing, Jinan, Tianjin, Fuzhou, Nanchang, and Changsha. The study period remains the same, covering eleven years from 2005 to 2015.

In the empirical analysis, DACC, DWACC and WACC continue to be incorporated as explanatory variables in the econometric model. These indicators represent the daily high-speed railway inter-city commuting benefit rate, the daily high-speed rail inter-city commuting benefit rate with an 8-hour time budget limit and the conventional railway weekly inter-city commuting benefit rate respectively. The design of these variables aims to explore how changes in inter-city transport conditions affect the output of the primary, secondary, and tertiary industries, and to compare how the three industries in different cities correlate with accessibility for high-speed and slow-speed travel. Therefore, the previously mentioned accessibility econometric analysis model has been adapted accordingly.

Firstly, the dependent variable has shifted from the difference in a certain indicator between two cities to the industrial value of the destination city associated with accessibility indices, corresponding to Y_j^{ps}, Y_j^{ss}, and Y_j^{ts}. The base year of 2005 was still selected, and the output data were deflated to a uniform price level based on annual CPI, reflecting the real economic development level.

Secondly, logarithms have been applied to both the independent and dependent variables. At this point, the coefficients of the regression variables represent the elasticity coefficients of industrial output in relation to accessibility. Given the widening gap in the scale of the three industries across different cities, comparing the regression coefficients between different industry groups directly is not feasible. Thus, taking logarithms and measuring elasticity allows for a comparison between industrial development and changes in accessibility.

Thirdly, before the introduction of high-speed rail services, the speed of conventional rail services was relatively slow, making it impossible for many long-distance inter-city commutes to be completed within a day. This resulted in the presence of zero values in the accessibility coefficients, which cannot be logarithmically transformed. To address this, the non-zero minimum value for each group of accessibility data has been identified, and a deviation value has been established based on the decimal places of the minimum value, allowing for a very small logarithmic value to be assigned to zero accessibility coefficients.

Fourthly, the control variable SACCD has been omitted. Since the dependent variable is the industrial output data of the destination city, and this chapter's empirical analysis discusses the impact of improved transport benefits to the destination on the destination's industry, the SACCD variable has been removed.

$$\ln(Y_j) = \ln(ACC_{ij}{}') \times \beta_{ACC} + z'_i\delta + u_i + \varepsilon_{it} \quad 4\text{-}8$$

$$ACC_{ij}{}' = \begin{pmatrix} DACC_{ij}^{t1} & DWACC_{ij}^{t1} & WACC_{ij}^{t1} \\ \vdots & \vdots & \vdots \\ DACC_{ij}^{tn} & DWACC_{ij}^{tn} & WACC_{ij}^{tn} \end{pmatrix}; \beta_{ACC} = \begin{pmatrix} \beta_{DACC} \\ \beta_{DWACC} \\ \beta_{WACC} \end{pmatrix} \quad 4\text{-}9$$

i and j: Start point and destination;

t: Research period, 1 to n;

Y_j: Explained variable; Industry output of destination j;

ACC_{ij}: Accessibility value matrix;

$DACC_{ij}$: Daily accessibility; $DWACC_{ij}$: Daily working accessibility with a fixed 8-hour working time budget; $WACC_{ij}$: Weekly working accessibility;

β_{DACC}, β_{DWACC}, β_{WACC}: Parameters of the different levels of the corresponding ACC index;

$z'_i\delta$: Time-invariant variable; $u_i + \varepsilon_{it}$: composite error term.

For a city, the transportation services connecting it are not limited to railway services, and commuters also come from various places, not just those specified by the railway routes in the cases selected. The choice to use panel data for regression analysis of all data sets, without setting up sub-panels, is also aimed at increasing the volume of data in the regression cases to enhance credibility.

In the real world economy, the output values of the primary, secondary, and tertiary industries are influenced by many factors, such as interest rates, investment volumes, labour force, technological levels, and demand, among others. In the analysis of this chapter, the model only includes the level of accessibility and cannot fully analyse the specific reasons for the growth of the three industries in detail. Therefore, the results focus and comparatively pay more attention to the elasticity between accessibility and industrial output changes under different travel speeds.

4.5.3 Regression result

Table 31 displays the panel data regression results for the three industries, with all regression models achieving relatively good fits. In the three sets of results, the elasticity coefficients of all accessibility data, which were logarithmically transformed, passed the 95% significance test.

Table 31 – Industry Output Fixed Effects Panel Test Result

All-Cities Fixed Effects Panel Test Result; Service: 50; Years: 11; Samples: 550;			
Primary sector (PS)	Coefficient	p-value	Within R-sq
Log Daily ACC (logDACC)	0.017	0.000	0.5747
Log Daily work ACC (logDWACC)	0.041	0.000	
Log Weekly work ACC (logWACC)	0.341	0.000	
Constant	3.32	0.000	
Secondary sector (SS)	Coefficient	p-value	Within R-sq
Log Daily ACC (logDACC)	0.032	0.000	0.6205
Log Daily work ACC (logDWACC)	0.064	0.000	
Log Weekly work ACC (logWACC)	0.557	0.000	
Constant	6.38	0.000	
Tertiary sector (TS)	Coefficient	p-value	Within R-sq
Log Daily ACC (logDACC)	0.037	0.000	0.6897
Log Daily work ACC (logDWACC)	0.072	0.000	
Log Weekly work ACC (logWACC)	0.631	0.000	
Constant	6.642	0.000	

In the first set of regression results, the elasticity coefficients of DACC, DWACC, and WACC relative to the primary industry output are 0.017, 0.041, and 0.341, respectively, showing a gradual increase. In the second set of regression results, the elasticity coefficients of the three different speeds of accessibility for the secondary industry are 0.032, 0.064, and 0.557. In the final set of regressions, the elasticity coefficients of the three accessibility indicators relative to the tertiary industry are 0.037, 0.072, and 0.631. All coefficient signs are positive, indicating that improvements in inter-city commuting accessibility have a positive effect on industrial output. Overall, the elasticity of changes in the first, second, and third industries relative to changes in accessibility indicators is low, all below 1, indicating inelasticity, which means a 1% increase in passenger accessibility leads to less than a 1% increase in destination industry output. In each industry, the same order of coefficient magnitude is observed, with logWACC greater than logDWACC greater than log DACC, indicating that slower rail and high-speed rail daily commutes with an 8-hour time budget can have a more significant effect on economic development. Comparing the accessibility coefficients of the three combined cases vertically, it can be seen that sensitivity to transport accessibility gradually increases from the primary to the tertiary industry. Taking WACC and DWACC as examples, their sensitivity to the tertiary industry increased by 13.3% and 12.5% respectively compared to the secondary industry, and compared to the primary industry, elasticity increased by 85% and 75.6%. This reflects that the tertiary sector, mainly including services and high-tech industries, has a higher demand for transport services compared to traditional agriculture and industry.

4.6 Conclusion

This chapter presented a series of empirical analyses to validate the accessibility indicators designed to measure the impact of high-speed rail on local economies and population migration. Through the analyses, several key findings emerged, highlighting the dynamic relationship between high-speed rail services and regional socio-economic development.

The first analysis focused on optimal intercity traffic service speeds. Results indicated that increases in service speed significantly enhanced passengers' accessibility and reduced travel costs. For example, the DACC coefficient, representing daily intercity commuting accessibility, showed a notable improvement for cities like Hefei and Nanjing, with travel speeds increasing by over 50% on certain routes. Furthermore, the daily work accessibility index (DWACC) reflected increased economic benefits as service speeds grew, demonstrating the positive correlation between accessibility and economic growth.

In the second analysis, the impact of high-speed rail on population migration was investigated. The results revealed that high-speed rail services are particularly effective in reducing population disparities between cities. For example, in cities like Hefei, the DACC coefficient improved by 0.940 in the period between 2005 and 2010, facilitating greater population mobility. This finding was especially pronounced for smaller and developing cities, where high-speed rail significantly reduced the reliance on slower transport modes, allowing for more balanced regional growth.

The third analysis, termed Dynamic Population-Accessibility Effectiveness, explored the fluctuating impacts of population migration following the introduction of new high-speed rail services. It was observed that the effect of high-speed rail on population dynamics typically occurred within a period of four to five years. For instance, the All Cities case study demonstrated a 0.940 increase in the DACC coefficient during the 2005-2010 period, showing rapid growth in daily commuting accessibility. However, as the model progressed to a later period (2007-2012), the DACC coefficient dropped to -0.362, indicating a shift in commuting patterns and accessibility dynamics as the network matured.

Finally, the analysis extended to the economic impact of high-speed rail services on different industrial sectors. The regression results revealed that the tertiary sector exhibited the highest sensitivity to changes in accessibility, with the WACC coefficient showing an elasticity of 0.631. This finding underscores the importance of fast and reliable intercity commuting for advanced industries, particularly in services and high-tech sectors. The secondary sector followed with an elasticity of 0.557, while the primary sector demonstrated lower elasticity, at 0.341. These results suggest that high-speed rail plays a crucial role in driving industrial development, particularly in more advanced and service-oriented economies.

In conclusion, the findings from Chapter 4 validate the practicality of the accessibility indicators, highlighting the significant role of high-speed rail in shaping regional economic integration, population mobility, and industrial development. The results underscore the importance of continued investment in high-speed rail infrastructure to support balanced growth across both developing and established urban regions.

Chapter 5. Conclusions and Future Work

5.1 Conclusion

This research investigates the impact of high-speed railway systems on local economic development using a novel accessibility measurement methodology. By creating three levels of accessibility indicators tailored to the frequency and timing of travellers' commutes, the study links technical railway data with economic outcomes, offering a fresh perspective from the average traveller's benefit level to assess a transport system's utility and its economic impact. The focus is particularly on the demands commuting imposes on transport systems and how these affect individuals' income levels and life strategies, simulating the experience from the viewpoint of a typical commuter considering both benefits and costs.

In Chapter 1, the backgroud and significance of HSR in both Europe and Asia were introduced. It reviewed existing studies on the economic benefits of HSR, such as regional integration, economic growth, and population distribution. Despite these benefits, challenges like cost-effectiveness and long-term impacts on housing markets and regional development were highlighted, presenting research gaps that this study aimed to address.

The Chapter 2 detailed the methodology for measuring accessibility. A new approach was introduced, focusing on three levels of accessibility indicators: Daily Accessibility (DACC), Daily Work Commuting Accessibility (DWACC), and Weekly Return Accessibility (WACC). This chapter also defined the variables and structure of the econometric model used to test these indicators, offering a comprehensive framework for understanding how HSR impacts population migration and economic performance.

In the initial phase of empirical analysis，the Chapter 3, eleven cities within the East China high-speed railway network were selected to evaluate economic accessibility. This sample included five core hub cities centrally located and six peripheral cities. Data from over 50 sources, encompassing histories of high-speed and conventional railway services, intra-city traffic, economic statistics, and demographic profiles, were compiled for analysis. The results indicated that for most individuals during the study period, opting for a daily commute via high-speed railway over distances exceeding 400 km was still not practical. However, a significant finding was that high-speed railway services have expanded the feasibility of daily inter-city commutes, connecting an increasing number of cities. Particularly notable was the impact on cities at the periphery of the conventional rail network, where high-speed railways have made it possible to undertake daily round trips involving over 7 hours of travel and 8 hours of work within a single day, thus broadening the scope of opportunities for commuters.

In Chapter 4, four empirical applications were conducted to validate the accessibility indicators using statistical data. The first application involved an analysis of optimal intercity traffic service speeds, where the relationship between the speed of the train—from below 100 km/h to over 600 km/h for Maglev trains—and changes in passengers' travel expenditures was modelled. This involved building a service speed and traveller's cost function across three distinct service routes. Based on the developed speed-cost function, six groups representing the daily accessibility index for round trips on these routes were evaluated. The findings indicate a year-over-year increase in passengers' perceived travel benefits, aligning with economic growth and stable ticket prices. Concurrently, the speed of intercity travel at the same accessibility level increased, suggesting that travellers can now access higher speeds of commuting without incurring additional costs relative to the benefits of living, effectively enhancing the cost-effectiveness of faster travel options. In the second part of the accessibility application, the relationship between population dynamics and accessibility was examined. This study introduced three levels of the accessibility indicator, representing the intercity commuter's profit level from slow travel speed to fast speed, and demographical data, which were differentiated by registered resident and long-term resident, into the panel data regression model to analyse how different level of travel speed influence population migration patterns. The model result proved that the modern high-speed service could help to disperse the population, reducing the difference between a developed city and a developing one. On the other hand, the traditional slow-speed service could reverse this progress, enlarging the population difference and aggregating the labour force, leading to a local core city. Meanwhile, by comparing the parameters, the HSR has approximately 6 to 7 times greater strength than the conventional railway service and it has become the main travel-related power of local population migration. The third empirical analysis, termed Dynamic Population-Accessibility Effectiveness Analysis, extended the case study from the second part by employing different sampling intervals to examine the duration of effects. The model results revealed a fluctuation period of four to five years in population migration following the introduction of new, faster railway services. During this period, a pronounced divergence in the effectiveness on population concentration and dispersion was observed between the conventional slow-speed services and the new high-speed services. This analysis highlights how high-speed railway significantly alters the dynamic of population movements, contrasting sharply with the patterns established by older, slower services. The final accessibility application integrated economic data into the model, encompassing the industrial output of the primary, secondary, and tertiary sectors. By comparing the results between the groups, the test demonstrated that the tertiary and secondary sectors exhibited greater sensitivity to changes in traffic conditions, indicating that the more advanced industries in the economy have a higher demand for speed in intercity commuting. Even in the inside of each group, the high-speed railway service presented a higher influence and stronger relationship on the industry development than the normal speed railway service.

5.2 Future work

In this study, a series of accessibility-economy analysing indicators and structures were designed and applied to real-world empirical cases. Considering the limitations and insufficiency of this research, the future study will be extended to more aspects to promote the methodology and application. Further tasks and targets are suggested:

1) The current accessibility measuring method focuses on the individual's travel attractiveness and fiction. Meanwhile, the traffic flow information is also an essential element to asses the traffic condition. In future work, the intercity travel flow and railway service capacity will be integrated to improve the accessibility indicators' comprehensiveness.
2) In this research, the highspeed railway impact on the economy was discussed through the accessibility measurement with created indicators. In future work, not only the railway information but also the data of the other traffic forms, such as road, air and water traffic, will be integrated into the system, expanding the scale and enriching the content of this transport economy research.

3) Due to the limitation of the statistical data quality, the case study mainly used the data of the main railway hub cities in the east of China from 2005 to 2015. The future analysis will include more areas in different countries with longer periods to test and verify the methodology in various scenarios.
4) The accessibility indicator was applied in the field of demographic and macroeconomic analysis in this research. Considering its definition and method structure, the accessibility indicator is also able to be used for the investment planning and industrial policy-making process related to high-speed railway construction, transferring it from an analysis tool to a decision-making toolbox.

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Chapter 7. Appendix A – Publication during PhD research

Zhang, E., Chen, L., Kuang, P., & Dickinson, D. G. (2023). An Accessibility Measurement Based on Commuter Behaviour and Living Conditions: An Empirical Analysis of the High-Speed Railway Network in the East of China. Sustainability, 15(5), 4309.

Chapter 8. Appendix B - Data and table

Table 32 – Hefei-Nanjing TCF DACC

Speed (km/h)	Time(H)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
89.14	1.75	0.173	0.198	0.220	0.235	0.257	0.274	0.295	0.321	0.341	0.352	0.372
90.43	1.725	0.172	0.196	0.219	0.233	0.255	0.272	0.293	0.319	0.338	0.350	0.369
91.76	1.7	0.170	0.195	0.217	0.232	0.254	0.270	0.290	0.316	0.336	0.347	0.367
93.13	1.675	0.169	0.193	0.215	0.230	0.252	0.268	0.288	0.314	0.333	0.345	0.364
94.55	1.65	0.168	0.192	0.214	0.228	0.250	0.266	0.286	0.311	0.331	0.342	0.361
96.00	1.625	0.166	0.190	0.212	0.226	0.248	0.264	0.284	0.309	0.328	0.339	0.358
97.50	1.6	0.165	0.189	0.210	0.224	0.246	0.262	0.281	0.306	0.325	0.337	0.356
99.05	1.575	0.163	0.187	0.208	0.223	0.244	0.260	0.279	0.304	0.323	0.334	0.353
100.65	1.55	0.162	0.185	0.207	0.221	0.242	0.257	0.277	0.301	0.320	0.331	0.350
102.30	1.525	0.161	0.184	0.205	0.219	0.239	0.255	0.274	0.299	0.317	0.328	0.347
104.00	1.5	0.159	0.182	0.203	0.217	0.237	0.253	0.272	0.296	0.314	0.326	0.344
105.76	1.475	0.158	0.181	0.201	0.215	0.235	0.251	0.269	0.293	0.312	0.323	0.341
107.59	1.45	0.156	0.179	0.199	0.213	0.233	0.248	0.267	0.291	0.309	0.320	0.338
109.47	1.425	0.155	0.177	0.197	0.211	0.231	0.246	0.264	0.288	0.306	0.317	0.335
111.43	1.4	0.153	0.175	0.195	0.209	0.229	0.244	0.262	0.285	0.303	0.314	0.331
113.45	1.375	0.152	0.174	0.193	0.207	0.226	0.241	0.259	0.283	0.300	0.311	0.328
115.56	1.35	0.150	0.172	0.191	0.205	0.224	0.239	0.257	0.280	0.297	0.308	0.325
117.74	1.325	0.148	0.170	0.189	0.202	0.222	0.236	0.254	0.277	0.294	0.304	0.322
120.00	1.3	0.147	0.168	0.187	0.200	0.219	0.234	0.251	0.274	0.291	0.301	0.318
122.35	1.275	0.145	0.166	0.185	0.198	0.217	0.231	0.249	0.271	0.288	0.298	0.315
124.80	1.25	0.144	0.164	0.183	0.196	0.214	0.229	0.246	0.268	0.285	0.295	0.312
127.35	1.225	0.142	0.163	0.181	0.194	0.212	0.226	0.243	0.265	0.281	0.291	0.308
130.00	1.2	0.140	0.161	0.179	0.191	0.209	0.223	0.240	0.262	0.278	0.288	0.305
132.77	1.175	0.138	0.159	0.177	0.189	0.207	0.221	0.237	0.259	0.275	0.285	0.301
135.65	1.15	0.137	0.157	0.174	0.187	0.204	0.218	0.234	0.255	0.272	0.281	0.297
138.67	1.125	0.135	0.155	0.172	0.184	0.202	0.215	0.231	0.252	0.268	0.278	0.294
141.82	1.1	0.133	0.153	0.170	0.182	0.199	0.212	0.228	0.249	0.265	0.274	0.290
145.12	1.075	0.131	0.150	0.168	0.179	0.196	0.209	0.225	0.246	0.261	0.270	0.286
148.57	1.05	0.129	0.148	0.165	0.177	0.194	0.206	0.222	0.242	0.257	0.267	0.282
152.20	1.025	0.128	0.146	0.163	0.174	0.191	0.203	0.219	0.239	0.254	0.263	0.278
156.00	1	0.126	0.144	0.160	0.172	0.188	0.200	0.216	0.235	0.250	0.259	0.274
160.00	0.975	0.124	0.142	0.158	0.169	0.185	0.197	0.212	0.232	0.246	0.255	0.270
164.21	0.95	0.122	0.140	0.155	0.166	0.182	0.194	0.209	0.228	0.243	0.251	0.266
168.65	0.925	0.120	0.137	0.153	0.164	0.179	0.191	0.206	0.224	0.239	0.247	0.262
173.33	0.9	0.118	0.135	0.150	0.161	0.176	0.188	0.202	0.221	0.235	0.243	0.257
178.29	0.875	0.116	0.133	0.148	0.158	0.173	0.185	0.199	0.217	0.231	0.239	0.253
183.53	0.85	0.114	0.130	0.145	0.155	0.170	0.181	0.195	0.213	0.227	0.235	0.248
189.09	0.825	0.111	0.128	0.142	0.152	0.167	0.178	0.191	0.209	0.222	0.231	0.244
195.00	0.8	0.109	0.125	0.140	0.149	0.164	0.174	0.188	0.205	0.218	0.226	0.239
201.29	0.775	0.107	0.123	0.137	0.146	0.160	0.171	0.184	0.201	0.214	0.222	0.235
208.00	0.75	0.105	0.120	0.134	0.143	0.157	0.167	0.180	0.197	0.209	0.217	0.230
215.17	0.725	0.102	0.117	0.131	0.140	0.154	0.164	0.176	0.192	0.205	0.212	0.225
222.86	0.7	0.100	0.115	0.128	0.137	0.150	0.160	0.172	0.188	0.200	0.208	0.220
231.11	0.675	0.098	0.112	0.125	0.134	0.147	0.156	0.168	0.184	0.196	0.203	0.215
240.00	0.65	0.095	0.109	0.122	0.130	0.143	0.152	0.164	0.179	0.191	0.198	0.210
249.60	0.625	0.093	0.106	0.119	0.127	0.139	0.148	0.160	0.175	0.186	0.193	0.204
260.00	0.6	0.090	0.103	0.115	0.123	0.136	0.144	0.155	0.170	0.181	0.188	0.199
271.30	0.575	0.088	0.101	0.112	0.120	0.132	0.140	0.151	0.165	0.176	0.183	0.193
283.64	0.55	0.085	0.098	0.109	0.116	0.128	0.136	0.147	0.160	0.171	0.177	0.188
297.14	0.525	0.082	0.094	0.105	0.113	0.124	0.132	0.142	0.155	0.165	0.172	0.182
312.00	0.5	0.080	0.091	0.102	0.109	0.120	0.128	0.137	0.150	0.160	0.166	0.176
328.42	0.475	0.077	0.088	0.098	0.105	0.115	0.123	0.133	0.145	0.154	0.160	0.170
346.67	0.45	0.074	0.085	0.095	0.101	0.111	0.118	0.128	0.140	0.149	0.154	0.164
367.06	0.425	0.071	0.081	0.091	0.097	0.107	0.114	0.123	0.134	0.143	0.148	0.157
390.00	0.4	0.068	0.078	0.087	0.093	0.102	0.109	0.117	0.128	0.137	0.142	0.151
416.00	0.375	0.065	0.074	0.083	0.089	0.098	0.104	0.112	0.123	0.131	0.136	0.144
445.71	0.35	0.062	0.071	0.079	0.085	0.093	0.099	0.107	0.117	0.125	0.129	0.137
480.00	0.325	0.058	0.067	0.075	0.080	0.088	0.094	0.101	0.111	0.118	0.123	0.130
520.00	0.3	0.055	0.063	0.071	0.076	0.083	0.088	0.095	0.104	0.111	0.116	0.123
567.27	0.275	0.052	0.059	0.066	0.071	0.078	0.083	0.089	0.098	0.104	0.109	0.115
624.00	0.25	0.048	0.055	0.062	0.066	0.073	0.077	0.083	0.091	0.097	0.101	0.107

Table 33 – Hefei-Shanghai TCF DACC

Speed (Km/h)	Time(H)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
50.32	9.40	0.140	0.158	0.174	0.183	0.206	0.221	0.239	0.255	0.261	0.392	0.409
50.86	9.30	0.139	0.157	0.173	0.182	0.205	0.220	0.238	0.254	0.259	0.390	0.407
51.41	9.20	0.138	0.156	0.172	0.181	0.204	0.219	0.236	0.253	0.258	0.388	0.405
51.98	9.10	0.138	0.155	0.171	0.180	0.203	0.218	0.235	0.252	0.257	0.386	0.403
52.56	9.00	0.137	0.155	0.170	0.179	0.202	0.217	0.234	0.250	0.256	0.384	0.401
53.15	8.90	0.136	0.154	0.169	0.178	0.201	0.216	0.233	0.249	0.254	0.382	0.399
53.75	8.80	0.136	0.153	0.168	0.177	0.200	0.214	0.232	0.248	0.253	0.380	0.397
54.37	8.70	0.135	0.152	0.167	0.176	0.199	0.213	0.230	0.246	0.252	0.378	0.395
55.00	8.60	0.134	0.151	0.166	0.175	0.198	0.212	0.229	0.245	0.250	0.376	0.393
55.65	8.50	0.133	0.150	0.165	0.174	0.197	0.211	0.228	0.244	0.249	0.374	0.390
56.31	8.40	0.133	0.149	0.164	0.173	0.196	0.210	0.226	0.242	0.247	0.372	0.388
56.99	8.30	0.132	0.149	0.164	0.172	0.194	0.208	0.225	0.241	0.246	0.370	0.386
57.68	8.20	0.131	0.148	0.163	0.171	0.193	0.207	0.224	0.239	0.244	0.368	0.384
58.40	8.10	0.130	0.147	0.162	0.170	0.192	0.206	0.222	0.238	0.243	0.366	0.381
59.13	8.00	0.129	0.146	0.161	0.169	0.191	0.205	0.221	0.237	0.242	0.363	0.379
59.87	7.90	0.129	0.145	0.160	0.168	0.190	0.203	0.220	0.235	0.240	0.361	0.377
60.64	7.80	0.128	0.144	0.159	0.167	0.189	0.202	0.218	0.234	0.239	0.359	0.374
61.43	7.70	0.127	0.143	0.157	0.166	0.187	0.201	0.217	0.232	0.237	0.356	0.372
62.24	7.60	0.126	0.142	0.156	0.165	0.186	0.199	0.215	0.231	0.235	0.354	0.369
63.07	7.50	0.125	0.141	0.155	0.164	0.185	0.198	0.214	0.229	0.234	0.352	0.367
63.92	7.40	0.124	0.140	0.154	0.163	0.184	0.197	0.213	0.228	0.232	0.349	0.365
64.79	7.30	0.123	0.139	0.153	0.162	0.182	0.195	0.211	0.226	0.231	0.347	0.362
65.69	7.20	0.123	0.138	0.152	0.160	0.181	0.194	0.210	0.224	0.229	0.344	0.359
66.62	7.10	0.122	0.137	0.151	0.159	0.180	0.193	0.208	0.223	0.227	0.342	0.357
67.57	7.00	0.121	0.136	0.150	0.158	0.178	0.191	0.207	0.221	0.226	0.340	0.354
68.55	6.90	0.120	0.135	0.149	0.157	0.177	0.190	0.205	0.219	0.224	0.337	0.352
69.56	6.80	0.119	0.134	0.148	0.156	0.176	0.188	0.203	0.218	0.222	0.334	0.349
70.60	6.70	0.118	0.133	0.146	0.154	0.174	0.187	0.202	0.216	0.221	0.332	0.346
71.67	6.60	0.117	0.132	0.145	0.153	0.173	0.185	0.200	0.214	0.219	0.329	0.343
72.77	6.50	0.116	0.131	0.144	0.152	0.171	0.184	0.199	0.213	0.217	0.326	0.341
73.91	6.40	0.115	0.130	0.143	0.151	0.170	0.182	0.197	0.211	0.215	0.324	0.338
75.08	6.30	0.114	0.129	0.142	0.149	0.168	0.181	0.195	0.209	0.213	0.321	0.335
76.29	6.20	0.113	0.127	0.140	0.148	0.167	0.179	0.193	0.207	0.212	0.318	0.332
77.54	6.10	0.112	0.126	0.139	0.147	0.166	0.177	0.192	0.205	0.210	0.315	0.329
78.83	6.00	0.111	0.125	0.138	0.145	0.164	0.176	0.190	0.203	0.208	0.312	0.326
80.17	5.90	0.110	0.124	0.136	0.144	0.162	0.174	0.188	0.202	0.206	0.310	0.323
81.55	5.80	0.109	0.123	0.135	0.143	0.161	0.173	0.186	0.200	0.204	0.307	0.320
82.98	5.70	0.108	0.122	0.134	0.141	0.159	0.171	0.185	0.198	0.202	0.304	0.317
84.46	5.60	0.107	0.120	0.132	0.140	0.158	0.169	0.183	0.196	0.200	0.301	0.314
86.00	5.50	0.105	0.119	0.131	0.138	0.156	0.167	0.181	0.194	0.198	0.297	0.310
87.59	5.40	0.104	0.118	0.130	0.137	0.154	0.166	0.179	0.192	0.196	0.294	0.307
89.25	5.30	0.103	0.116	0.128	0.135	0.153	0.164	0.177	0.190	0.194	0.291	0.304
90.96	5.20	0.102	0.115	0.127	0.134	0.151	0.162	0.175	0.187	0.191	0.288	0.301
92.75	5.10	0.101	0.114	0.125	0.132	0.149	0.160	0.173	0.185	0.189	0.285	0.297
94.60	5.00	0.100	0.113	0.124	0.131	0.148	0.158	0.171	0.183	0.187	0.281	0.294
96.53	4.90	0.098	0.111	0.122	0.129	0.146	0.156	0.169	0.181	0.185	0.278	0.290
98.54	4.80	0.097	0.110	0.121	0.128	0.144	0.154	0.167	0.179	0.183	0.275	0.287
100.64	4.70	0.096	0.108	0.119	0.126	0.142	0.152	0.165	0.176	0.180	0.271	0.283
102.83	4.60	0.095	0.107	0.118	0.124	0.140	0.150	0.163	0.174	0.178	0.268	0.279
105.11	4.50	0.093	0.105	0.116	0.123	0.138	0.148	0.160	0.172	0.175	0.264	0.276
107.50	4.40	0.092	0.104	0.114	0.121	0.136	0.146	0.158	0.169	0.173	0.260	0.272
110.00	4.30	0.091	0.102	0.113	0.119	0.134	0.144	0.156	0.167	0.171	0.257	0.268
112.62	4.20	0.089	0.101	0.111	0.117	0.132	0.142	0.154	0.165	0.168	0.253	0.264
115.37	4.10	0.088	0.099	0.109	0.116	0.130	0.140	0.151	0.162	0.166	0.249	0.260
118.25	4.00	0.087	0.098	0.108	0.114	0.128	0.138	0.149	0.160	0.163	0.245	0.256
121.28	3.90	0.085	0.096	0.106	0.112	0.126	0.136	0.147	0.157	0.160	0.241	0.252
124.47	3.80	0.084	0.095	0.104	0.110	0.124	0.133	0.144	0.154	0.158	0.237	0.248
127.84	3.70	0.082	0.093	0.102	0.108	0.122	0.131	0.142	0.152	0.155	0.233	0.243
131.39	3.60	0.081	0.091	0.101	0.106	0.120	0.129	0.139	0.149	0.152	0.229	0.239
135.14	3.50	0.079	0.090	0.099	0.104	0.118	0.126	0.136	0.146	0.149	0.225	0.235
139.12	3.40	0.078	0.088	0.097	0.102	0.115	0.124	0.134	0.144	0.147	0.220	0.230
143.33	3.30	0.076	0.086	0.095	0.100	0.113	0.121	0.131	0.141	0.144	0.216	0.226
147.81	3.20	0.075	0.084	0.093	0.098	0.111	0.119	0.128	0.138	0.141	0.212	0.221
152.58	3.10	0.073	0.082	0.091	0.096	0.108	0.116	0.126	0.135	0.138	0.207	0.216
157.67	3.00	0.071	0.081	0.089	0.094	0.106	0.114	0.123	0.132	0.135	0.202	0.211

163.10	2.90	0.070	0.079	0.087	0.092	0.103	0.111	0.120	0.129	0.131	0.198	0.207
168.93	2.80	0.068	0.077	0.085	0.089	0.101	0.108	0.117	0.126	0.128	0.193	0.202
175.19	2.70	0.066	0.075	0.082	0.087	0.098	0.106	0.114	0.122	0.125	0.188	0.196
181.92	2.60	0.064	0.073	0.080	0.085	0.096	0.103	0.111	0.119	0.122	0.183	0.191
189.20	2.50	0.063	0.071	0.078	0.082	0.093	0.100	0.108	0.116	0.118	0.178	0.186
197.08	2.40	0.061	0.069	0.076	0.080	0.090	0.097	0.105	0.112	0.115	0.173	0.181
205.65	2.30	0.059	0.067	0.073	0.078	0.088	0.094	0.102	0.109	0.111	0.168	0.175
215.00	2.20	0.057	0.064	0.071	0.075	0.085	0.091	0.098	0.106	0.108	0.162	0.169
225.24	2.10	0.055	0.062	0.069	0.072	0.082	0.088	0.095	0.102	0.104	0.157	0.164
236.50	2.00	0.053	0.060	0.066	0.070	0.079	0.085	0.092	0.098	0.100	0.151	0.158
248.95	1.90	0.051	0.058	0.064	0.067	0.076	0.082	0.088	0.095	0.097	0.145	0.152
262.78	1.80	0.049	0.055	0.061	0.064	0.073	0.078	0.085	0.091	0.093	0.139	0.146
278.24	1.70	0.047	0.053	0.058	0.062	0.070	0.075	0.081	0.087	0.089	0.133	0.139
295.62	1.60	0.045	0.050	0.056	0.059	0.066	0.071	0.077	0.083	0.085	0.127	0.133
315.33	1.50	0.042	0.048	0.053	0.056	0.063	0.068	0.073	0.079	0.080	0.121	0.126
337.86	1.40	0.040	0.045	0.050	0.053	0.060	0.064	0.069	0.075	0.076	0.115	0.120
363.85	1.30	0.038	0.043	0.047	0.050	0.056	0.061	0.065	0.070	0.072	0.108	0.113
394.17	1.20	0.035	0.040	0.044	0.047	0.053	0.057	0.061	0.066	0.067	0.101	0.106
430.00	1.10	0.033	0.037	0.041	0.044	0.049	0.053	0.057	0.061	0.063	0.094	0.098
473.00	1.00	0.030	0.035	0.038	0.040	0.045	0.049	0.053	0.057	0.058	0.087	0.091
525.56	0.90	0.028	0.032	0.035	0.037	0.042	0.045	0.048	0.052	0.053	0.080	0.083
591.25	0.80	0.025	0.029	0.031	0.033	0.038	0.041	0.044	0.047	0.048	0.072	0.076
675.71	0.70	0.023	0.026	0.028	0.030	0.034	0.036	0.039	0.042	0.043	0.065	0.067

Table 34 – Hefei-Shanghai TCF DACC

Speed (Km/h)	Time(H)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
50.32	9.40	0.140	0.158	0.174	0.183	0.206	0.221	0.239	0.255	0.261	0.392	0.409
50.86	9.30	0.139	0.157	0.173	0.182	0.205	0.220	0.238	0.254	0.259	0.390	0.407
51.41	9.20	0.138	0.156	0.172	0.181	0.204	0.219	0.236	0.253	0.258	0.388	0.405
51.98	9.10	0.138	0.155	0.171	0.180	0.203	0.218	0.235	0.252	0.257	0.386	0.403
52.56	9.00	0.137	0.155	0.170	0.179	0.202	0.217	0.234	0.250	0.256	0.384	0.401
53.15	8.90	0.136	0.154	0.169	0.178	0.201	0.216	0.233	0.249	0.254	0.382	0.399
53.75	8.80	0.136	0.153	0.168	0.177	0.200	0.214	0.232	0.248	0.253	0.380	0.397
54.37	8.70	0.135	0.152	0.167	0.176	0.199	0.213	0.230	0.246	0.252	0.378	0.395
55.00	8.60	0.134	0.151	0.166	0.175	0.198	0.212	0.229	0.245	0.250	0.376	0.393
55.65	8.50	0.133	0.150	0.165	0.174	0.197	0.211	0.228	0.244	0.249	0.374	0.390
56.31	8.40	0.133	0.149	0.164	0.173	0.196	0.210	0.226	0.242	0.247	0.372	0.388
56.99	8.30	0.132	0.149	0.164	0.172	0.194	0.208	0.225	0.241	0.246	0.370	0.386
57.68	8.20	0.131	0.148	0.163	0.171	0.193	0.207	0.224	0.239	0.244	0.368	0.384
58.40	8.10	0.130	0.147	0.162	0.170	0.192	0.206	0.222	0.238	0.243	0.366	0.381
59.13	8.00	0.129	0.146	0.161	0.169	0.191	0.205	0.221	0.237	0.242	0.363	0.379
59.87	7.90	0.129	0.145	0.160	0.168	0.190	0.203	0.220	0.235	0.240	0.361	0.377
60.64	7.80	0.128	0.144	0.159	0.167	0.189	0.202	0.218	0.234	0.239	0.359	0.374
61.43	7.70	0.127	0.143	0.157	0.166	0.187	0.201	0.217	0.232	0.237	0.356	0.372
62.24	7.60	0.126	0.142	0.156	0.165	0.186	0.199	0.215	0.231	0.235	0.354	0.369
63.07	7.50	0.125	0.141	0.155	0.164	0.185	0.198	0.214	0.229	0.234	0.352	0.367
63.92	7.40	0.124	0.140	0.154	0.163	0.184	0.197	0.213	0.228	0.232	0.349	0.365
64.79	7.30	0.123	0.139	0.153	0.162	0.182	0.195	0.211	0.226	0.231	0.347	0.362
65.69	7.20	0.123	0.138	0.152	0.160	0.181	0.194	0.210	0.224	0.229	0.344	0.359
66.62	7.10	0.122	0.137	0.151	0.159	0.180	0.193	0.208	0.223	0.227	0.342	0.357
67.57	7.00	0.121	0.136	0.150	0.158	0.178	0.191	0.207	0.221	0.226	0.340	0.354
68.55	6.90	0.120	0.135	0.149	0.157	0.177	0.190	0.205	0.219	0.224	0.337	0.352
69.56	6.80	0.119	0.134	0.148	0.156	0.176	0.188	0.203	0.218	0.222	0.334	0.349
70.60	6.70	0.118	0.133	0.146	0.154	0.174	0.187	0.202	0.216	0.221	0.332	0.346
71.67	6.60	0.117	0.132	0.145	0.153	0.173	0.185	0.200	0.214	0.219	0.329	0.343
72.77	6.50	0.116	0.131	0.144	0.152	0.171	0.184	0.199	0.213	0.217	0.326	0.341
73.91	6.40	0.115	0.130	0.143	0.151	0.170	0.182	0.197	0.211	0.215	0.324	0.338
75.08	6.30	0.114	0.129	0.142	0.149	0.168	0.181	0.195	0.209	0.213	0.321	0.335
76.29	6.20	0.113	0.127	0.140	0.148	0.167	0.179	0.193	0.207	0.212	0.318	0.332
77.54	6.10	0.112	0.126	0.139	0.147	0.166	0.177	0.192	0.205	0.210	0.315	0.329
78.83	6.00	0.111	0.125	0.138	0.145	0.164	0.176	0.190	0.203	0.208	0.312	0.326
80.17	5.90	0.110	0.124	0.136	0.144	0.162	0.174	0.188	0.202	0.206	0.310	0.323
81.55	5.80	0.109	0.123	0.135	0.143	0.161	0.173	0.186	0.200	0.204	0.307	0.320
82.98	5.70	0.108	0.122	0.134	0.141	0.159	0.171	0.185	0.198	0.202	0.304	0.317
84.46	5.60	0.107	0.120	0.132	0.140	0.158	0.169	0.183	0.196	0.200	0.301	0.314
86.00	5.50	0.105	0.119	0.131	0.138	0.156	0.167	0.181	0.194	0.198	0.297	0.310
87.59	5.40	0.104	0.118	0.130	0.137	0.154	0.166	0.179	0.192	0.196	0.294	0.307
89.25	5.30	0.103	0.116	0.128	0.135	0.153	0.164	0.177	0.190	0.194	0.291	0.304
90.96	5.20	0.102	0.115	0.127	0.134	0.151	0.162	0.175	0.187	0.191	0.288	0.301
92.75	5.10	0.101	0.114	0.125	0.132	0.149	0.160	0.173	0.185	0.189	0.285	0.297
94.60	5.00	0.100	0.113	0.124	0.131	0.148	0.158	0.171	0.183	0.187	0.281	0.294
96.53	4.90	0.098	0.111	0.122	0.129	0.146	0.156	0.169	0.181	0.185	0.278	0.290
98.54	4.80	0.097	0.110	0.121	0.128	0.144	0.154	0.167	0.179	0.183	0.275	0.287
100.64	4.70	0.096	0.108	0.119	0.126	0.142	0.152	0.165	0.176	0.180	0.271	0.283
102.83	4.60	0.095	0.107	0.118	0.124	0.140	0.150	0.163	0.174	0.178	0.268	0.279
105.11	4.50	0.093	0.105	0.116	0.123	0.138	0.148	0.160	0.172	0.175	0.264	0.276
107.50	4.40	0.092	0.104	0.114	0.121	0.136	0.146	0.158	0.169	0.173	0.260	0.272
110.00	4.30	0.091	0.102	0.113	0.119	0.134	0.144	0.156	0.167	0.171	0.257	0.268
112.62	4.20	0.089	0.101	0.111	0.117	0.132	0.142	0.154	0.165	0.168	0.253	0.264
115.37	4.10	0.088	0.099	0.109	0.116	0.130	0.140	0.151	0.162	0.166	0.249	0.260
118.25	4.00	0.087	0.098	0.108	0.114	0.128	0.138	0.149	0.160	0.163	0.245	0.256
121.28	3.90	0.085	0.096	0.106	0.112	0.126	0.136	0.147	0.157	0.160	0.241	0.252
124.47	3.80	0.084	0.095	0.104	0.110	0.124	0.133	0.144	0.154	0.158	0.237	0.248
127.84	3.70	0.082	0.093	0.102	0.108	0.122	0.131	0.142	0.152	0.155	0.233	0.243
131.39	3.60	0.081	0.091	0.101	0.106	0.120	0.129	0.139	0.149	0.152	0.229	0.239
135.14	3.50	0.079	0.090	0.099	0.104	0.118	0.126	0.136	0.146	0.149	0.225	0.235
139.12	3.40	0.078	0.088	0.097	0.102	0.115	0.124	0.134	0.144	0.147	0.220	0.230
143.33	3.30	0.076	0.086	0.095	0.100	0.113	0.121	0.131	0.141	0.144	0.216	0.226
147.81	3.20	0.075	0.084	0.093	0.098	0.111	0.119	0.128	0.138	0.141	0.212	0.221
152.58	3.10	0.073	0.082	0.091	0.096	0.108	0.116	0.126	0.135	0.138	0.207	0.216
157.67	3.00	0.071	0.081	0.089	0.094	0.106	0.114	0.123	0.132	0.135	0.202	0.211

163.10	2.90	0.070	0.079	0.087	0.092	0.103	0.111	0.120	0.129	0.131	0.198	0.207
168.93	2.80	0.068	0.077	0.085	0.089	0.101	0.108	0.117	0.126	0.128	0.193	0.202
175.19	2.70	0.066	0.075	0.082	0.087	0.098	0.106	0.114	0.122	0.125	0.188	0.196
181.92	2.60	0.064	0.073	0.080	0.085	0.096	0.103	0.111	0.119	0.122	0.183	0.191
189.20	2.50	0.063	0.071	0.078	0.082	0.093	0.100	0.108	0.116	0.118	0.178	0.186
197.08	2.40	0.061	0.069	0.076	0.080	0.090	0.097	0.105	0.112	0.115	0.173	0.181
205.65	2.30	0.059	0.067	0.073	0.078	0.088	0.094	0.102	0.109	0.111	0.168	0.175
215.00	2.20	0.057	0.064	0.071	0.075	0.085	0.091	0.098	0.106	0.108	0.162	0.169
225.24	2.10	0.055	0.062	0.069	0.072	0.082	0.088	0.095	0.102	0.104	0.157	0.164
236.50	2.00	0.053	0.060	0.066	0.070	0.079	0.085	0.092	0.098	0.100	0.151	0.158
248.95	1.90	0.051	0.058	0.064	0.067	0.076	0.082	0.088	0.095	0.097	0.145	0.152
262.78	1.80	0.049	0.055	0.061	0.064	0.073	0.078	0.085	0.091	0.093	0.139	0.146
278.24	1.70	0.047	0.053	0.058	0.062	0.070	0.075	0.081	0.087	0.089	0.133	0.139
295.62	1.60	0.045	0.050	0.056	0.059	0.066	0.071	0.077	0.083	0.085	0.127	0.133
315.33	1.50	0.042	0.048	0.053	0.056	0.063	0.068	0.073	0.079	0.080	0.121	0.126
337.86	1.40	0.040	0.045	0.050	0.053	0.060	0.064	0.069	0.075	0.076	0.115	0.120
363.85	1.30	0.038	0.043	0.047	0.050	0.056	0.061	0.065	0.070	0.072	0.108	0.113
394.17	1.20	0.035	0.040	0.044	0.047	0.053	0.057	0.061	0.066	0.067	0.101	0.106
430.00	1.10	0.033	0.037	0.041	0.044	0.049	0.053	0.057	0.061	0.063	0.094	0.098
473.00	1.00	0.030	0.035	0.038	0.040	0.045	0.049	0.053	0.057	0.058	0.087	0.091
525.56	0.90	0.028	0.032	0.035	0.037	0.042	0.045	0.048	0.052	0.053	0.080	0.083
591.25	0.80	0.025	0.029	0.031	0.033	0.038	0.041	0.044	0.047	0.048	0.072	0.076
675.71	0.70	0.023	0.026	0.028	0.030	0.034	0.036	0.039	0.042	0.043	0.065	0.067

Table 35 – Shanghai-Hefei TCF DACC

Speed (Km/h)	Time(H)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
50.32	9.40	0.081	0.091	0.104	0.113	0.125	0.135	0.149	0.166	0.177	0.181	0.189
50.86	9.30	0.080	0.090	0.104	0.112	0.124	0.134	0.149	0.165	0.176	0.180	0.188
51.41	9.20	0.080	0.090	0.103	0.112	0.124	0.133	0.148	0.164	0.175	0.179	0.187
51.98	9.10	0.079	0.089	0.103	0.111	0.123	0.133	0.147	0.163	0.174	0.178	0.186
52.56	9.00	0.079	0.089	0.102	0.111	0.122	0.132	0.147	0.162	0.174	0.177	0.185
53.15	8.90	0.079	0.088	0.101	0.110	0.122	0.131	0.146	0.162	0.173	0.176	0.184
53.75	8.80	0.078	0.088	0.101	0.110	0.121	0.131	0.145	0.161	0.172	0.175	0.183
54.37	8.70	0.078	0.087	0.100	0.109	0.120	0.130	0.144	0.160	0.171	0.174	0.182
55.00	8.60	0.077	0.087	0.100	0.108	0.120	0.129	0.143	0.159	0.170	0.173	0.181
55.65	8.50	0.077	0.086	0.099	0.108	0.119	0.128	0.143	0.158	0.169	0.172	0.181
56.31	8.40	0.076	0.086	0.099	0.107	0.119	0.128	0.142	0.157	0.168	0.171	0.180
56.99	8.30	0.076	0.085	0.098	0.107	0.118	0.127	0.141	0.156	0.167	0.170	0.179
57.68	8.20	0.075	0.085	0.098	0.106	0.117	0.126	0.140	0.155	0.166	0.170	0.178
58.40	8.10	0.075	0.084	0.097	0.105	0.116	0.126	0.139	0.155	0.165	0.169	0.177
59.13	8.00	0.075	0.084	0.096	0.105	0.116	0.125	0.139	0.154	0.164	0.168	0.176
59.87	7.90	0.074	0.083	0.096	0.104	0.115	0.124	0.138	0.153	0.163	0.167	0.174
60.64	7.80	0.074	0.083	0.095	0.103	0.114	0.123	0.137	0.152	0.162	0.165	0.173
61.43	7.70	0.073	0.082	0.095	0.103	0.114	0.122	0.136	0.151	0.161	0.164	0.172
62.24	7.60	0.073	0.082	0.094	0.102	0.113	0.122	0.135	0.150	0.160	0.163	0.171
63.07	7.50	0.072	0.081	0.093	0.101	0.112	0.121	0.134	0.149	0.159	0.162	0.170
63.92	7.40	0.072	0.081	0.093	0.101	0.111	0.120	0.133	0.148	0.158	0.161	0.169
64.79	7.30	0.071	0.080	0.092	0.100	0.111	0.119	0.132	0.147	0.157	0.160	0.168
65.69	7.20	0.071	0.079	0.091	0.099	0.110	0.118	0.132	0.146	0.156	0.159	0.167
66.62	7.10	0.070	0.079	0.091	0.098	0.109	0.118	0.131	0.145	0.155	0.158	0.166
67.57	7.00	0.070	0.078	0.090	0.098	0.108	0.117	0.130	0.144	0.154	0.157	0.165
68.55	6.90	0.069	0.078	0.089	0.097	0.107	0.116	0.129	0.143	0.152	0.156	0.163
69.56	6.80	0.069	0.077	0.089	0.096	0.107	0.115	0.128	0.141	0.151	0.154	0.162
70.60	6.70	0.068	0.077	0.088	0.096	0.106	0.114	0.127	0.140	0.150	0.153	0.161
71.67	6.60	0.067	0.076	0.087	0.095	0.105	0.113	0.126	0.139	0.149	0.152	0.160
72.77	6.50	0.067	0.075	0.087	0.094	0.104	0.112	0.125	0.138	0.148	0.151	0.158
73.91	6.40	0.066	0.075	0.086	0.093	0.103	0.111	0.124	0.137	0.147	0.150	0.157
75.08	6.30	0.066	0.074	0.085	0.092	0.102	0.110	0.123	0.136	0.145	0.148	0.156
76.29	6.20	0.065	0.073	0.084	0.092	0.101	0.109	0.122	0.135	0.144	0.147	0.155
77.54	6.10	0.065	0.073	0.084	0.091	0.101	0.108	0.120	0.133	0.143	0.146	0.153
78.83	6.00	0.064	0.072	0.083	0.090	0.100	0.107	0.119	0.132	0.142	0.145	0.152
80.17	5.90	0.063	0.071	0.082	0.089	0.099	0.106	0.118	0.131	0.140	0.143	0.151
81.55	5.80	0.063	0.071	0.081	0.088	0.098	0.105	0.117	0.130	0.139	0.142	0.149
82.98	5.70	0.062	0.070	0.080	0.087	0.097	0.104	0.116	0.129	0.138	0.140	0.148
84.46	5.60	0.062	0.069	0.080	0.087	0.096	0.103	0.115	0.127	0.136	0.139	0.146
86.00	5.50	0.061	0.069	0.079	0.086	0.095	0.102	0.114	0.126	0.135	0.138	0.145
87.59	5.40	0.060	0.068	0.078	0.085	0.094	0.101	0.113	0.125	0.133	0.136	0.143
89.25	5.30	0.060	0.067	0.077	0.084	0.093	0.100	0.111	0.123	0.132	0.135	0.142
90.96	5.20	0.059	0.066	0.076	0.083	0.092	0.099	0.110	0.122	0.131	0.133	0.140
92.75	5.10	0.058	0.066	0.075	0.082	0.091	0.098	0.109	0.121	0.129	0.132	0.139
94.60	5.00	0.058	0.065	0.075	0.081	0.090	0.097	0.108	0.119	0.128	0.130	0.137
96.53	4.90	0.057	0.064	0.074	0.080	0.089	0.096	0.106	0.118	0.126	0.129	0.136
98.54	4.80	0.056	0.063	0.073	0.079	0.088	0.094	0.105	0.116	0.125	0.127	0.134
100.64	4.70	0.055	0.062	0.072	0.078	0.086	0.093	0.104	0.115	0.123	0.126	0.132
102.83	4.60	0.055	0.062	0.071	0.077	0.085	0.092	0.102	0.113	0.121	0.124	0.131
105.11	4.50	0.054	0.061	0.070	0.076	0.084	0.091	0.101	0.112	0.120	0.122	0.129
107.50	4.40	0.053	0.060	0.069	0.075	0.083	0.090	0.100	0.110	0.118	0.121	0.127
110.00	4.30	0.052	0.059	0.068	0.074	0.082	0.088	0.098	0.109	0.117	0.119	0.126
112.62	4.20	0.052	0.058	0.067	0.073	0.081	0.087	0.097	0.107	0.115	0.117	0.124
115.37	4.10	0.051	0.057	0.066	0.072	0.079	0.086	0.095	0.106	0.113	0.116	0.122
118.25	4.00	0.050	0.056	0.065	0.071	0.078	0.084	0.094	0.104	0.111	0.114	0.120
121.28	3.90	0.049	0.056	0.064	0.069	0.077	0.083	0.092	0.102	0.110	0.112	0.118
124.47	3.80	0.048	0.055	0.063	0.068	0.076	0.082	0.091	0.101	0.108	0.110	0.116
127.84	3.70	0.048	0.054	0.062	0.067	0.074	0.080	0.089	0.099	0.106	0.108	0.114
131.39	3.60	0.047	0.053	0.061	0.066	0.073	0.079	0.088	0.097	0.104	0.106	0.112
135.14	3.50	0.046	0.052	0.060	0.065	0.072	0.077	0.086	0.095	0.102	0.104	0.110
139.12	3.40	0.045	0.051	0.058	0.064	0.070	0.076	0.084	0.094	0.100	0.103	0.108
143.33	3.30	0.044	0.050	0.057	0.062	0.069	0.074	0.083	0.092	0.098	0.101	0.106
147.81	3.20	0.043	0.049	0.056	0.061	0.068	0.073	0.081	0.090	0.096	0.098	0.104
152.58	3.10	0.042	0.048	0.055	0.060	0.066	0.071	0.079	0.088	0.094	0.096	0.102
157.67	3.00	0.041	0.047	0.054	0.058	0.065	0.070	0.078	0.086	0.092	0.094	0.100
163.10	2.90	0.040	0.045	0.052	0.057	0.063	0.068	0.076	0.084	0.090	0.092	0.098
168.93	2.80	0.039	0.044	0.051	0.056	0.062	0.067	0.074	0.082	0.088	0.090	0.095
175.19	2.70	0.038	0.043	0.050	0.054	0.060	0.065	0.072	0.080	0.086	0.088	0.093

181.92	2.60	0.037	0.042	0.048	0.053	0.058	0.063	0.070	0.078	0.083	0.085	0.090
189.20	2.50	0.036	0.041	0.047	0.051	0.057	0.061	0.068	0.076	0.081	0.083	0.088
197.08	2.40	0.035	0.040	0.046	0.050	0.055	0.060	0.066	0.074	0.079	0.081	0.085
205.65	2.30	0.034	0.038	0.044	0.048	0.054	0.058	0.064	0.071	0.076	0.078	0.083
215.00	2.20	0.033	0.037	0.043	0.047	0.052	0.056	0.062	0.069	0.074	0.076	0.080
225.24	2.10	0.032	0.036	0.041	0.045	0.050	0.054	0.060	0.067	0.072	0.073	0.078
236.50	2.00	0.031	0.035	0.040	0.044	0.048	0.052	0.058	0.064	0.069	0.071	0.075
248.95	1.90	0.030	0.033	0.038	0.042	0.046	0.050	0.056	0.062	0.066	0.068	0.072
262.78	1.80	0.028	0.032	0.037	0.040	0.045	0.048	0.054	0.059	0.064	0.065	0.069
278.24	1.70	0.027	0.031	0.035	0.038	0.043	0.046	0.051	0.057	0.061	0.062	0.066
295.62	1.60	0.026	0.029	0.034	0.037	0.041	0.044	0.049	0.054	0.058	0.060	0.063
315.33	1.50	0.025	0.028	0.032	0.035	0.039	0.042	0.047	0.052	0.055	0.057	0.060
337.86	1.40	0.023	0.026	0.030	0.033	0.037	0.040	0.044	0.049	0.052	0.054	0.057
363.85	1.30	0.022	0.025	0.029	0.031	0.035	0.037	0.042	0.046	0.049	0.051	0.054
394.17	1.20	0.021	0.023	0.027	0.029	0.032	0.035	0.039	0.043	0.046	0.047	0.051
430.00	1.10	0.019	0.022	0.025	0.027	0.030	0.033	0.036	0.040	0.043	0.044	0.047
473.00	1.00	0.018	0.020	0.023	0.025	0.028	0.030	0.034	0.037	0.040	0.041	0.044
525.56	0.90	0.016	0.018	0.021	0.023	0.026	0.028	0.031	0.034	0.037	0.037	0.040
591.25	0.80	0.015	0.017	0.019	0.021	0.023	0.025	0.028	0.031	0.033	0.034	0.036
675.71	0.70	0.013	0.015	0.017	0.019	0.021	0.022	0.025	0.028	0.030	0.030	0.032

Table 36 – Nanjing-Shanghai TCF DACC

Speed	Tij	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
99.03	3.10	0.103	0.116	0.128	0.135	0.152	0.163	0.177	0.189	0.193	0.291	0.303
100.66	3.05	0.102	0.115	0.126	0.133	0.150	0.161	0.174	0.187	0.191	0.287	0.299
102.33	3.00	0.100	0.113	0.124	0.131	0.148	0.159	0.172	0.184	0.188	0.283	0.295
104.07	2.95	0.099	0.111	0.123	0.129	0.146	0.157	0.169	0.181	0.185	0.278	0.291
105.86	2.90	0.097	0.110	0.121	0.127	0.144	0.154	0.167	0.179	0.182	0.274	0.286
107.72	2.85	0.096	0.108	0.119	0.125	0.142	0.152	0.164	0.176	0.180	0.270	0.282
109.64	2.80	0.094	0.106	0.117	0.123	0.139	0.150	0.162	0.173	0.177	0.266	0.278
111.64	2.75	0.093	0.105	0.115	0.121	0.137	0.147	0.159	0.170	0.174	0.262	0.273
113.70	2.70	0.091	0.103	0.113	0.119	0.135	0.145	0.156	0.168	0.171	0.257	0.269
115.85	2.65	0.089	0.101	0.111	0.117	0.133	0.142	0.154	0.165	0.168	0.253	0.264
118.08	2.60	0.088	0.099	0.109	0.115	0.130	0.140	0.151	0.162	0.165	0.249	0.259
120.39	2.55	0.086	0.097	0.107	0.113	0.128	0.137	0.148	0.159	0.162	0.244	0.255
122.80	2.50	0.085	0.096	0.105	0.111	0.125	0.135	0.146	0.156	0.159	0.240	0.250
125.31	2.45	0.083	0.094	0.103	0.109	0.123	0.132	0.143	0.153	0.156	0.235	0.245
127.92	2.40	0.081	0.092	0.101	0.107	0.121	0.130	0.140	0.150	0.153	0.230	0.241
130.64	2.35	0.080	0.090	0.099	0.105	0.118	0.127	0.137	0.147	0.150	0.226	0.236
133.48	2.30	0.078	0.088	0.097	0.103	0.116	0.124	0.134	0.144	0.147	0.221	0.231
136.44	2.25	0.076	0.086	0.095	0.100	0.113	0.122	0.131	0.141	0.144	0.216	0.226
139.55	2.20	0.075	0.084	0.093	0.098	0.111	0.119	0.129	0.138	0.141	0.212	0.221
142.79	2.15	0.073	0.082	0.091	0.096	0.108	0.116	0.126	0.135	0.138	0.207	0.216
146.19	2.10	0.071	0.080	0.089	0.094	0.106	0.113	0.123	0.131	0.134	0.202	0.211
149.76	2.05	0.069	0.078	0.086	0.091	0.103	0.111	0.120	0.128	0.131	0.197	0.206
153.50	2.00	0.068	0.076	0.084	0.089	0.100	0.108	0.117	0.125	0.128	0.192	0.201
157.44	1.95	0.066	0.074	0.082	0.087	0.098	0.105	0.114	0.122	0.124	0.187	0.195
161.58	1.90	0.064	0.072	0.080	0.084	0.095	0.102	0.110	0.118	0.121	0.182	0.190
165.95	1.85	0.062	0.070	0.077	0.082	0.092	0.099	0.107	0.115	0.118	0.177	0.185
170.56	1.80	0.060	0.068	0.075	0.080	0.090	0.096	0.104	0.112	0.114	0.172	0.179
175.43	1.75	0.059	0.066	0.073	0.077	0.087	0.094	0.101	0.108	0.111	0.167	0.174
180.59	1.70	0.057	0.064	0.071	0.075	0.084	0.091	0.098	0.105	0.107	0.162	0.169
186.06	1.65	0.055	0.062	0.068	0.072	0.082	0.088	0.095	0.102	0.104	0.156	0.163
191.88	1.60	0.053	0.060	0.066	0.070	0.079	0.085	0.092	0.098	0.100	0.151	0.158
198.06	1.55	0.051	0.058	0.064	0.067	0.076	0.082	0.088	0.095	0.097	0.146	0.152
204.67	1.50	0.049	0.056	0.061	0.065	0.073	0.079	0.085	0.091	0.093	0.140	0.147
211.72	1.45	0.047	0.054	0.059	0.062	0.070	0.076	0.082	0.088	0.090	0.135	0.141
219.29	1.40	0.045	0.051	0.057	0.060	0.068	0.073	0.079	0.084	0.086	0.130	0.135
227.41	1.35	0.044	0.049	0.054	0.057	0.065	0.070	0.075	0.081	0.083	0.124	0.130
236.15	1.30	0.042	0.047	0.052	0.055	0.062	0.067	0.072	0.077	0.079	0.119	0.124
245.60	1.25	0.040	0.045	0.049	0.052	0.059	0.064	0.069	0.074	0.075	0.113	0.118
255.83	1.20	0.038	0.043	0.047	0.050	0.056	0.060	0.065	0.070	0.072	0.108	0.113
266.96	1.15	0.036	0.041	0.045	0.047	0.053	0.057	0.062	0.067	0.068	0.102	0.107
279.09	1.10	0.034	0.038	0.042	0.045	0.051	0.054	0.059	0.063	0.064	0.097	0.101
292.38	1.05	0.032	0.036	0.040	0.042	0.048	0.051	0.055	0.060	0.061	0.091	0.096
307.00	1.00	0.030	0.034	0.037	0.040	0.045	0.048	0.052	0.056	0.057	0.086	0.090
323.16	0.95	0.028	0.032	0.035	0.037	0.042	0.045	0.049	0.052	0.054	0.081	0.084
341.11	0.90	0.026	0.030	0.033	0.035	0.039	0.042	0.046	0.049	0.050	0.075	0.079
361.18	0.85	0.024	0.028	0.030	0.032	0.036	0.039	0.042	0.045	0.046	0.070	0.073
383.75	0.80	0.023	0.025	0.028	0.030	0.034	0.036	0.039	0.042	0.043	0.064	0.067
409.33	0.75	0.021	0.023	0.026	0.027	0.031	0.033	0.036	0.038	0.039	0.059	0.062
438.57	0.70	0.019	0.021	0.023	0.025	0.028	0.030	0.033	0.035	0.036	0.054	0.056
472.31	0.65	0.017	0.019	0.021	0.022	0.025	0.027	0.030	0.032	0.032	0.049	0.051
511.67	0.60	0.015	0.017	0.019	0.020	0.023	0.024	0.026	0.028	0.029	0.044	0.046
558.18	0.55	0.014	0.015	0.017	0.018	0.020	0.022	0.023	0.025	0.026	0.039	0.040
614.00	0.50	0.012	0.013	0.015	0.016	0.018	0.019	0.021	0.022	0.023	0.034	0.035

Table 37 – Shanghai-Nanjing TCF DACC

Speed (Km/h)	Time(H)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
99.03	3.10	0.092	0.106	0.118	0.126	0.138	0.147	0.158	0.173	0.184	0.191	0.199
100.66	3.05	0.091	0.104	0.116	0.124	0.136	0.145	0.156	0.171	0.182	0.189	0.197
102.33	3.00	0.090	0.103	0.114	0.122	0.134	0.143	0.153	0.169	0.179	0.186	0.194
104.07	2.95	0.088	0.101	0.113	0.120	0.132	0.141	0.151	0.166	0.177	0.183	0.191
105.86	2.90	0.087	0.100	0.111	0.119	0.130	0.139	0.149	0.164	0.174	0.181	0.188
107.72	2.85	0.086	0.098	0.109	0.117	0.128	0.136	0.147	0.161	0.172	0.178	0.186
109.64	2.80	0.084	0.097	0.108	0.115	0.126	0.134	0.145	0.159	0.169	0.175	0.183
111.64	2.75	0.083	0.095	0.106	0.113	0.124	0.132	0.142	0.156	0.166	0.172	0.180
113.70	2.70	0.082	0.094	0.104	0.111	0.122	0.130	0.140	0.154	0.164	0.170	0.177
115.85	2.65	0.080	0.092	0.102	0.109	0.120	0.128	0.138	0.151	0.161	0.167	0.174
118.08	2.60	0.079	0.090	0.101	0.107	0.118	0.126	0.135	0.148	0.158	0.164	0.171
120.39	2.55	0.077	0.089	0.099	0.106	0.116	0.123	0.133	0.146	0.155	0.161	0.168
122.80	2.50	0.076	0.087	0.097	0.104	0.114	0.121	0.130	0.143	0.152	0.158	0.165
125.31	2.45	0.074	0.085	0.095	0.102	0.112	0.119	0.128	0.140	0.150	0.155	0.162
127.92	2.40	0.073	0.084	0.093	0.100	0.110	0.117	0.125	0.138	0.147	0.152	0.159
130.64	2.35	0.071	0.082	0.091	0.098	0.107	0.114	0.123	0.135	0.144	0.149	0.156
133.48	2.30	0.070	0.080	0.090	0.096	0.105	0.112	0.120	0.132	0.141	0.146	0.153
136.44	2.25	0.068	0.079	0.088	0.094	0.103	0.109	0.118	0.129	0.138	0.143	0.150
139.55	2.20	0.067	0.077	0.086	0.092	0.101	0.107	0.115	0.127	0.135	0.140	0.147
142.79	2.15	0.065	0.075	0.084	0.089	0.098	0.105	0.113	0.124	0.132	0.137	0.143
146.19	2.10	0.064	0.073	0.082	0.087	0.096	0.102	0.110	0.121	0.129	0.134	0.140
149.76	2.05	0.062	0.072	0.080	0.085	0.094	0.100	0.107	0.118	0.126	0.130	0.137
153.50	2.00	0.061	0.070	0.078	0.083	0.091	0.097	0.105	0.115	0.123	0.127	0.133
157.44	1.95	0.059	0.068	0.076	0.081	0.089	0.095	0.102	0.112	0.119	0.124	0.130
161.58	1.90	0.058	0.066	0.074	0.079	0.087	0.092	0.099	0.109	0.116	0.121	0.127
165.95	1.85	0.056	0.064	0.072	0.077	0.084	0.090	0.096	0.106	0.113	0.117	0.123
170.56	1.80	0.054	0.062	0.070	0.074	0.082	0.087	0.094	0.103	0.110	0.114	0.120
175.43	1.75	0.053	0.061	0.067	0.072	0.079	0.084	0.091	0.100	0.106	0.111	0.116
180.59	1.70	0.051	0.059	0.065	0.070	0.077	0.082	0.088	0.097	0.103	0.107	0.113
186.06	1.65	0.049	0.057	0.063	0.068	0.074	0.079	0.085	0.094	0.100	0.104	0.109
191.88	1.60	0.048	0.055	0.061	0.065	0.072	0.076	0.082	0.090	0.096	0.100	0.105
198.06	1.55	0.046	0.053	0.059	0.063	0.069	0.074	0.079	0.087	0.093	0.097	0.102
204.67	1.50	0.044	0.051	0.057	0.061	0.067	0.071	0.077	0.084	0.090	0.093	0.098
211.72	1.45	0.043	0.049	0.055	0.058	0.064	0.068	0.074	0.081	0.086	0.090	0.094
219.29	1.40	0.041	0.047	0.052	0.056	0.062	0.066	0.071	0.078	0.083	0.086	0.091
227.41	1.35	0.039	0.045	0.050	0.054	0.059	0.063	0.068	0.074	0.079	0.083	0.087
236.15	1.30	0.037	0.043	0.048	0.051	0.057	0.060	0.065	0.071	0.076	0.079	0.083
245.60	1.25	0.036	0.041	0.046	0.049	0.054	0.057	0.062	0.068	0.073	0.075	0.079
255.83	1.20	0.034	0.039	0.044	0.047	0.051	0.055	0.059	0.065	0.069	0.072	0.076
266.96	1.15	0.032	0.037	0.041	0.044	0.049	0.052	0.056	0.061	0.066	0.068	0.072
279.09	1.10	0.031	0.035	0.039	0.042	0.046	0.049	0.053	0.058	0.062	0.065	0.068
292.38	1.05	0.029	0.033	0.037	0.040	0.044	0.046	0.050	0.055	0.059	0.061	0.064
307.00	1.00	0.027	0.031	0.035	0.037	0.041	0.044	0.047	0.052	0.055	0.057	0.061
323.16	0.95	0.025	0.029	0.033	0.035	0.038	0.041	0.044	0.048	0.052	0.054	0.057
341.11	0.90	0.024	0.027	0.030	0.033	0.036	0.038	0.041	0.045	0.048	0.050	0.053
361.18	0.85	0.022	0.025	0.028	0.030	0.033	0.035	0.038	0.042	0.045	0.047	0.049
383.75	0.80	0.020	0.023	0.026	0.028	0.031	0.033	0.035	0.039	0.041	0.043	0.045
409.33	0.75	0.019	0.021	0.024	0.026	0.028	0.030	0.032	0.036	0.038	0.039	0.042
438.57	0.70	0.017	0.020	0.022	0.023	0.026	0.027	0.029	0.032	0.035	0.036	0.038
472.31	0.65	0.015	0.018	0.020	0.021	0.023	0.025	0.027	0.029	0.031	0.033	0.034
511.67	0.60	0.014	0.016	0.018	0.019	0.021	0.022	0.024	0.026	0.028	0.029	0.031
558.18	0.55	0.012	0.014	0.016	0.017	0.018	0.020	0.021	0.023	0.025	0.026	0.027
614.00	0.50	0.011	0.012	0.014	0.015	0.016	0.017	0.019	0.020	0.022	0.023	0.024