# The impacts of high-speed rail extensions on accessibility and spatial equity changes in South Korea from 2004 to 2018

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## Abstract:

The construction of South Korean High-Speed Rail (HSR) or Korea Train eXpress (KTX) has been evolving in phases since its first operation in 2004. This development raises concerns whether the benefits from the extended HSR network would again be limited to the initial HSR corridors and will deepen the inequalities in accessibility with the rising issue of uneven regional development of the country. This paper measures the accessibility of each stage of HSR network extension and evaluates its spatial distribution, variation, and changes using weighted averaged travel time and potential accessibility indicators. The results of this study find different accessibility impacts from each stage of HSR extension. Although travel-time reduction and increased attractions have been widened in more cities by each HSR extension, the spatial equity is degenerated by the extension in 2010/2011 as the improvement of accessibility has been concentrated in cities along the primary HSR corridor near the already-advantageous Seoul capital area. In contrast, the future HSR extension in 2018 will enhance equitable accessibility to the isolated regions such as the northeast and the southwest regions of the country. However, the relative degree of accessibility improvement will not be large enough for increasing the spatial equity of accessibility without more extended HSR networks between provinces.

**Keywords:** High-speed rail (HSR) | Accessibility | Spatial equity | South Korea

## Article:

### 1. Introduction

With operating speeds ranging between 250 and 350 km/h—twice that of the current ground transportation of automobiles or conventional trains, high-speed rail (HSR) operation brings entirely different impacts in the transportation system of a country. This increased speed reduces travel times and reorganizes the spatial interaction, unity, and competitiveness between cities and surrounding metropolitan regions (Forslund and Johansson, 1995, Martin, 1997, Vickerman et al., 1999, Martin et al., 2004). The degree of benefits enhanced by the HSR transport infrastructures in cities is commonly represented by accessibility (Gutiérrez, 2001, Cao et al., 2013)—a term generally defined as the potential opportunity for spatial interaction among spatially separated human activities promoted by transportation (Hansen, 1959). Improving accessibility is a common goal in almost all transportation plans (Handy and Niemeier, 1997), and hence, the construction of the HSR network is justified.

Benefits received from the HSR system are not evenly distributed across the country (Monzón et al., 2013). Considering construction costs and the large number of passengers required to sustain its service, there is no choice, but to focus on densely populated areas and HSR systems first must be constructed in the most economically efficient corridors. Direct effects from the HSR service are naturally limited to certain cities having HSR stations within this corridor, which foster further changes in land use and economic growth around this corridor and may eventually transform into a "regional core" (Martin, 1997). On the contrary, cities not served by HSR may suffer from relative disadvantages because of the relative loss of travel time to other cities (Vickerman, 1997, Ureña et al., 2009, Monzón et al., 2013). Although cities without HSR may receive some advantage indirectly from the network effect of being connected with HSR, these benefits are usually limited (Garmendia et al., 2012). Thus, the isolation from the initial HSR network may intensify spatial disparities of interactions among cities.

Providing equality in access from HSR transportation services is gaining popularity in transport-policy documents, and further HSR network extensions are in practice to increase network efficiency and reduce the unequal accessibility distribution to the periphery (Bruinsma and Rietveld, 1993, Gutiérrez et al., 1996, Martin, 1997). Pursuing network efficiency, however, can be reversely interpreted as creating disadvantaged areas that are far from the HSR network. Acceptable levels of equal access can be guaranteed while ensuring maximum economic benefits from the HSR network if improvement of the HSR infrastructure focuses on closing the gap. Therefore, the comparison of disparities and benefits from the construction of a current HSR network and future HSR networks can be an important process to identify the areas where improvement of the HSR infrastructure is necessary (Gutiérrez, 2001, Monzón et al., 2013).

In this context, the purpose of this study is to examine the disparity of accessibility as an indicator of benefits that cities have received or will receive from the Korean High-Speed Rail or Korea Train eXpress (KTX) at different stages of extensions: stage-1 (S1) (year 2004), stage-2 (S2) (year 2010/2011), and stage-3 (S3) (year 2018) using a multi-modal ground transportation networks. There is a paucity of research examining changes in accessibility and equity issues using proper accessibility measures from HSR networks (e.g., Monzón et al., 2013, Jiao et al., 2014, Marti-Henneberg, 2015), especially focusing on South Korean HSR. Limited research exists evaluating the effects of the first stage of HSR operation in 2004 (Chang and Lee, 2008), and this work was principally from the perspective of advantages of network efficiency. Chung and Lee (2011) used factor analysis to verify the relationship of socioeconomic and accessibility changes based on the average travel time to all destinations. Comparing the absolute travel-time changes between cities is an easy way to show the benefits of accessibility, but it does not reflect the importance of the travel time between two places—a crucial consideration to measure accessibility. Park and Ha (2006) and Chang and Lee (2008) conducted a disaggregated survey data analysis and represented the characteristics of passengers, degree of satisfaction, and major complaints of the HSR service. To our knowledge, no research has focused on the impacts of the HSR extensions in South Korea since S2 by using accessibility measures, especially addressing the issues of spatial equity using multimodal transportation network.

## 2. Review on accessibility measures and impacts of HSR

### 2.1. Accessibility measures

The concept and measurement of accessibility is an important implication for urban transportation researchers and planners because it evaluates the impact of transportation systems on travel and land-use patterns. Accessibility, therefore, has been used in various aspects such as location choice, travel demand forecasting, and appraisal of land-use changes (Handy and Niemeier, 1997). The concept of accessibility pursues practical applications in policy-making processes, yet the measurement of accessibility is more central to transportation research (Páez et al., 2012). Measures of accessibility are crucial for understanding the benefits of a transportation system through changes in proximity and supremacy of access from destinations and can be examined in terms of either population or economic status (Weber, 2012, Weber and Sultana, 2013).

Thorough reviews of accessibility measures exist (Geurs and van Wee, 2004, Páez et al., 2012), so we limit our discussion on accessibility measures relevant to the importance and interpretation of our study. Several types of accessibility measures exist for different uses, but two components that commonly influence accessibility measurements are: (1) ease of access, and (2) attractiveness of location (Páez et al., 2012). Since improving locational position of cities or regions is among the most important economic aspect for the constructions of HSR, location-based accessibility measures are most appropriate to evaluate the impact of this transportation infrastructure (Givoni, 2006, Martin, 1997, Gutiérrez, 2001, Chang and Lee, 2008, López et al., 2008, Monzón et al., 2013). These measures analyze accessibility at locations that are typically macro scale and describe the level of accessibility to spatially distributed activities, which include the land use and transportation components at locations (Geurs and van Wee, 2004).

The most widely used locational-based measures include distance or connectivity measure and gravity-based or potential accessibility (PA) measure. Distance measure evaluates degree of connectivity between locations by using distance; and the lowest total distance at the location is considered to have highest accessibility to all other locations. Using the same concept as distance measure, weighted average travel time (WATT) measure emphasizes the relationship between regions by calculating travel time (instead of distance) of a location to all other destinations considering the size of destinations. The size of the destination is used as weight in order to value the importance of the minimal travel time routes (Gutiérrez, 2001, Cao et al., 2013). The mathematical expression is as follows:

$$T_i = \frac{\sum_j M_j \cdot t_{ij}}{\sum_j M_j} \tag{1}$$

where $T_i$ is the accessibility of location $i$, $t_{ij}$ is the travel time to destination $j$, and $M_j$ is the size of $j$. Generally, the minimal travel time is used for $t_{ij}$, and the number of population or gross product is used for $M_j$ (in our case it is the total population of each city). This indicator focuses on the shortest travel time rather than the shortest distance. The data of population or gross product at locations are to value the importance of the travel time route. The interpretation of this indicator is simple: the reduced value of $T_i$ after the operation of the new HSR means a travel time saving of location $i$; and the lowest average travel time at the location is considered to have highest accessibility to all other locations.

Since WATT accessibility measure focuses only the travel-time benefits, not the economic potential at the location, another widely used accessibility indicator is potential accessibility (PA), which is a gravity-based measure using distance decay affects. PA measure focuses on the nearness of opportunity of economic activities in a location (Hansen, 1959, Gutiérrez, 2001, Martin et al., 2004, López et al., 2008, Cao et al., 2013, Monzón et al., 2013) with the assumption that the nearer and bigger a destination to a location, the higher its market potential. It is a gravity-based measure determined by the volume of the size of destinations divided by the travel time between them. The expression is as follows:

$$P_i = \sum_j \frac{M_j}{t_{ij}^{x}} \tag{2}$$

where $P_i$ is the PA of location $i$, $t_{ij}$ is the travel time between locations $i$ and $j$, $M_j$ is the size of destination $j$ (in our case it is the total population of each city), and $\alpha$ is a distance friction parameter. In this study, the value of $\alpha$ is used as 1. The use of a higher value of $\alpha$ has the problem of excessive reflection of adjacent destinations, so we use 1 as a parameter because it has been used by other researchers dealing with the similar measure at a national scale (Gutiérrez, 2001, Cao et al., 2013). The result is interpreted as the chances of economic potential of each city caused by the new HSR extensions. Higher values indicate higher potential adjacency of opportunities.

### 2.2. Efficiency impacts of HSR

Despite the uncertainty of the relationship between connectivity and economic growth (Martin, 1997, Pol, 2003, Givoni, 2006, Gutiérrez et al., 2010, Monzón et al., 2013), the efficiency impact of the network remains an important criterion for assessing the benefits of HSR. The improved efficiency of the HSR network has been evaluated widely from the perspective of the positive changes in accessibility because this is a major justification for the investment of the HSR network construction (Martin, 1997). As a result, when a HSR network across the border of European countries was proposed to achieve integration and efficiency in production and economic development among major cities in European countries, the evaluation of the impact of HSR became an important subject of study at various spatial scales (e.g., Gutiérrez et al., 1996, Vickerman et al., 1999, Gutiérrez, 2001, López et al., 2008, Monzón et al., 2013).

Using a potential accessibility (PA) measure, Gutiérrez et al. (1996) evaluated the impact of the future plan of the 2010 HSR network on major cities within the European Union and found that HSR could bring the highest accessibility between large cities within these countries.
Later, Gutiérrez (2001) predicted significant travel time benefits and economic expansions from the future new Madrid–Barcelona–French border HSR line in Europe by calculating the WATT

and PA values. However, both of these studies have taken into consideration only rail network, and hence, an approach to calculate accessibility by considering other ground transportation modes was required in the perspective of all other transportation networks. In reality, HSR competes with other transportation modes such as roads or airlines. Kotavaara et al. (2011) integrated the railway and road network in Finland to identify the relationship between accessibility and population change and found that the improvement of both the road and the rail networks promoted the increase of population. Instead of synthesizing different transportation networks, Cao et al. (2013) calculated improved accessibility by comparing the HSR network and air transportation in China and found that the eastern central cities show higher attractiveness or less total travel time in the current HSR network compared with the airplane because of locational advantage.

In summary, most studies focused on the accomplishment of planned accessibility from HSR construction and found that the major accessibility improvements were confined to existing large cities because of their initial locational advantage to the HSR service (Gutiérrez, 2001, Martin et al., 2004, Ureña et al., 2009). Thus, the anticipation of improved accessibility to its service region is related to enhanced dominance of cities benefitting from improved accessibility and diminishes a common goal, equity, in transport development (Litman, 2014).

## 2.3. Spatial equity issues with HSR

Historically, transport funding has been allocated so that the wealthier areas of a country or region get more transport benefits because of demand and the peripheral regions receive inadequate transport services, which exacerbates differences between regions. Much literature has analyzed the changes in accessibility benefits by the HSR network, but the evaluation of equity impacts of HSR is limited (Monzón et al., 2013). The major reason for this is that the concept of equity in transportation studies is rather ambiguous. In general, equity refers to the fairness and justice with which benefits and costs are appropriately distributed by the transportation projects. There are several types of equity, numerous impacts to consider, various ways to categorize people for analysis, and many ways of measuring impacts (Karner and Niemeier, 2013, Welch and Mishra, 2013, Litman, 2014) and these kind of data are not easily retrievable and projected, which pose challenges to measure it in terms of transportation benefits.

Considering the complexity, one useful approach in measuring transportation equity as a target is treating as either horizontal or vertical equity (Litman, 2014). Horizontal equity refers to providing an even service to all target groups or locations, treated as spatial equity by the researchers. This approach focuses on the equal distribution of benefits from public service to all areas. However, the horizontal equity approach has been criticized for ignoring the geographical discordance of socioeconomic condition. Thus, research focusing on evaluating public transportation service in the perspective of equity is closer to vertical equity, which treats relative service quality that benefits transportation-disadvantaged people (Delbosc and Currie, 2011, Foth et al., 2013). Vertical equity is also treated by researchers as social equity, which is increasingly important considerations in evaluating equity issues for any transportation project, especially in areas that already have high-quality transportation (van Wee and Geurs, 2011).

Research measuring equity issues from the development of HSR can be better addressed using the horizontal focus to examine the distribution of accessibility unevenness in the transportation network. This is because the key factor of the development of HSR is to enhance and strengthen economic competitiveness between cities and regions by reduction of travel time and congestion. Here the objects are cities and their spatial and locational organization as well as production, consumption, and interactions result from the HSR operation; not from the concern of individual passengers' needs. It is assumed living in cities with high HSR accessibility offer high potential for everyone. Research on the perspective of equity from HSR, therefore, measures whether HSR fosters disparity in accessibility or polarization in a county resulting from the uneven improvement of transportation services (e.g., Gutiérrez, 2001, Martin et al., 2004, Monzón et al., 2013).

Since accessibility usually has been measured by different indicators with different interpretations in accessibility gains, Martin et al. (2004) tried to measure overall accessibility inequalities among the cities and regions in Spain from the Madrid–Barcelona–French border corridor line. These authors developed a single synthetic accessibility index called the Data Employment Analysis index (DEA) by combining all well-established measurements of different accessibility indicators. The results of their inequality measures showed that the construction of the Madrid–Barcelona–French border HSR line will increase regional accessibility disparity. Monzón et al. (2013) specifically dealt with inequality as an important issue from the HSR in Spain focusing on the polarization by uneven growth of cities due to HSR. Using coefficient variance and normalized value of the improvement of accessibility of each city, their study showed more equitable accessibility value through the Spanish cities after the HSR extensions in Spain but does not alter the existing differences and the dominant positions of certain cities. Jiao et al. (2014)showed disparities in accessibility by using local variation of accessibility by city size and region and an exponential function of accessibility values with rank of cities.

The inclusion of efficiency and equity effects is increasing in demand by policy makers for any large-scale transportation investment such as the HSR (Bröcker et al., 2010, Monzón et al., 2013, Perl and Goetz, 2015), suggesting that South Korean HSR should be further evaluated. Our study evaluates both efficiency and equity improvements from the extensions of South Korean networks at different stages including from the future extensions, which limit our focus solely at spatial scale. While the impacts of HSR service are not only associated with spatial access (horizontal issues), they are also associated with vertical equity issues, such as the barriers of ticket prices or different HSR demands based on different kind of jobs and income status (Currie, 2010). Nonetheless, focusing only on horizontal or spatial equity issues does not undermine the contributions of this study for two reasons. First, during the onset of any mega-transportation project such as HSR, horizontal equity issues have primacy (van Wee and Geurs, 2011) because at this stage cities are the focal point as opposed to individual passengers. Second, addressing vertical equity issues is problematic from the future extension because this kind of analysis would require to predict the social needs and mode choices of various groups, and changes of land use to a non-existence situation (van Wee and Geurs, 2011), which may actually change after the operation.

## 3. Settings, data, and methodology

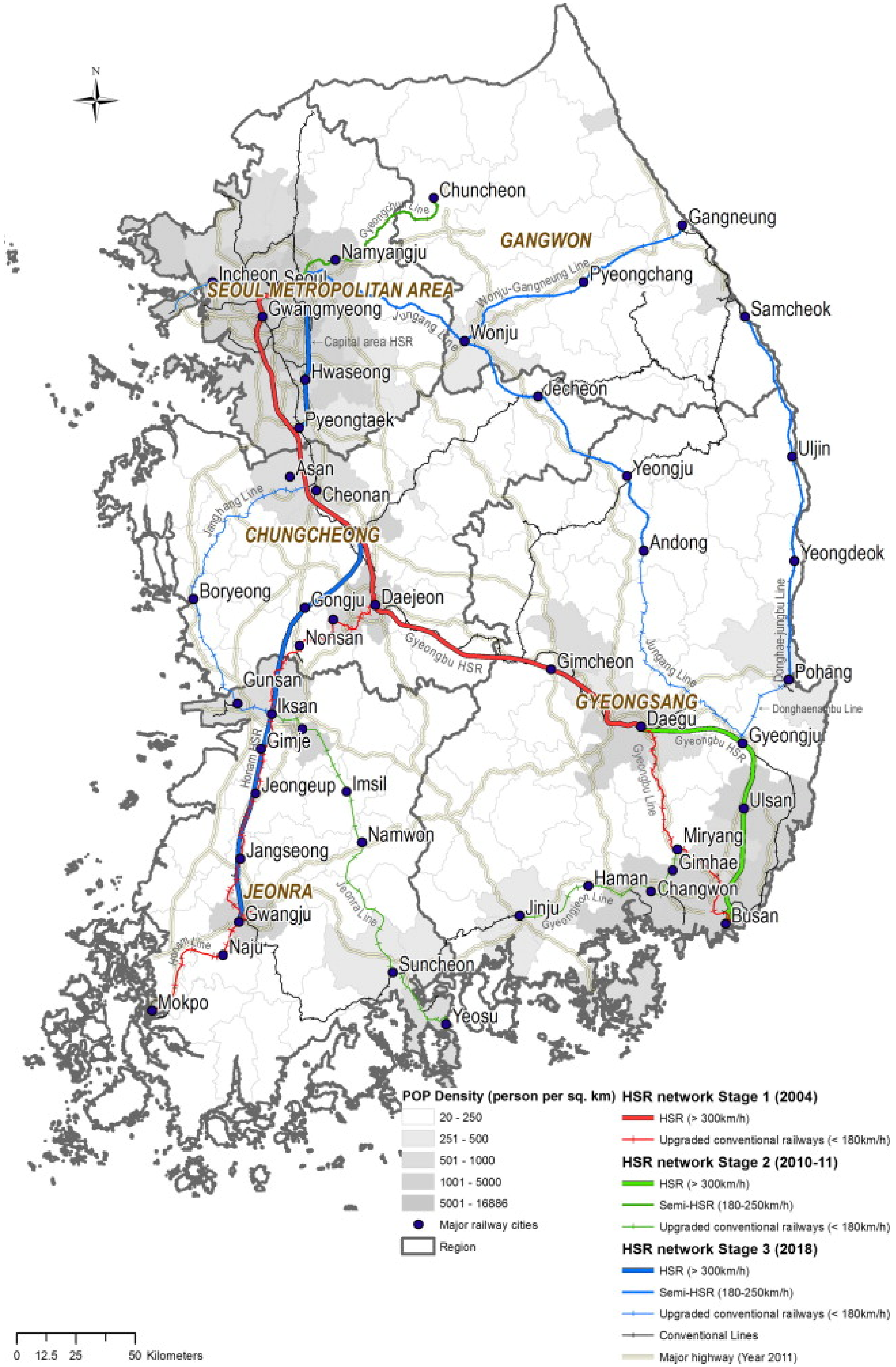


**Figure 1.** Railway network in South Korea by each stage of HSR.

### 3.1. The development of High-Speed Rail in South Korea

The construction decision of HSR in South Korea was initiated in the 1980s when the country was suffering from severe congestion due to its rapid economic growth since the 1960s along the major corridor of Seoul, the capital of South Korea, to Busan (Fig. 1). This corridor alone contained about 80% of the country's manufacturing facilities and 73% of the national population and carried 66% of all rail passengers every day (Korean Statistical Information Service, 2011). Therefore, relieving congestion between Seoul and Busan became the most important part of the economic development strategy in the country in the 1980s. Among various alternatives for the solutions, the construction and operation of high-speed railways became obvious (Park and Ha, 2006, Chung and Lee, 2011, Mun and Kim, 2012).

KTX service has three turning points that are represented in Fig. 1. Although S1 of the HSR network was promised to be built directly between Seoul and Busan in 2004, only the Gyeongbu HSR line was completed from Seoul to Daegu because of the economic crisis in 1998. Not to delay further the KTX service, the South Korean railway authority upgraded many conventional rail lines with a max speed of 150 km/h by straightening and electrifying tracks before the first stage of HSR operation in 2004 (Kim, 2005). The Gyeongbu HSR line is also used to provide the Honam KTX service between Seoul and Mokpo using an upgraded Honam conventional line from Daejeon to Mokpo.

In S2 (2010/2011) of the HSR network extension, the Gyeongbu KTX service was fully operational after the completion of the HSR network from Daegu to Busan (Fig. 1, shown in green[1]). The Gyeongjeon KTX service also began to operate directly between Seoul and Jinju using the upgraded Gyeongbu conventional line from Daegu to Miryang and an upgraded Gyeongjeon conventional line from Miryang to Jinju. To serve the southwest region of the country, the Jeonra KTX service started operation using the Gyeongbu HSR line between Seoul and Daejeon and by linking with an upgraded Honam conventional line between Daejeon and Iksan and an upgraded Jeonra conventional line between Iksan and Yeosu. The South Korean railway authority also upgraded the Gyeongchun line that serves between Seoul and Chuncheon as a semi-HSR service, but that was not part of the KTX service.

In addition to the completion of a few HSR lines, the Korean railway authority will also upgrade additional conventional lines to serve as semi-HSRs by 2018, which we refer to here as the S3 of the HSR network extension (Fig. 1, shown in blue) (MOLIT, 2011). The Honam KTX service between Seoul and Mokpo will be improved using the Honam HSR line between Cheongju (integrated with Cheongwon in 2014) and Gwangju, providing 300 km/h service to the underdeveloped southwest region. To secure a sufficient rail capacity in the Seoul metropolitan area (SMA), an additional HSR line between Pyeongtaek and Seoul, named the Capital area HSR line, will be in operation by 2018. The Pohang KTX service will also be in operation directly between Seoul and Pohang using the Gyeongbu HSR line between Seoul and Gyeongju and via an upgraded Donghaenambu conventional line between Gyeongju and Pohang. Along the east coast, the Donghaejungbu semi-HSR will be constructed as single-track with holding the construction of double-track between Pohang and Gangneung. Table 1shows how the service extension in 2018 will expand compared with the previous stage. In particular, the Jungang line, Wonju-Gangneung line, and Donghaejungbu line are designed for service speeds of 180–

250 km/h of semi-HSR through the current poor higher-speed rail service region (MOLIT, 2011).

**Table 1.** Stages of HSR network extensions in South Korea.

| Stage | HSR (300 km/h) | Semi-HSR (180–250 km/h) | Electrified conventional railway directly connected with HSR |
|---|---|---|---|
| Stage 1 (S1) (2004) | Gyeongbu HSR (Seoul-Daegu) | | Gyeongbu Line (Daegu-Busan)<br>Honam Line (Daejeon-Mokpo) |
| Stage 2 (S2) (2010–2011) | Gyeongbu HSR (Daegu-Busan) | Gyeongchun Line (Seoul-Chuncheon) | Gyeongjeon Line (Miryang-Jinju)<br>Jeonra Line (Iksan-Yeosu) |
| Stage 3 (S3) (2018) | Honam HSR (Cheongju-Gwangju)<br>Capital Area HSR (Seoul-Pyeongtaek) | Jungang Line (Seoul-Gyeongju)<br>Wonju-Gangneung Line<br>Donghaejungbu Line (Donghae-Pohang)<br>Donghaenambu Line (Gyeongju-Pohang) | Incheon International Airport Line (Seoul-Incheon International Airport) |

*Source*: Korail, Korean Rail Network Authority.

**Table 2.** Travel time reduction by HSR in South Korea.

| Railway service | Route | | Travel time | | | | Travel time saving (2003–2018) | |
|---|---|---|---|---|---|---|---|---|
| | From | To | Before HSR (2003) | HSR Stage 1 (2004) | HSR Stage 2 (2011) | HSR Stage 3[a] (2018) | Absolute | % |
| Gyeongbu | Seoul | Cheonan | 1:03 | 0:30 | 0:30 | 0:30 | 0:33 | 52.4 |
| | Seoul | Daejeon | 1:30 | 0:50 | 0:45 | 0:45 | 0:45 | 50.0 |
| | Seoul | Gimcheon | 3:00 | 3:00 | 1:25 | 1:25 | 1:35 | 52.8 |
| | Seoul | Daegu | 3:30 | 1:40 | 1:35 | 1:35 | 1:55 | 54.8 |
| | Seoul | Ulsan | 5:30 | 3:40 | 2:05 | 2:00 | 3:30 | 63.6 |
| | Seoul | Busan | 4:30 | 2:40 | 2:13 | 2:05 | 2:25 | 53.7 |
| Gyeongjeon | Seoul | Miryang | 4:10 | 2:20 | 2:00 | 2:00 | 2:10 | 52.0 |
| | Seoul | Changwon | 4:50 | 3:00 | 2:40 | 2:40 | 2:10 | 44.8 |
| | Seoul | Jinju | 6:30 | 4:50 | 3:20 | 2:10 | 4:20 | 66.7 |
| Donghaenambu | Seoul | Pohang | 5:30 | 4:00 | 4:00 | 2:10 | 3:20 | 60.6 |
| Honam | Seoul | Iksan | 3:00 | 1:54 | 1:54 | 1:08 | 1:52 | 62.2 |
| | Seoul | Gwangju | 4:20 | 2:50 | 2:50 | 1:30 | 2:50 | 65.4 |
| | Seoul | Mokpo | 5:00 | 3:20 | 3:20 | 1:50 | 3:10 | 63.3 |
| Jeonra | Seoul | Jeonju | 3:20 | 2:30 | 2:10 | 1:23 | 1:57 | 58.5 |
| | Seoul | Namwon | 3:51 | 3:51 | 2:40 | 1:53 | 1:58 | 51.1 |
| | Seoul | Suncheon | 4:15 | 4:15 | 3:10 | 2:23 | 1:52 | 43.9 |
| | Seoul | Yeosu | 4:40 | 4:40 | 3:30 | 2:43 | 1:57 | 41.8 |
| Wonju-Gangneung | Seoul | Wonju | 1:35 | 1:35 | 1:10 | 0:45 | 0:50 | 52.6 |
| | Seoul | Gangneung | 6:30 | 6:30 | 6:30 | 1:30 | 5:00 | 76.9 |

*Source*: Korail, Korean Rail Network Authority.
[a] Estimated travel time based on the planned network.

Although the HSR network has been extended in the second stage, the service region has not expanded to a larger area because the KTX service was still limited to major cities. However, service was extended from 9.1% of the country's area in 2004 to 22% of the total area in 2011 and from 45% of the population in 2004 to 56% of the total population in 2011 (KOSIS, 2011). It is projected that if the third stage of the HSR network is completed in 2018, the KTX will serve 43% of the area of the country and 74% of the population (KOSIS, 2011). Whether the HSR service would improve accessibility to that extent is still questionable as research based on European high-speed rail suggested that intermediate cities on the HSR line may actually experience relative disadvantage from the improvement of accessibility of major cities in Europe (Ureña et al., 2009).

Reduced travel time by HSR operation can represent its impact, which can be an important method to show changes in accessibility (e.g., Sánchez-Mateos and Givoni, 2012). Table 2 shows the travel time changes with HSR extension in the different time periods. Since all the KTX services start from Seoul, the capital of South Korea, the route course is selected from Seoul to major cities and travel time represents the fastest train in the proposed period. Table 2 indicates the absolute percentage of changes of travel time by HSR. HSR explicitly reduces travel times by 40–80% and may imply significant impact in cities served by KTX in different stages of HSR extension in South Korea.

The travel time savings indicator is not enough to evaluate changes of interaction and disparity between cities (Vickerman et al., 1999). Accessibility is a measure that combines the complex interactions of location, network efficiency, and potential interactions due to changes in the economic power of cities and urban systems (Martin et al., 2004). In this context, the purpose of this study is to examine the disparity of accessibility as an indicator of the benefits that cities have received or will receive from the HSR network extension in South Korea from different stages: S1 (year 2004), S2 (year 2010/2011), and S3 (year 2018).

## 3.2. Data, research design and methodology

This study includes all 160 inland cities (si) and counties (gun) in South Korea for our accessibility analysis. In South Korea, a city or a county is treated in the same level as that of an administration unit, but whether it will be called a city or a county depends on the population size. Generally, a county becomes a city when its population reaches to 50,000. To calculate WATT and PA, the geodatabase of HSR and the conventional railway network of 2004 and 2011 are acquired from the Korea Transport Database of the Korea Transport Institute (KTDB). The future railway network geodatabase of 2018 was not made publicly available by Korean government organizations, and hence, it was created in the ArcGIS Network Analyst based on the future plans of the official national railway network. The geographic boundary of cities and counties was downloaded from the KTDB website. The demographic data of 2004 and 2011 were collected from Statistics Korea, the national competent authority of statistics (Korean Statistical Information Service, 2011). There were no official projected demographic data of small administrative units like city and county, thus, the 2011 population data were used to calculate accessibility for 2018.

Accessibility values can be calculated using only the railway network as most researchers used, but to reflect the realistic ease of access to all cities and counties by shortest travel time, one has to consider other ground networks. Unlike other studies, our study integrated both railway and road networks to calculate a realistic accessibility of each stage of HSR. Our method allows us to account for the transfer time between road network and HSR connections and includes all cities and counties in the analysis instead of selected cities in the single railway network. We kept the road network data identical in each stage of the HSR network extension to isolate the effects of HSR network extensions for our analysis and hence, the 2011 road network is used. To reflect the transfer time between modes in our calculation, the two networks are linked at the major

HSR stations with short-line segments containing transfer time constraints and assuming a walking speed of 4 km/h. Although real-time operation data would be more appropriate to calculate travel time, those data are not available for S3 extensions. Thus, to keep the consistency in the analysis our study calculated network travel time based on physical network distance and speed between cities. Our study considered both travel-time changes and population changes to examine the impact of HSR network changes. Two widely used locational based accessibility measures, weighted average travel time (WATT) and potential accessibility (PA), were calculated applying the corresponding formula (discussed in Section 2.1) for each stage of HSR networks. Since cities are the focal point of our analysis, centroids of cities and counties are used as nodes for keeping evenness in the travel time and population of each city is used as size of the city. All the calculations including accessibility were performed within the environment of ArcGIS Network Analyst.

As a criterion for measuring the disparity in benefits from the improved accessibility among cities by the improved transportation infrastructure such as HSR and highway, the coefficients of variation (CV) index and normalized value of the changes in accessibility were used (e.g., Li and Shum, 2001, Martin et al., 2004, López et al., 2008, Monzón et al., 2013). The CV index evaluates the degrees of spatial variation in accessibility across cities and helps to understand the trend of accessibility disparity at each stage of the HSR. CV is expressed as follows:

$$\mathrm{CV} = \frac{\sigma^P}{\frac{\sum A_i \cdot M_i}{\sum M_i}} \tag{3}$$

where CV is the coefficient of variation in the whole area, $\sigma^P$ is the standard deviation of accessibility values of $A_i$, and $M_i$ is population as weight. A CV value of “zero” represents a perfect equality scenario and higher CV values indicate greater inequality. The CV value solely reflects the nationwide trend of equality and may not represent local conditions well. To supplement the deficiency, a spatial distribution of the normalized values of accessibility changes were used (Monzón et al., 2013). We hypothesized that the HSR extensions will bring the peripheral regions closer to the central ones, but will also increase imbalances between the major cities and their hinterlands in South Korea.

## 4. Results and discussion

### 4.1. Efficiency evaluation of HSR by location (cities and counties)

The two most widely used locational based accessibility measures—WATT and PA—are calculated to evaluate the efficiency impact of the HSR network extensions in the South Korea. While WATT focuses on travel-time reduction in cities, the PA measure focuses on the increase of competitiveness or attractiveness of cities in terms of enhancing accessibility. Reflected by the decreasing WATT and increasing PA values for the each stage of HSR extensions, South Korean cities and counties have become more accessible to each other: about 13% by travel-time savings and 11% by increasing attractiveness (Table 3). After the S1 operation of HSR, cities experienced low WATT values were located along the Gyeongbu HSR Line between Seoul and Daejeon corridor and only 28 cities received the WATT values below 80 min. WATT values were significantly reduced in almost every city (e.g., Andong and Pyeongtaek) following the implementation of S2 extension, with 38 cities receiving 80 min or less WATT values (Table 3 and Fig. 2). However, significant travel-time reductions are again received by cities (e.g., Gyeongju, and Ulsan) along the Gyeongbu HSR Line, the initial HSR corridor. Cities along the conventional Honam Line and Jeonra line (southwest region of South Korea) received some travel-time reduction benefits, but continue to experience higher absolute WATT values (Table 3).

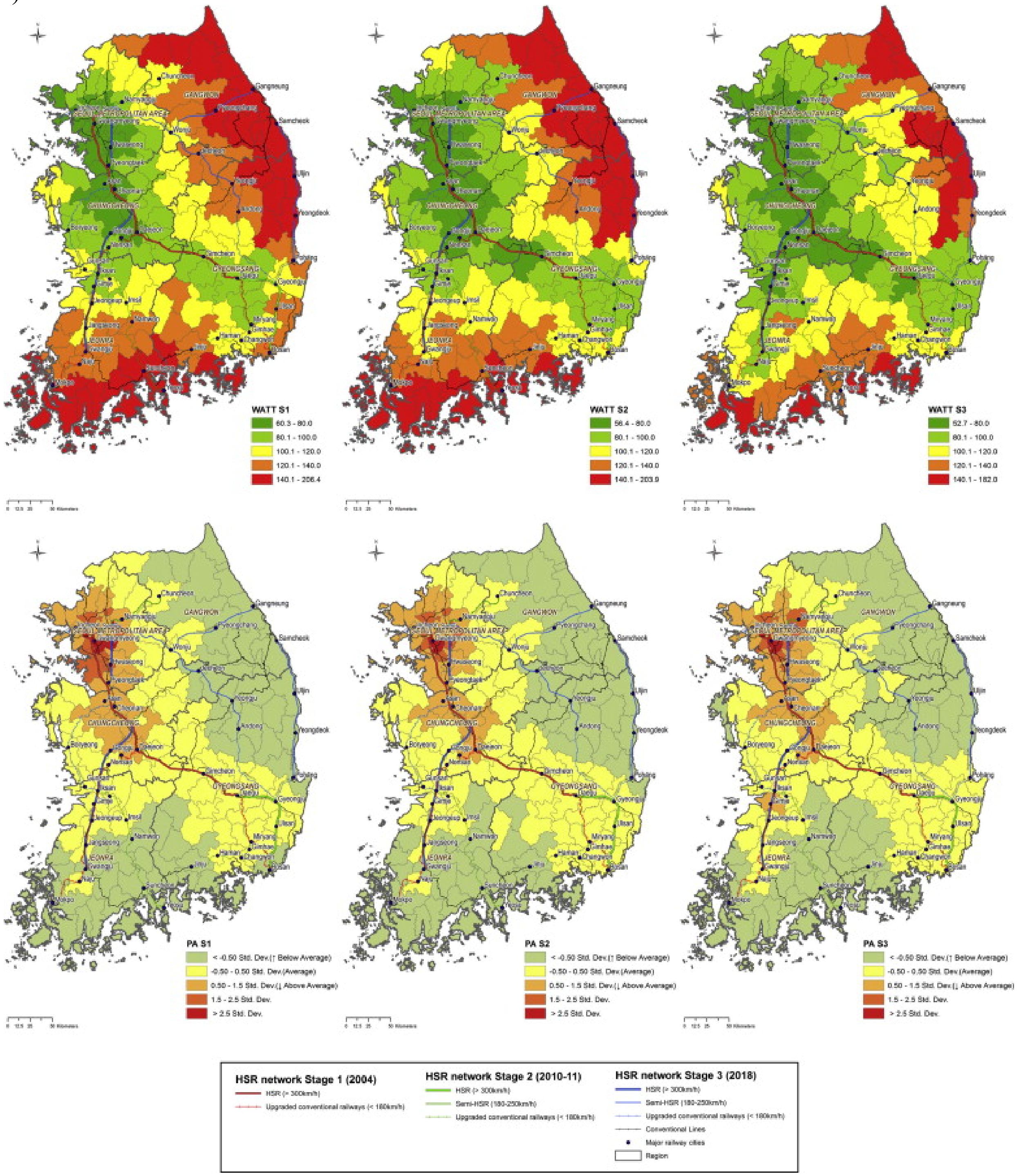


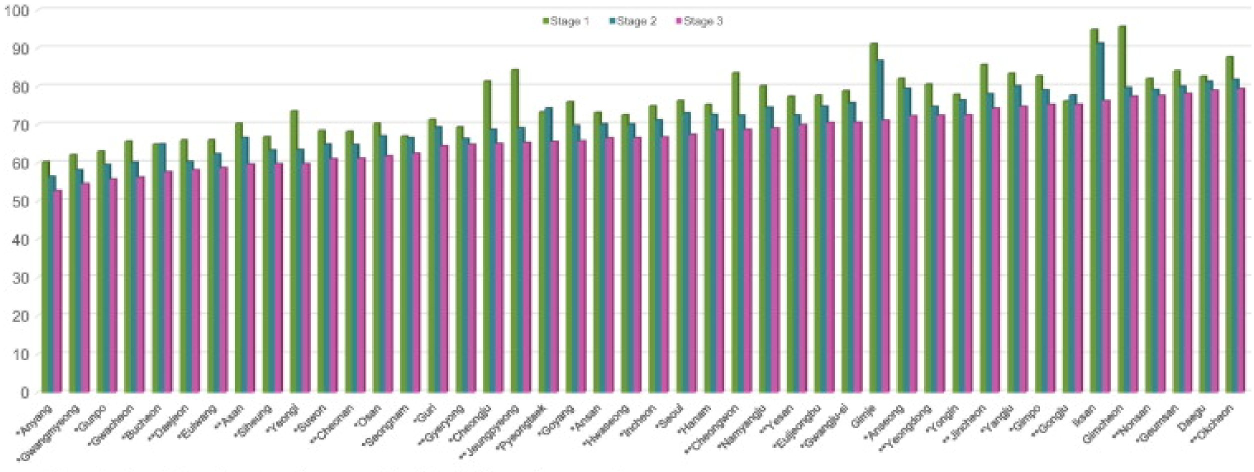
**Figure 2.** Spatial distribution of accessibility by WATT and PA.

**Table 3.** Weighted travel time (WATT) and potential accessibility (PA) by each stage of HSR extensions.

| | | WATT (min) | | | | | | PA | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Corridor** | **Cities (with major Railway station)** | **S1** | **S2** | **S3** | **Change (S1–S2) (%)** | **Change (S2–S3) (%)** | **Change (S1–S3) (%)** | **S1** | **S2** | **S3** | **Change (S1–S2) (%)** | **Change (S2–S3) (%)** | **Change (S1–S3) (%)** |
| National | | 114.9 | 109.9 | 100.2 | −4.4 | −8.8 | −12.8 | 603,972 | 629,519 | 669,997 | 4.2 | 6.4 | 10.9 |
| Gyeongbu | Total | 84.9 | 76.6 | 73.0 | −9.8 | −4.7 | −14.0 | 795,143 | 861,891 | 893,308 | 8.4 | 3.6 | 12.3 |
| | Seoul | 76.3 | 73.0 | 67.5 | −4.3 | −7.5 | −11.5 | 866,046 | 865,373 | 915,436 | −0.1 | 5.8 | 5.7 |
| | Gwangmyeong | 62.2 | 58.2 | 54.6 | −6.4 | −6.2 | −12.2 | 1,508,827 | 1,602,095 | 1,623,256 | 6.2 | 1.3 | 7.6 |
| | Suwon | 68.5 | 64.9 | 61.1 | −5.3 | −5.9 | −10.8 | 1,206,971 | 1,241,260 | 1,269,729 | 2.8 | 2.3 | 5.2 |
| | Hwaseong | 72.6 | 70.1 | 66.6 | −3.4 | −5.0 | −8.3 | 1,048,050 | 1,055,630 | 1,070,240 | 0.7 | 1.4 | 2.1 |
| | Pyeongtaek | 73.3 | 74.3 | 65.7 | 1.4 | −11.6 | −10.4 | 891,089 | 868,361 | 1,021,128 | −2.6 | 17.6 | 14.6 |
| | Cheonan | 68.3 | 64.8 | 61.2 | −5.1 | −5.6 | −10.4 | 907,802 | 942,449 | 968,981 | 3.8 | 2.8 | 6.7 |
| | Asan | 70.3 | 66.7 | 59.7 | −5.1 | −10.5 | −15.1 | 891,558 | 924,116 | 1,019,931 | 3.7 | 10.4 | 14.4 |
| | Cheongju | 81.4 | 68.8 | 65.1 | −15.5 | −5.4 | −20.0 | 715,945 | 859,945 | 887,612 | 20.1 | 3.2 | 24.0 |
| | Yeongi | 73.6 | 63.5 | 59.8 | −13.7 | −5.8 | −18.8 | 805,079 | 958,701 | 991,097 | 19.1 | 3.4 | 23.1 |
| | Daejeon | 66.0 | 60.4 | 58.2 | −8.5 | −3.6 | −11.8 | 851,437 | 923,872 | 943,849 | 8.5 | 2.2 | 10.9 |
| | Gimcheon | 95.7 | 79.7 | 77.4 | −16.7 | −2.9 | −19.1 | 567,246 | 702,386 | 713,651 | 23.8 | 1.6 | 25.8 |
| | Gumi | 110.4 | 88.3 | 86.0 | −20.0 | −2.6 | −22.1 | 485,503 | 623,769 | 633,300 | 28.5 | 1.5 | 30.4 |
| | Daegu | 82.7 | 81.3 | 79.0 | −1.7 | −2.8 | −4.5 | 630,912 | 662,060 | 674,032 | 4.9 | 1.8 | 6.8 |
| | Miryang | 96.1 | 97.0 | 94.9 | 0.9 | −2.2 | −1.2 | 628,107 | 622,025 | 629,213 | −1.0 | 1.2 | 0.2 |
| | Gyeongju | 102.0 | 90.9 | 88.6 | −10.9 | −2.5 | −13.1 | 575,369 | 663,274 | 670,393 | 15.3 | 1.1 | 16.5 |
| | Ulsan | 123.1 | 97.8 | 95.4 | −20.6 | −2.5 | −22.5 | 480,905 | 599,341 | 608,569 | 24.6 | 1.5 | 26.5 |
| | Busan | 121.5 | 103.2 | 100.7 | −15.1 | −2.4 | −17.1 | 456,579 | 537,483 | 545,824 | 17.7 | 1.6 | 19.5 |
| Honam | Total | 104.0 | 99.2 | 83.3 | −4.6 | −16.0 | −19.9 | 580,676 | 605,850 | 696,249 | 4.3 | 14.9 | 19.9 |
| | Gyeryong | 69.4 | 66.4 | 64.9 | −4.3 | −2.3 | −6.5 | 856,830 | 894,451 | 905,573 | 4.4 | 1.2 | 5.7 |
| | Nonsan | 80.2 | 74.5 | 69.1 | −7.1 | −7.2 | −13.8 | 683,295 | 700,959 | 710,607 | 2.6 | 1.4 | 4.0 |
| | Iksan | 94.9 | 91.3 | 76.3 | −3.8 | −16.4 | −19.6 | 586,890 | 606,035 | 729,198 | 3.3 | 20.3 | 24.2 |
| | Gimje | 91.1 | 86.8 | 71.2 | −4.7 | −18.0 | −21.8 | 650,407 | 677,038 | 831,067 | 4.1 | 22.8 | 27.8 |
| | Jeongeup | 103.9 | 100.4 | 84.5 | −3.4 | −15.8 | −18.7 | 549,998 | 568,110 | 685,593 | 3.3 | 20.7 | 24.7 |
| | Gwangju | 126.0 | 117.8 | 92.9 | −6.5 | −21.1 | −26.3 | 425,892 | 456,814 | 576,752 | 7.3 | 26.3 | 35.4 |
| | Naju | 123.9 | 120.3 | 96.1 | −2.9 | −20.1 | −22.4 | 493,747 | 521,118 | 628,684 | 5.5 | 20.6 | 27.3 |
| | Mokpo | 142.5 | 135.8 | 111.5 | −4.7 | −17.9 | −21.8 | 398,347 | 422,273 | 502,518 | 6.0 | 19.0 | 26.2 |
| Jeonra | Total | 129.2 | 126.6 | 112.7 | −2.0 | −11.0 | −12.8 | 435,473 | 442,901 | 496,459 | 1.7 | 12.1 | 14.0 |
| | Jeonju | 101.7 | 98.3 | 82.8 | −3.3 | −15.8 | −18.6 | 545,493 | 557,223 | 661,804 | 2.2 | 18.8 | 21.3 |
| | Namwon | 120.5 | 118.3 | 104.6 | −1.8 | −11.6 | −13.2 | 455,649 | 462,478 | 514,336 | 1.5 | 11.2 | 12.9 |
| | Suncheon | 140.7 | 139.1 | 125.8 | −1.1 | −9.6 | −10.6 | 393,107 | 396,947 | 428,108 | 1.0 | 7.9 | 8.9 |
| | Yeosu | 153.8 | 150.6 | 137.4 | −2.1 | −8.8 | −10.7 | 347,643 | 354,954 | 381,588 | 2.1 | 7.5 | 9.8 |
| Jungang | Total | 113.1 | 110.6 | 97.2 | −2.2 | −12.1 | −14.1 | 640,667 | 634,017 | 695,632 | −1.0 | 9.7 | 8.6 |
| | Guri | 71.4 | 69.4 | 64.4 | −2.8 | −7.2 | −9.8 | 1,404,650 | 1,348,724 | 1,386,948 | −4.0 | 2.8 | −1.3 |
| | Wonju | 111.8 | 105.7 | 92.1 | −5.5 | −12.9 | −17.6 | 530,786 | 546,613 | 624,577 | 3.0 | 14.3 | 17.7 |
| | Jecheon | 121.5 | 115.9 | 105.2 | −4.6 | −9.2 | −13.4 | 451,739 | 466,214 | 517,792 | 3.2 | 11.1 | 14.6 |
| | Yeongju | 132.3 | 127.4 | 104.9 | −3.7 | −17.7 | −20.7 | 401,589 | 413,817 | 505,837 | 3.0 | 22.2 | 26.0 |
| | Andong | 128.3 | 134.7 | 119.3 | 5.0 | −11.4 | −7.0 | 414,570 | 394,716 | 443,004 | −4.8 | 12.2 | 6.9 |
| Donghaejungbu | Total | 164.1 | 159.2 | 119.1 | −3.0 | −25.2 | −27.4 | 342,453 | 353,897 | 468,784 | 3.3 | 32.5 | 36.9 |
| | Gangneung | 178.7 | 174.6 | 125.3 | −2.3 | −28.2 | −29.9 | 303,266 | 306,150 | 432,043 | 1.0 | 41.1 | 42.5 |
| | Donghae | 191.8 | 186.3 | 135.4 | −2.9 | −27.3 | −29.4 | 276,991 | 283,765 | 389,178 | 2.4 | 37.1 | 40.5 |
| | Pohang | 121.7 | 116.6 | 96.7 | −4.2 | −17.1 | −20.5 | 447,102 | 471,776 | 585,130 | 5.5 | 24.0 | 30.9 |
| Gyeongjeon | Total | 116.7 | 116.8 | 115.4 | 0.1 | −1.2 | −1.1 | 533,455 | 533,120 | 536,769 | −0.1 | 0.7 | 0.6 |
| | Gimhae | 105.9 | 107.0 | 105.0 | 1.0 | −1.9 | −0.8 | 640,095 | 636,191 | 642,089 | −0.6 | 0.9 | 0.3 |
| | Changwon | 112.3 | 111.6 | 110.4 | −0.6 | −1.1 | −1.7 | 521,198 | 523,828 | 527,119 | 0.5 | 0.6 | 1.1 |
| | Jinju | 132 | 131.8 | 130.8 | −0.2 | −0.8 | −0.9 | 439,071 | 439,340 | 441,100 | 0.1 | 0.4 | 0.5 |
| Gyeongchun | Total | 99.5 | 83.3 | 77.9 | −16.3 | −6.5 | −21.7 | 741,985 | 857,498 | 937,936 | 15.6 | 9.4 | 26.4 |
| | Namyangju | 80.2 | 74.5 | 69.1 | −7.1 | −7.2 | −13.8 | 983,750 | 1,023,213 | 1,138,173 | 4.0 | 11.2 | 15.7 |
| | Chuncheon | 118.7 | 92.1 | 86.7 | −22.4 | −5.9 | −27.0 | 500,220 | 691,782 | 737,699 | 38.3 | 6.6 | 47.5 |

S1: Stage 1, S2: Stage 2, S3: Stage 3 of HSR network.

The Honam Line will be converted into HSR trucks by the completion of S3 HSR network extension and will have a significant positive impact of travel-time reduction on the cities in the southwest region including Iksan, Jeoungeup, Gwangju, and Mokpo (Table 3 and Fig. 2). In addition, cities along the Jungang and Donghaejungbu lines will also have reduced WATT values, but these values are still higher compared to the Gyeongbu and Honam Lines (Table 3 and Fig. 2). We posit this is because of the limited speed of semi-HSR tracks that serve in the peripheral regions and locational isolation from a geometrically central region. Further, following the completion of S3 HSR network extensions, 44 cities will receive less than 80 WATT values (Fig. 3) and of those, 24 cities are located in the SMA served by the Gyeongbu Line and 14 cities are in Chungcheong region served by the Gyeongchun Line (Fig. 2, Fig. 3). Both of these regions are spatially closer to each other.



Note: * cities in Seoul metropolitan area / ** cities in Chungcheong region

**Figure 3.** Cities with less than 80 min WATT in each stage of HSR network extensions.

The high PA values from the S1 of HSR network are shown in the most densely populated cities between Seoul and Daejeon, while cities between Daejeon and Daegu such as Gimcheon and Gumi show lower accessibility values though these areas are served by the Gyeongbu Line (Table 3 and Fig. 2). The later scenario is likely due to the low population density and lack of intermediate HSR stations between Daejeon and Daegu. In addition, Busan and the surrounding cities, the second largest concentration of population in South Korea, indicate low PA values compared to cities in SMA. This is most likely because of the incompletion of the dedicated HSR network between Daegu and Busan. Likewise, PA value is not significantly high in southwest region served by the Honam Line. After the S2 operation of HSR made already-prominent capital region even more attractive, whereas the northeast and southwest coastal regions remain less attractive (Table 3 and Fig. 2).

After the implementation of S3 operations, cities with high PA are disproportionately concentrated again in the SMA despite the improved accessibility in previously low-accessible cities along the Honam HSR Line (Table 3 and Fig. 2). The most competitive or attractive cities around SMA are: Anyang, Bucheon, Euiwang, Gunpo, and Gwacheon (PA values above 2.5 standard deviations), Euijeongbu, Goyang, Guri, Hanam, Namyangju, Seongnam, Siheung, and Suwon (PA values above 1.5 standard deviations). These cities most likely receive the benefits from the nearest presence of Seoul – the largest and the most densely in the country. Other cities along the Gyeongbu HSR corridor, between Seoul and Daejeon that have higher attractiveness than the average PA of the country (above 0.5 standard deviation) are: Asan, Cheonan, Cheongju, Daejeon, Hwaseong, and Yeongi (part of Sejong from 2012) (Fig. 2).

## 4.2. The impacts of the HSR on spatial equity

The calculated CV values of WATT and PA at each stage of HSR extensions are used as major indicators for the evaluation of the degree of spatial disparity variability changes by nation, region, and city size (Table 4). The increased (4.5%) CV value of WATT from S1 to S2 implies that the country went a little far away from the relief of disparity from the travel-time reduction after the operation of S2 HSR. The CV values of WATT by the size of cities from S1 to S2 imply that the large reduction of spatial disparity (−5.1%) was limited to the large cities, while inequality increased by 4.7% in smaller cities or counties. The CV values of WATT by region indicates cities in Seoul metropolitan region received 4.8% decrease in travel time spatial disparity from S1 to S2 HSR operation, whereas, spatial disparity in travel time increased for other regions. The Gangwon (16%) and Gyeongsang (8%) regions saw significant increase in spatial disparity, followed by Chungcheong (6.4%) and Jeonra (2%) regions. Clearly, after the construction of S2 HSR network, the disparity in travel time within small cities and within peripheral regions was intensified with the expense of travel-time equity benefits received by the large cities along the Gyeongbu HSR corridor and SMA (Table 4).

HSR extensions at S3 provide countrywide relief from the spatial inequality of travel time as reflected by the decreased CV values from S2 to S3 (7.4%) of WATT (Table 4). While cities within the SMA show a slight increase (2.5%) in spatial inequality of WATT, small cities will experience some reduction (7.7%) of inequality. A number of regions whose spatial equity aggravated after the S2 operation will also witness largest decrease in spatial inequality in S3 extension of HSR with the exception of Jeonra region (Table 4). Overall from S1 to S3 extensions, there will be a small amount of spatial disparity reduction (only 3.2%) within the country, but the greatest spatial equity benefits (about 10.2%) will be distributed within the largest cities. In contrast, spatial disparity will be intensified within peripheral regions such as Gangwon and Jeonra regions, even though Gangwon received some equity benefits from the S3 extension, but not large enough to be at S1 level.

Reduction of spatial variability of attractiveness in South Korea was insignificant after the S2 extensions and the concentration of significant reduction (8%) of attractiveness gap was limited to only within large cities reflect by the CV values of PA (Table 4). Attractiveness disparities in cities within their regions have also been intensified. Though cities within the SMA reflected a small increase in disparity, cities within the Gangwon region received the greatest spatial disparity increase (22.6%) followed by cities within the Chungcheong (7.1%) and Gyeongsang regions (6%) (Table 4). Consequently, even after the S3 extensions, spatial-equity benefits will decrease in cities within all the regions with the exception of Jeonra, these benefits will not be large enough to reach at S1 level. For example, Gangwon region will receive 9.6% decrease in spatial attractiveness benefits from the S3 extensions, but the unequal gap in this region will remain larger (10.9% gap) than what was at the initial stage of HSR network (S1 extension). Similarly, the internal attractiveness disparity gap within the Jeonra region will be greatly intensified after the S3 HSR network extension, 10.4% increase from that of S2 extension.

**Table 4.** Coefficient of variance (CV) of WATT and PA at each stage of HSR extensions by region and city size.

| **Category** | | **Number of cities** | **WATT** | | | | | | | | | **PA** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **S1** | | **S2** | | **S3** | | **S1–S2 CV change (%)** | **S2–S3 CV change (%)** | **S1–S3 CV change (%)** | **S1** | | **S2** | | **S3** | | **S1–S2 CV change (%)** | **S2–S3 CV change (%)** | **S1–S3 CV change (%)** |
| | | | **Avg.** | **CV** | **Avg.** | **CV** | **Avg.** | **CV** | | | | **Avg.** | **CV** | **Avg.** | **CV** | **Avg.** | **CV** | | | |
| Region | National | 160 | 114.9 | 0.309 | 109.9 | 0.323 | 100.2 | 0.299 | 4.5 | −7.4 | −3.2 | 603,972 | 0.484 | 629,519 | 0.479 | 669,997 | 0.451 | −1.0 | −5.8 | −6.8 |
| | Seoul Metropolitan Area | 33 | 78.8 | 0.167 | 75.0 | 0.159 | 70.1 | 0.163 | −4.8 | 2.5 | −2.4 | 1,042,829 | 0.285 | 1,067,291 | 0.289 | 1,113,681 | 0.274 | 1.4 | −5.2 | −3.9 |
| | Gangwon | 18 | 159.6 | 0.175 | 151.0 | 0.203 | 132.0 | 0.189 | 16.0 | −6.9 | 8.0 | 362,514 | 0.230 | 386,992 | 0.282 | 438,105 | 0.255 | 22.6 | −9.6 | 10.9 |
| | Chungcheong | 29 | 89.9 | 0.171 | 83.7 | 0.182 | 79.1 | 0.167 | 6.4 | −8.2 | −2.3 | 660,300 | 0.196 | 705,827 | 0.210 | 735,715 | 0.198 | 7.1 | −5.7 | 1.0 |
| | Jeonra | 37 | 134.0 | 0.204 | 130.4 | 0.208 | 113.2 | 0.218 | 2.0 | 4.8 | 6.9 | 433,976 | 0.208 | 446,245 | 0.212 | 509,456 | 0.234 | 1.9 | 10.4 | 12.5 |
| | Gyeongsang | 43 | 124.2 | 0.225 | 119.5 | 0.243 | 113.0 | 0.219 | 8.0 | −9.9 | −2.7 | 476,539 | 0.237 | 501,314 | 0.251 | 520,385 | 0.227 | 5.9 | −9.6 | −4.2 |
| City size | All cities/counties | 160 | 114.9 | 0.309 | 109.9 | 0.324 | 100.2 | 0.299 | 4.5 | −7.4 | −3.2 | 603,972 | 0.484 | 629,519 | 0.479 | 669,997 | 0.451 | −1.0 | −5.8 | −6.8 |
| | Large cities | 22 | 86.5 | 0.254 | 81.2 | 0.241 | 75.3 | 0.228 | −5.1 | −5.4 | −10.2 | 882,861 | 0.400 | 909,294 | 0.368 | 953,600 | 0.354 | −8.0 | −3.8 | −11.5 |
| | Small cities/counties | 138 | 119.4 | 0.296 | 114.5 | 0.310 | 104.2 | 0.286 | 4.7 | −7.7 | −3.4 | 559,512 | 0.459 | 584,917 | 0.465 | 624,785 | 0.435 | 1.3 | −6.5 | −5.2 |

S1: Stage 1, S2: Stage 2, S3: Stage 3 of HSR networks.

However, cities within the Gyeongsang regions will receive the largest reduction (9.6% decreases from S2 to S3 extensions) in the spatial-equity gap, and will close 4.2% of the spatial-equity gap of the initial stage (S1 extension). Overall, the S3 extensions will reduce 6.8% spatial attractiveness disparities from initial stage (S1) at national level and the greatest disparity reductions (11.5%) will be within the large cities. Small cities will also receive some relief from the attractiveness disparity gap, but cities within Gangwon and Jeonra will suffer from a greater inequality than that of initial stage of the HSR network.

To further supplement relative improvement in equity gain by cities, a series of maps are produced with normalized values of percentage of accessibility changes between stages of HSR extensions (Fig. 4). In addition, both absolute and relative improvements for those cities that received the most significant changes for each of the scenarios are presented in Table 5, Table 6. Clearly, while the number of cities and counties of South Korea received the average travel time saving improvements after the S2 HSR extension, fewer cities received above-average travel savings changes. The greatest relative travel time saving gains (WATT values < 2.5 standard deviation from the mean) received by the cities (e.g., Ulsan, Gimcheon, Gumi, and Chuncheon) that have new HSR or semi-HSR stations (Fig. 4). However, the effect of proximity to a new HSR or Semi-HSR station is also important as number of counties have received substantial higher travel time changes along the Gyeongbu and Gyeongchun lines (Fig. 4 and Table 5).

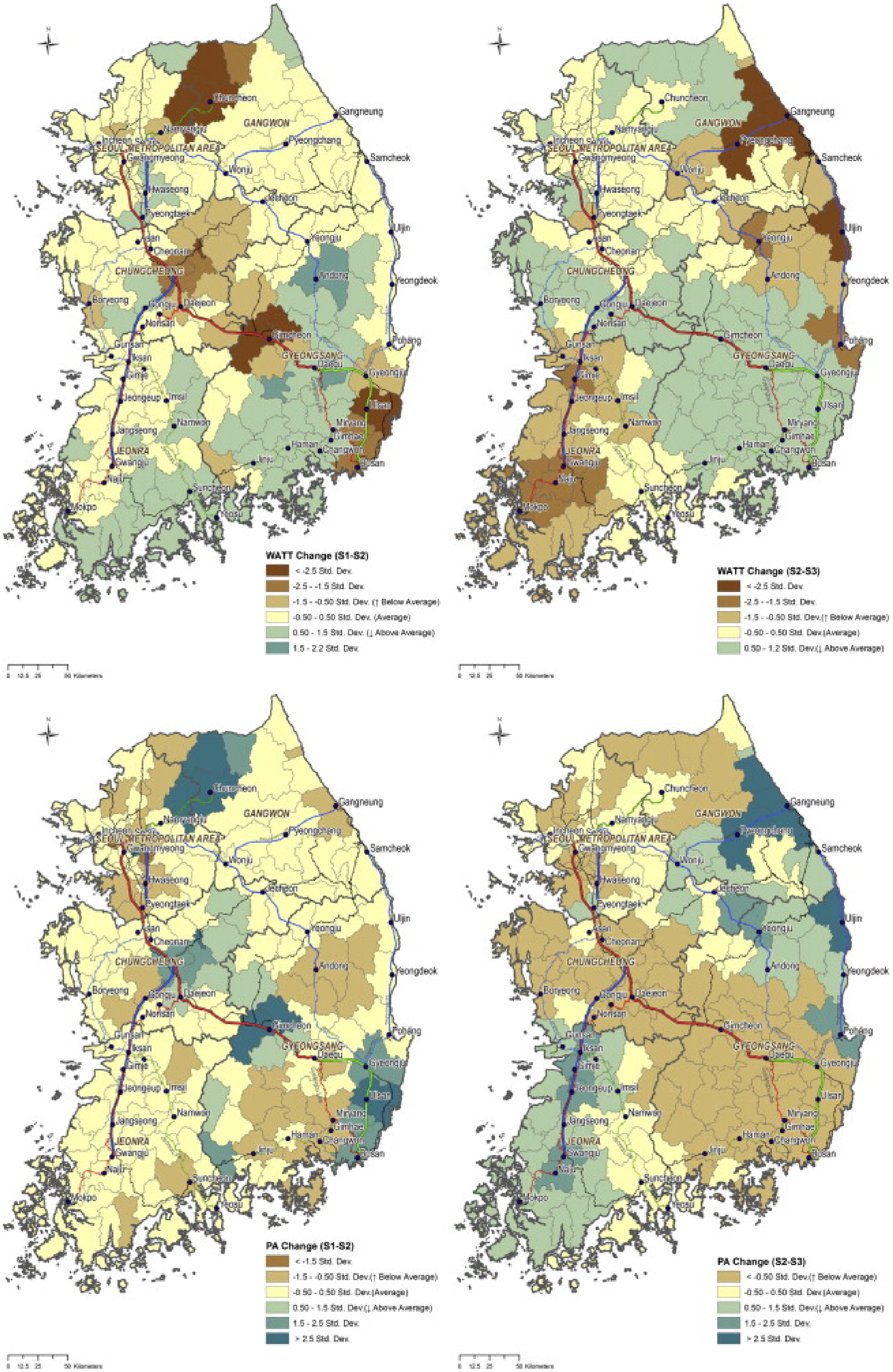


**Figure 4.** Normalized value of relative improvement in cities by WATT and PA.

**Table 5.** Cities with overall 20% of above WATT changes.

| Cities | Population (2011) | HSR service | WATT changes | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | S1–S2 | | S2–S3 | | S1–S3 | |
| | | | Absolute (min) | Change (%) | Absolute (min) | Change (%) | Absolute (min) | Change (%) |
| Gangneung | 217571 | Semi-HSR* | −4.1 | −2.3 | −49.3 | −28.2 | −53.4 | −29.9 |
| Donghae | 95804 | Semi-HSR* | −5.5 | −2.8 | −51.0 | −27.4 | −56.4 | −29.4 |
| Chuncheon | 272805 | Semi-HSR | −26.5 | −22.4 | −5.4 | −5.9 | −32.0 | −26.9 |
| Pyeongchang | 43577 | Semi-HSR* | −6.1 | −4.0 | −34.8 | −23.8 | −40.8 | −26.8 |
| Gwangju | 1463464 | HSR* | −8.2 | −6.5 | −24.9 | −21.1 | −33.1 | −26.2 |
| Uljin | 52045 | Semi-HSR* | −5.4 | −2.8 | −43.2 | −23.2 | −48.6 | −25.3 |
| Yangyang | 27942 | No | −5.3 | −2.7 | −43.8 | −23.1 | −49.0 | −25.2 |
| Gapyeong | 59358 | Semi-HSR | −19.7 | −18.2 | −5.3 | −6.0 | −25.0 | −23.1 |
| Ulsan | 1135494 | HSR | −25.4 | −20.6 | −2.4 | −2.5 | −27.8 | −22.6 |
| Jeungpyeong | 34009 | No | −15.2 | −18.0 | −3.8 | −5.5 | −19.0 | −22.5 |
| Naju | 88243 | Semi-HSR | −3.5 | −2.9 | −24.3 | −20.2 | −27.8 | −22.4 |
| Gumi | 413446 | HSR | −22.1 | −20.0 | −2.3 | −2.6 | −24.4 | −22.1 |
| Gimje | 93111 | HSR* | −4.3 | −4.8 | −15.6 | −18.0 | −20.0 | −21.9 |
| Mokpo | 244871 | Semi-HSR | −6.7 | −4.7 | −24.3 | −17.9 | −31.0 | −21.7 |
| Hwacheon | 24945 | No | −27.8 | −17.6 | −5.4 | −4.1 | −33.1 | −21.0 |
| Muan | 75718 | No | −4.7 | −3.4 | −24.2 | −18.0 | −29.0 | −20.8 |
| Yeongju | 114148 | Semi-HSR* | −5.0 | −3.7 | −22.5 | −17.7 | −27.4 | −20.7 |
| Hampyeong | 36134 | Semi-HSR | −4.5 | −3.3 | −24.2 | −18.0 | −28.8 | −20.6 |
| Pohang | 517088 | Semi-HSR* | −5.1 | −4.2 | −19.9 | −17.1 | −25.0 | −20.6 |
| Cheongju | 661946 | HSR | −12.6 | −15.5 | −3.7 | −5.4 | −16.3 | −20.0 |

Note: HSR: HSR operates in 2010/2011, HSR*: HSR operates in 2018, Semi-HSR: semi-HSR operates in 2010/2011, Semi-HSR*: semi-HSR will operate in 2018.

In contrast, cities in interior Gyeongsang and eastern Jeonra regions received relatively lower travel time savings improvement (WATT value > 0.5 standard deviation from the mean) (Fig. 4) because of their isolation from the HSR connection with a limited highway and railway network. For example, Andong received the least travel time gains (WATT value > 1.5 standard deviation from the mean) because of its dependency on the single conventional railway and highway network. Some other cities such as Daegu also received low relative gains from the S2 extension, due to their gain from prior extension S1. Similarly, SMA received average relative improvement of travel time accessibility from the extension because this area received the highest rate of travel time improvement from their initial stage, S1. These findings demonstrate clearly that after the constructions of S2 extension, cities that directly connected with new HSR line such as Capital HSR received higher-equity advantages.

Consistent with equity distributions, it is expected that cities and counties of northeast and southwest will receive relatively high improvement of travel-time changes after the S3 network extensions (Fig. 4 and Table 5). These regions have long been affected by the constraints of limited railway and highway connections. After the completion of three semi-HSR networks-Wonju-Gangneung, Jungang and Donghaejungbu lines at S3 extension will bring the most significant impact of relative travel-time changes (WATT < 2.5 standard deviation from the mean) among cities (e.g., Donghae, Gangneung, Pohang, Pyeongchang, Uljin, and Yeongju) of northeastern South Korea. The completion of Honam HSR line from S3 extension also will also bring significant changes in relative travel savings in cities of the Jeonra region (SW part of South Korea) such as Gimje, Gwangju, Naju, and Mokpo. These results are consistent with the

CV values that show (Table 4) that nationwide spatial-equity disparity reductions due to improvement in cities were previously in disadvantaged regions.

**Table 6.** Cities with overall 20% of above PA changes.

| **Cities** | **Population (2011)** | **HSR service** | **PA changes** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **S1–S2** | | **S2–S3** | | **S1–S3** | |
| | | | **Absolute (min)** | **Change (%)** | **Absolute (min)** | **Change (%)** | **Absolute (min)** | **Change (%)** |
| Chuncheon | 272,805 | Semi HSR | 191,562 | 38.3 | 45,917 | 6.6 | 237,479 | 47.5 |
| Gangneung | 217,571 | Semi HSR$^*$ | 2884 | 1.0 | 125,894 | 41.1 | 128,778 | 42.5 |
| Donghae | 95,804 | Semi HSR$^*$ | 6774 | 2.4 | 105,413 | 37.1 | 112,187 | 40.5 |
| Pyeongchang | 43,577 | Semi HSR$^*$ | 8617 | 2.4 | 128,886 | 34.4 | 137,502 | 37.6 |
| Gapyeong | 59,358 | Semi HSR | 164,578 | 28.2 | 52,865 | 7.1 | 217,443 | 37.2 |
| Gwangju | 1,463,464 | HSR$^*$ | 30,922 | 7.3 | 119,938 | 26.3 | 150,860 | 35.4 |
| Uljin | 52,045 | Semi-HSR$^*$ | 8169 | 3.0 | 85,720 | 30.5 | 93,889 | 34.4 |
| Yangyang | 27,942 | No | 4304 | 1.5 | 83,774 | 29.1 | 88,077 | 31.1 |
| Pohang | 517,088 | Semi-HSR$^*$ | 24,673 | 5.5 | 113,355 | 24.0 | 138,028 | 30.9 |
| Gumi | 413,446 | HSR | 138,266 | 28.5 | 9531 | 1.5 | 147,797 | 30.4 |
| Hwacheon | 24,945 | No | 82,489 | 23.3 | 16,950 | 3.9 | 99,440 | 28.1 |
| Gimje | 93,111 | HSR$^*$ | 26,632 | 4.1 | 154,029 | 22.8 | 180,661 | 27.8 |
| Gwacheon | 71,955 | No | 348,901 | 25.8 | 25,819 | 1.5 | 374,720 | 27.7 |
| Naju | 88,243 | No | 27,371 | 5.5 | 107,566 | 20.6 | 134,938 | 27.3 |
| Jeungpyeong | 34,009 | No | 158,594 | 23.0 | 28,606 | 3.4 | 187,201 | 27.1 |
| Danyang | 31,595 | Semi-HSR$^*$ | 20,639 | 4.8 | 94,513 | 20.9 | 115,152 | 26.7 |
| Ulsan | 1,135,494 | HSR | 118,436 | 24.6 | 9228 | 1.5 | 127,664 | 26.5 |
| Mokpo | 244,871 | No | 23,925 | 6.0 | 80,246 | 19.0 | 104,171 | 26.2 |
| Yeongju | 114,148 | Semi HSR$^*$ | 12,228 | 3.0 | 92,020 | 22.2 | 104,248 | 26.0 |
| Gimcheon | 136,185 | HSR | 135,140 | 23.8 | 11,265 | 1.6 | 146,406 | 25.8 |
| Jeongeup | 120,466 | HSR$^*$ | 18,112 | 3.3 | 117,484 | 20.7 | 135,596 | 24.7 |
| Iksan | 309,804 | HSR$^*$ | 19,145 | 3.3 | 123,163 | 20.3 | 142,307 | 24.2 |
| Chungju | 208,433 | No | 45,680 | 8.7 | 81,451 | 14.2 | 127,132 | 24.1 |
| Cheongju | 661,946 | HSR | 144,000 | 20.1 | 27,667 | 3.2 | 171,667 | 24.0 |
| Muan | 75,718 | No | 16,941 | 4.1 | 81,425 | 18.8 | 98,366 | 23.7 |
| Seocheon | 59,541 | No | 30,917 | 6.1 | 86,657 | 16.2 | 117,574 | 23.3 |
| Yeongi | 82,890 | No | 153,622 | 19.1 | 32,396 | 3.4 | 186,018 | 23.1 |
| Hampyeong | 36,134 | No | 14,500 | 3.5 | 81,063 | 18.9 | 95,563 | 23.0 |
| Yeongam | 60,139 | No | 14,813 | 3.9 | 71,046 | 17.9 | 85,859 | 22.5 |
| Bonghwa | 34,192 | No | 11,186 | 3.2 | 67,361 | 18.7 | 78,548 | 22.5 |
| Gunsan | 275,659 | No | 15,019 | 2.8 | 105,650 | 19.0 | 120,669 | 22.2 |
| Yanggu | 22,285 | No | 58,306 | 18.0 | 12,399 | 3.2 | 70,706 | 21.8 |
| Jeonju | 645,894 | Semi-HSR | 11,730 | 2.2 | 104,581 | 18.8 | 116,312 | 21.3 |
| Hadong | 53,975 | No | 59,956 | 15.6 | 18,921 | 4.3 | 78,878 | 20.5 |
| Hwasun | 68,985 | No | 11,181 | 2.6 | 76,174 | 17.4 | 87,355 | 20.5 |
| Shinan | 44,355 | No | 12,155 | 3.3 | 62,539 | 16.6 | 74,694 | 20.5 |

Note: HSR: HSR operates in 2010/2011, HSR$^*$: HSR operates in 2018, Semi-HSR: semi-HSR operates in 2010/2011, Semi-HSR$^*$: semi-HSR will operate in 2018.

Overall, the normalized relative improvements of PA are as identical as significant locational benefits that cities received from the relative WATT changes by HSR or semi-HSR extensions (Fig. 4). However, more cities gain higher changes of locational attractiveness (Table 6) than changes in travel time reduction benefits (Table 5) from the HSR extensions, which imply HSR extensions contribute to more PA among cities. Moreover, the degree of attractiveness benefits is higher than the travel-time change benefits. The highest relative changes of PA are among the smaller cities along the semi-HSR lines such as Chuncheon (overall 47.5%), Gangneung (42.5%), Donghae (40.5%), and Pohang (30.9%), which will help to reduce the geographic disparity of attractiveness in the country. Significant accessibility improvement occurred in cities with poor accessibility in the previous stage of the HSR network, with less-improved accessibility occurring in large cities that already had high relative accessibility (Table 5, Table 6). These results explain that semi-HSR lines can contribute relieving spatial disparity of accessibility considering efficiency in construction such as lower construction cost compared to HSR.

Despite decreased overall disparity of accessibility from HSR extensions and improved percentage of accessibility in the previously low-accessible cities does not mean their spatial equity is high. A city may have high absolute accessibility but still have a low relative improvement because of its initial low accessibility value. In reality, the dominance of the Seoul metropolitan area remains unchanged. This may because there is still a lack of nationwide HSR or semi-HSR network as well as concentrated population along the Gyeongbu corridor, especially in the SMA.

## 5. Conclusions

Much literature has analyzed the changes in accessibility benefits of the HSR network, yet the evaluation of spatial equity impacts of HSR is limited, especially based on the South Korean HSR. Our study evaluates both efficiency and the spatial variations of equity impacts in cities and counties of South Korea from the HSR extensions at different stages (S1, S2, and S3) by using WATT and PA measures. Like many other countries' HSR (e.g., Gutiérrez, 2001), efficiency may have played a more important consideration than spatial equity at the initial stage (S1) of HSR network development in South Korea. As expected, this trend not only continues even after the completion of S2, but the internal inequality declined in many regions more so than the initial stage (S1) of HSR network. Geographically, there is a polarization regarding receiving accessibility benefits (both the travel time reduction and increasing attractiveness): the concentration of the greatest increase in accessibility benefits were in cities along the Gyeongbu HSR corridor—between Seoul and Daejeon; whereas, cities especially in the northeast and southwest regions encountered a spatially disadvantaged position due to a lack of direct connection with HSR networks.

Increasing spatial-equity benefits seems to have become a more important concern for the extension of future HSR network (S3) in South Korea reflected by the decreased coefficient of variation (CV) values of both WATT and PA. The cities that received the least equity benefits from the prior extensions (S1 and S2) will experience the highest percentage of accessibility improvements from the S3 HSR extension—a critical reflection of addressing equity issues. For example, the construction of the Honan-dedicated HSR line and other semi-HSR lines at S3 will improve accessibility in the least-accessible cities of the southwest and northeast regions with the decreased regional variance of accessibility to some degree. However, the overall relative degree of improvement will not be as large enough to compare with the areas that had high equality from the prior extensions such as Seoul and its adjacent cities. As a result, despite the larger supplementation of equity benefits from the future HSR extension to the previously disadvantaged cities such as Gangneung, Donghae, and Gwangju, cities directly served by the initial HSR network (S1) will continue to maintain the dominance in both travel time and attractiveness locational advantages in South Korea. This similar trend is also noted in Europe from the European HSR studies (e.g., Li and Shum, 2001, Monzón et al., 2013). In addition, our study identifies areas with a lack of accessibility between provinces such as Jinju, Suncheon, Andong, Uljin, and areas in the interior southeast and interior mid-south even after the future HSR extension (S3).

The results of this study have an important implication for balancing economic development in South Korea. Some (Chung and Lee, 2011) note that South Korea's HSR network is nothing more than a faster connection to the SMA than the conventional railway and highway network that potentially polarized the growth pattern. The concern exists that the rest of the provincial areas may decline further because of the relative loss of economy to the SMA area (Sasaki et al., 1997, Jun and Lee, 2007). The increased access to the provinces from Seoul by reduced travel time can supplement lagged competitiveness of the provinces far from Seoul. That said, the equality in transportation services may be a prior condition for the balanced development of the country. In this perspective, our study suggests that the lack of accessibility could be supplemented by an additional high-speed connector corridor such as Gwangju-Busan, Mokpo-Suncheon, Daejeon-Jecheon, Andong-Uljin, and Andong-Daegu for balancing the country's unequal accessibility and growth. Considering efficiency and construction costs of the HSR line, this study suggests that semi-HSR lines can be an option for both increasing efficiency and relieving spatial disparity of accessibility within lower-density areas of the country with limited financial conditions.

Our study offers a platform for further assessments of equity issues for monitoring the long-term progress of HSR development, yet it has some limitations. We used location-based measures for evaluating the impact of HSR network extensions that provide clear and easily interpreted results reflecting spatial interactions between cities at a macro-scale. These measures, however, are limited because they cannot measure vertical-equity issues at the micro-scale. Utility-based accessibility measures would overcome these weaknesses in future research focusing on travel costs using detailed variances, but complicated data would be required (Gulhan et al., 2013). For example, the social needs, abilities (cost of ticket prices), and mode choices of various groups based on age, gender, job and income status need to be predicted and included in accessibility measures to handle equity issues more thoroughly. In addition, the Gini coefficient and the Lorenz curve could be utilized to show the overall degree of inequality across an entire HSR system and a visual representation of equality gaps in accessibility relative to affordability level.

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