A Geographic Assessment of High-speed rail stations on urban development: the implications from the Korea Train eXpress (KTX)

By: Hyojin Kim, Selima Sultana, and Joe Weber

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Abstract:

As part of the balanced-development strategy, the Korean high-speed rail system−Korean Train eXpress (KTX)−is expected to serve not only as the next-generation intercity transit system, but also to have effects on regional development. With increased accessibility, HSR station locations have the potential to act as transport nodes as well as evolving as localized urban places by attracting higher-volume passenger flow and increasing economic activity. This paper evaluates the performance of KTX stations as an economic development strategy using the node-place concept, which simultaneously assesses a station's role as node and place. The calculated scores from the node-place index suggest various outcomes of KTX stations. While balanced stations are performing as both nodes and places and are located in urban centers, imbalanced stations that perform neither role well are found on urban peripheries. Our findings indicate imbalanced stations are less effective for attracting passengers and other economic activities. HSR station vitality is depends on interactions with existing urbanized areas, and those located in urban peripheries typically lack this. Station proximity to central business districts is an important consideration for locating future KTX stations in either mid-size cities or suburban areas, in order to maximize the economic impacts of KTX services.

Keywords: High-speed rail | KTX stations | Urban development | Node-place model

Article:

1. Introduction

High-speed rail systems (HSR) are at the forefront of advanced transportation systems worldwide and are important not just for improved mobility but for their potential effects on regional development. The space-time compression produced by HSR networks can foster economic and social development throughout a country (e.g., in Japan, France, Spain, and China) at several spatial scales such as for a city, regiona, or even the area surrounding a station (Givoni, 2006, Jiao et al., 2017). Locating HSR stations has become an important strategy for decentralizing and improving urban and regional development (Kim, 2000, Priemus, 2008, Garmendia et al., 2012, Yin et al., 2015). For example, the National Planning Policy of South Korea established a balanced development strategy utilizing the KTX network and stations as points for new development with the hope that this will restructure the national urban system (Korea National Statistical Office, 2015). Similarly, the locations of new HSR stations in China has been considered as part of that country's urban and economic growth strategy, with medium-sized cities being specifically targeted (Yin et al., 2015). Planning efforts in both countries favor locating rail stations in suburban or peripheral areas to decentralize regional development.

HSR stations not only serve as a transportation node but by attracting a higher volume of passenger flows they may have the potential to serve as activity centers for shopping, dining, business meetings, and leisure (Peek and Louw, 2008), thus taking on the functions of an urban central place (Bertolini, 1999). For example, a number of firms and offices relocated near the Lille, France, HSR station because it played a role as a transportation hub serving a large volume of daily commuters and business trips (Ureña et al., 2009, Vickerman, 2015). With increased accessibility as a transport node and attractiveness as a business center, Lille also experienced residential population growth in the surrounding area (Ureña et al., 2009). Similar impacts have been identified around many HSR stations in Japan (Murayama, 1994, Murakami and Cervero, 2010). These examples suggest that planners can utilize the increased accessibility and attractiveness of high-speed services as a means to develop the regional economy (Wang et al., 2013).

Many successful HSR stations (e.g., Lille, Tokyo, Paris, Madrid, Beijing, and Seoul) are located either at or near their city centers where high demand for inter-city travel exists (Givoni, 2006, Vickerman, 2015). High-speed systems typically have fewer stops than traditional rail services to minimize the loss of travel time since each station is required to serve a larger population than stations for traditional rail lines. The effectiveness of HSR stations on economic development is mixed (e.g., Yin et al., 2015), with evidence suggesting stations located in suburban areas have lower ridership than expected and fewer expected economic outcomes. That said, locating HSR stations in either suburban areas or in smaller cities as part of a development strategy may pose uncertainty and financial risk, suggesting a great need for planners and policymakers to better understand the potential for development of different station locations (Moyano and Dobruszkes, 2017). This paper addresses these issues by examining the locations of various high-speed rail stations in South Korea's KTX system and their performance as transport hubs as well as urban places using the node-place concept. The intensity and diversity of transportation options through the network determine a station's role as a node, while its performance as a place is reflected by the economic activity surrounding the station.

2. Conceptual background

2.1. HSR infrastructure and development

Investment in transport infrastructure is considered an important catalyst for development (e.g., population and economic growth) and spatial integration either within or across countries (Aschauer, 1989, Bruinsma and Rietveld, 1993). Thus, investment in high-speed rail infrastructure has been perceived as a means for promoting regional development beyond the direct results of faster intercity travel (Vickerman, 1997, Campos and De Rus, 2009). Cities served by a high-speed network have increased accessibility and competitiveness (e.g., Martin, 1997, Vickerman, 1997, Jiao et al., 2014a, Jiao et al., 2014b, Shaw et al., 2014, Kim and Sultana, 2015), which can lead to employment growth and greater social inclusion (Givoni, 2006, Andersson et al., 2010, Chen and Haynes, 2015, Marti-Henneberg, 2015, Yin et al., 2015, Diao et al., 2016). For instance, improved accessibility by high-speed rail has contributed to European regional political and economic integration (Gutiérrez et al., 1996; Gutiérrez, 2001, Vickerman, 1997). Likewise, the integration of Chinese cities and provinces has been enhanced by the rapid expansion of the Chinese HSR network (Cao et al., 2013, Wang et al., 2013, Jiao et al., 2017).

Integrating HSR networks with other modes of transportation services is another recent strategy for regional development. HSR makes travel easier than other modes, such as airplanes, hence there is potential for a net increase in the number of passengers in the entire transportation market when the spatial interaction between places is increased. The growing market share of HSR creates constructive competition between other modes of transportation. Although HSR is in competition with air travel for trips between 400 and 600 km, high-speed trains have also been competitive with other ground transportation for long-distance intercity commuters (Vickerman, 1997, Levinson, 2012). Intercity bus services have been upgraded with lower fares, luxury buses, wi-fi connections, and seat power outlets to compete with high-speed trains. Likewise, air service has been improved with lower airfares and more connecting flights to compete with HSR (Albalate et al., 2015). Consequently, as competition between modes of transportation increases so does the quality of services for all modes of transportation. Additionally, HSR stations that are part of an integrated transportation network can serve as a feeder or supplement role to air transportation networks (Givoni and Banister, 2006). These competitive and cooperative networks reduce travel costs and generate more passenger for commuting, business travel, and leisure, which ultimately promotes economic development.

HSR also can contribute to accessibility inequalities between those cities served by both high-speed and conventional trains (Vickerman et al., 1999, Kim and Sultana, 2015). In Europe the high-speed network facilitated economic concentration in major cities, while negatively affecting economic activities in small and peripheral cities that were left off the network (Vickerman, 1997, Gutiérrez, 2001, Monzón et al., 2013, Chen and Haynes, 2015, Jia et al., 2017). Additional research suggests that intermediate cities on the HSR network have disadvantages in accessibility and have only limited success in attracting ridership compared to larger cities(Marti-Henneberg, 2015, Vickerman, 2015). In these cases, the absence of an HSR station has become an obstacle for balanced development despite the HSR's overall positive effects at the national scale (Moyano and Dobruszkes, 2017). The disparityof the benefits of HSR remains an ongoing issue where these networks have been constructed (Vickerman, 1997, Ureña et al., 2009, Garmendia et al., 2012, Kim and Sultana, 2015, Vickerman, 2015).

The spatial inequity from high-speed rail is unlikely to be mitigated without careful consideration of station locations and the utilization of surrounding space with integrated intraregional transport connections (Ureña et al., 2009, Higgins and Kanaroglou, 2016). Traditionally railway stations attract businesses and other commercial and residential activities due to the relatively high accessibility these places offer. The remote location of some HSR services can be problematic for attracting development activities since HSR is designed for intercity travel and cannot provide 'door-to-door' service without the combination of other modes of transportation. Diao et al. (2016) investigated how the location of high-speed stations determines the quality of access to travelers, which is a crucial condition for attracting greater traffic flows and urban development. They pointed out that the integration of HSR stations and local transportation is required for any increase in intercity commuting by high-speed trains. Vickerman (2015) also noted that the new HSR stations in intermediate cities in Europe are mostly located in exurban areas (e.g., TGV-Haute Picardie, TGV-Lorraine) where transport options and urban development are very limited. Similarly, some HSR stations in Germany, South Korea, and Taiwan have lower ridership than expected, which is most likely due to the inappropriate location of these stations, resulting in a lack of development around the area (Marti-Henneberg, 2015, Yin et al., 2015). While not conclusive, these preliminary studies imply that the suburban HSR stations may have unfavorable conditions for generating traffic and hence attracting economic activities nearby.

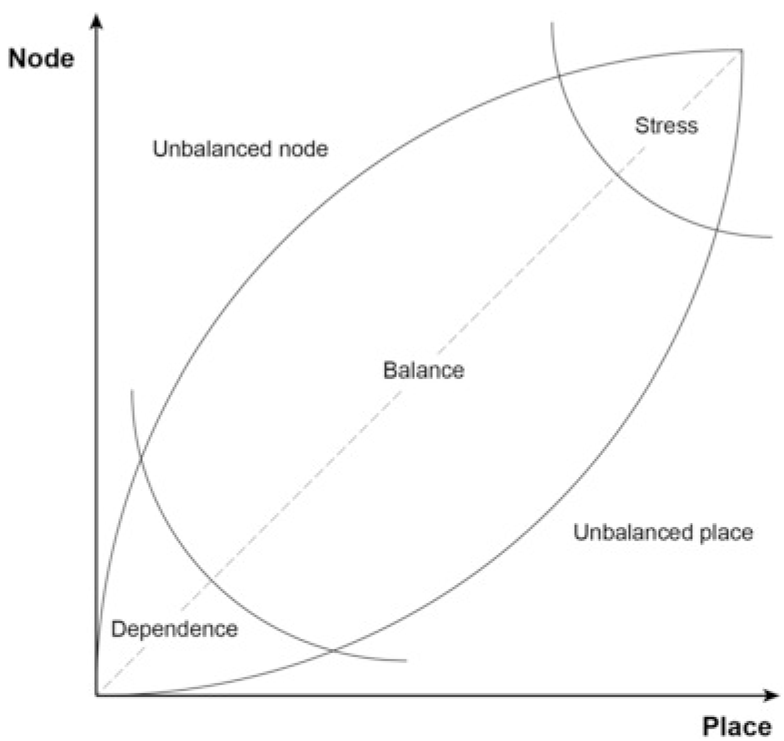

Fig. 1. The concept of node-place model.
Source: Bertolini, 1999 and Vale, 2015.

2.2. The node-place model: a station area typology

Accessibility analysis is a common means for evaluating levels of locational benefits between cities after the introduction of high-speed trains in a country (Gutiérrez, 2001, Kim and Sultana, 2015, Jiao et al., 2017). Accessibility analysis, however, has limitations for examining activities such as land-use intensification and economic diversification around station areas. To fill this gap, the node-place model was developed (Bertolini, 1999) to evaluate the degree of performance for each station by focusing on the simultaneous roles of a station as a node on their transport network and as a place by the intensity of various economic activities resulting from the function of the node. In this model (Fig. 1), the node index measures the connectivity, accessibility, and service quality of a station (y-axis), and the place index measures the intensity and diversity of land uses resulting from various human activities around that station (x-axis).

The node-place model identifies five typical situations for a station area, labeled balance, dependence, stress, unbalanced node, and unbalanced place (Fig. 1). The "balanced" part in the middle area of the diagram indicates stations functioning as both 'nodes' and 'places'. In other words, in this scenario, both intensity and diversity of transportation and economic activities around the station area are functioning as expected. The highest performance of a station is identified as a "stress" situation, at the top right corner of the diagram, which indicates both a high supply of transportation and strong place function of a station operating at capacity. In this situation, development around the station area is already saturated and further development of the station area will require more land, which may cause conflicts around the station area. On the contrary, stations in the "dependence" situation have little demand for local land uses as well as less connected and infrequent transportation services. An "unbalanced node" indicates that a station is in a position serving relatively strongly as a node with crowded rail services, but has played a relatively weak role for attracting economic activities. In contrast, "unbalanced places" have thriving station areas, but an insufficient supply of rail services (Fig. 1).

The node-place model has been applied to many studies of urban and transportation planning (Reusser et al., 2008, Vale, 2015). For example, Reusser et al. (2008) applied this model to categorize 1684 train stations in Switzerland and utilized a hierarchical cluster analysis for identifying five types of stations in their node-place model, using log-transformation and z-score normalization indicators, while Vale (2015) focused on the walkability of the station areas when computing the node-place balance using a hierarchical cluster analysis. Chorus and Bertolini (2011) reduced the complexity of the selected indicators for node and place indices in their classification of 99 station areas in Tokyo, Japan. They used a principal components analysis to find factors related to real estate development and concluded that the proximity of station areas to the central business district by train and government policies are significant factors in development around the station area.

Alternatively, there have been attempts to define station areas using various functions instead of finding the node-place combination degrees for the performance of station areas. Zemp et al. (2011) applied the model to classify 700 train stations in Switzerland by performing hierarchical cluster analysis that resulted in seven clusters of rail stations. Kamruzzaman et al. (2014) used a two-step cluster analysis based on selected node-place indicators with 1734 censustracts in Brisbane, Australia. In addition, Higgins and Kanaroglou (2016) used a latent-class method to identify the performance of 372 rapid-transit stations in Toronto and concluded that there were ten types of station areas.

3. Study area and methodology

3.1. Study area: KTX in South Korea

Since the beginning of the Korea Train eXpress (KTX) service in 2004, the South Korean government has invested 34.4 billion USD in the development of this network based on high-speed and semi-high-speed rail services. These aim to reduce intercity travel costs as well as promoting balanced development of the country (MOLIT, 2012). As of 2015 KTX serves three major routes (Seoul-Busan, Seoul-Mokpo, Seoul-Yeosu) and four branch routes (Seoul-Busan via Miryang, Seoul-Jinju via Miryang, Seoul-Pohang via Daegu, Seoul-Iksan via Daejeon) (Fig. 2). Some trains on most KTX lines also serve Goyang or Incheon International Airports for convenience. As with other countries' first high-speed routes, the KTX focused on sharing the excess traffic of the Gyeongbu corridor between Seoul and Busan, which covers approximately 70–80% of businesses in the country, and since then the network has been extended to the rest of South Korea (Kim and Sultana, 2015). With continued investment, the KTX now operates 1528 km of track with five main routes (Gyeongbu, Honam, Jeonra, Gyeongjeon, and Donghae) serving 155,628 daily passengers as of April 2015 (Korea Railroad Corporation, 2015). Currently, 60% of the country's population is within a half-day's travel time from an HSR station (Korea National Statistical Office, 2015) and 84% of the population is expected to receive the same level of coverage by 2025 (MOLIT, 2012).

The HSR network has been spreading in South Korea, yet locating stations in the KTX network has been contentious (Kim, 2014, Lee, 2008). Pressure to relocate some of the KTX stations from urban centers to suburban or rural areas as railroads has been unpopular with many suburban residents because of the negative perceptions of noise and fragmentation of an area by tracks (Reusser et al., 2008). In response, the promise of economic growth has become a strong argument in support of building stations in these areas. However, experience from elsewhere, such as Germany and Taiwan, suggest that HSR stations located in suburban areas or mid- to small-sized cities are unable to serve as a nucleus for regional economic development (Yin et al., 2015). Consequently, locating HSR stations in either suburban areas or in smaller cities as part of a Korean's development strategy poses uncertainty and financial risk, and highlights the importance of better understanding the tradeoffs and conditions involved in various station locations and their potential for economic development.

3.2. Methodology

Given the effectiveness of the node-place model for classifying the performance of station areas (e.g., Kamruzzaman et al., 2014, Higgins and Kanaroglou, 2016), we use this methodology for evaluating the balance of transport supply and land useactivities for 18 KTX stations in South Korea. The node-place model is applied to classify the condition of station areas based on the balancing degrees of transport and land use activities. We converted indicators of node and place indices by log-transformation and z-score normalization to distinguish the different performance of stations. Then, we computed node and place indices and their balance (i.e., node and place) allowing us to identify the performance of all 18 KTX stations and their potential for urban development. Since the number of KTX stations available for our analysis is small, the performance of cluster analysis was not useful and hence was excluded from analysis.

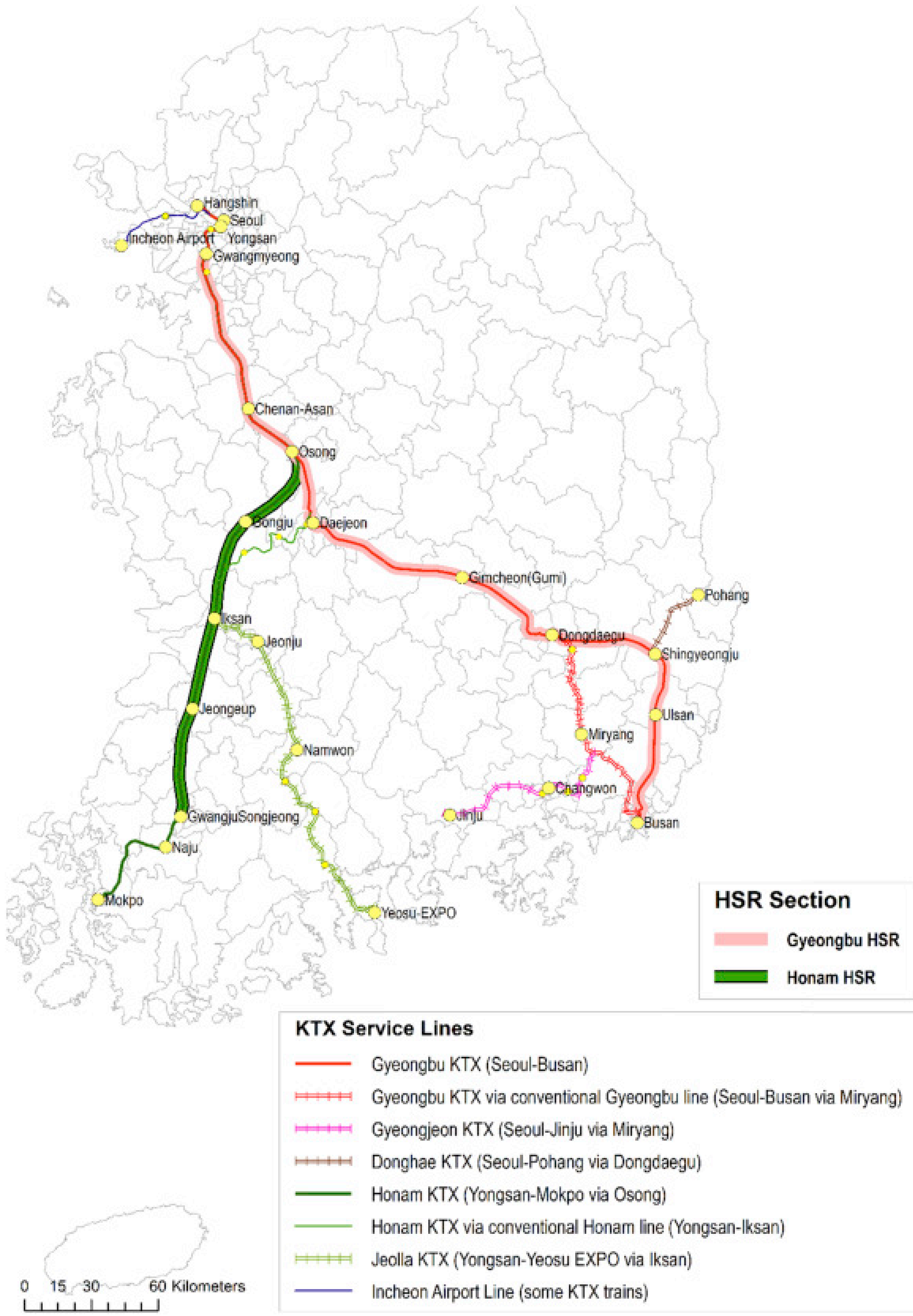

Fig. 2. KTX service network in 2015.

Ideally, improvements to the transportation network of a city by the arrival of KTX service should both enhance its nodal value from the increase of accessibility as well as increasing the attractiveness of the station area for economic activities. KTX routes use both dedicated HSR tracks and upgraded conventional railway tracks. For consistency, we excluded KTX stations on branch routes based on upgraded conventional railroads. We selected 18 KTX stations along two major HSR routes that mainly use dedicated HSR tracks and together serve 84% of total KTX passengers (Korea Railroad Corporation, 2015). These two routes are Gyeongbu (Seoul to Busan via Daejeon and Daegu) and Honam (Seoul to Mokpo via Iksan and Gwangju). Stations on these two routes should have a high potential to show significant impacts on development compared to other KTX stations on branch routes. The node values are analyzed by selecting ten specific variables based on previous research with consideration for the South Korean context (Table 1).

Table 1. Variables used to calculate node and place indices.

Node values (Y)	**Place values (X)**
y_1 = Number of directions on KTX routes.	x_1 = Distance to urban center (converted to the reciprocal number)
y_2 = Number of KTX train stops in a day.	x_2 = Residents within 1 km of a station
y_3 = Number of conventional rail stations within 40 min of travel by conventional train.	x_3 = Number of hotels within 1 km of a station
y_4 = Regional railway routes connectivity.	x_4 = Number of convenience stores within 1 km of a station
y_5 = Number of terminal stations by metro.	x_5 = Number of pharmacies within 1 km of a station
y_6 = Number of bus routes.	x_6 = Number of florists within 1 km of a station
y_7 = Total daily frequency of local buses.	x_7 = Number of coffee shops within 1 km of a station
y_8 = Distance to highway entrance.	x_8 = Number of corporations within 1 km of a station
y_9 = Car parking capacity.	x_9 = Number of companies within 1 km of a station
y_{10} = Daily passengers of a station.	

The various spatial and sociodemographic variables selected to determine node and place values for this study come from several sources (Table 1). The ridership data for each KTX station were collected from the official website (http://kosis.kr) of Korean National Statistical Information Service (2015). Demographic data for the area around the station were collected from the same website. The specific operation of KTX, such as the number of routes and connectivity of local transportation, train frequency, daily passengers and parking spaces for each station, were calculated manually from the website of Korail, the operator of KTX (http://info.korail.com). Likewise, daily bus frequency, bus and metro routes for each station, and distance to highway entrances were calculated from the Daum Map service websites (http://map.daum.net). The number of destinations by train is closely related to ridership as a station offering multiple destinations attracts more travelers. For instance, the Gyeongbu and Honam lines share the section between Seoul and Osong and stations located on the shared section (such as Gwangmyeong, Cheonan-Asan, and Osong) have more services compared to stations with a single route. The numbers of Metro and bus routes indicate the convenience of traveling to local destinations for inter-city travelers. In addition, the quality of these local public transportation systems has an impact on intra-city travel between the station area and other urban areas. Car parking capacity is another indicator showing the convenience of access to the station by car (Table 1).

We used nine indicators to determine place values based on previous studies (e.g., Chorus and Bertolini, 2011) and data availability (Table 1). We selected proximity to urban centers using the network distance reciprocal as the place indicator, considering (e.g., Reusser et al., 2008, Chorus and Bertolini, 2011) that proximity to urban center influences the degree of economic activity. There is no standard protocol for defining station buffer areas, but many studies (Lee and Oh, 2008, Jung, 2015, Vale, 2015, Higgins and Kanaroglou, 2016) applied a one km buffer to analyze station area activities. A one km buffer represents the region where most individuals walk to either the station or to access local bus service. The number of hotels, convenience stores, florists, coffee shops, and corporations represent the range of economic activities used for the determination of the place values, and were calculated manually using GIS and the Daum Map service (http://map.daum.net).

To produce each node and place index, each variable was log-transformed to reduce skewness. All variables were then rescaled to range between 0 and 1 for standardization. Each index is calculated by the summation of all variables of each category of node and place (e.g., node index $Y=\sum \ln(y_i)$, place index $X=\sum \ln(x_i)$) (Fig. 1). The scores calculated by the node-place model were used for comparison of different cities, which implies the degree of balance between node and place function of a city indicates the performance of the station in regional development. Specifically, improving the transportation system of a city enhances its nodal value by increasing its accessibility, which influences the station area.

3.3. Analysis of node and place data

3.3.1. Node perspective

The overall ridership and market sharing of KTX is increasing on major service routes with its network extension by 2014 (Table 2). The number of passengers along the Gyeongbu line shows the highest ridership of all KTX routes. The volume of passengers along this line has also increased by 61.5% between 2005 and 2014. In addition, the seat occupancy rate of HSR also reflects a growing demand, though it remains below 80%. This rate increased above 90% in 2010 after the second stage of the network upgrade was completed. Significantly, the seat occupancy value of the Gyeongbu line was around 100% after the opening of additional sections between Daegu and Busan since 2010. In contrast to the popularity of the Gyeongbu line, the seat occupancy of other KTX lines such as Honam or Jeonra has shown a relatively low volume of passengers, because major cities are concentrated along the Gyeongbu KTX line (Table 2). Therefore, cities along Gyeongbu line are assumed to have more spatial activities through their KTX stations.

Table 2. Annual ridership changes after HSR in South Korea.

KTX line		**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Total	Annual Ridership (thousand people)	32,368	36,490	37,284	38,015	37,394	41,303	50,309	52,802	54,829	56,916	60,535
	Ratio of passengers[a](%)	70	75	75	73	72	81	95	95	91	98	
Gyeongbu	Annual Ridership (thousand people)	26,852	30,191	30,979	31,533	31,010	34,342	39,060	39,896	42,005	43,621	41,702
	Ratio of passengers[a](%)	79	83	82	79	78	87	103	101	96	103	
Honam	Annual Ridership (thousand people)	5516	6299	6305	6482	6384	6842	7313	6967	6873	6626	
	Ratio of passengers[a](%)	45	52	52	53	52	60	67	68	70	72	
Gyeongjeon	Annual Ridership (thousand people)	–	–	–	–	0	118	3627	4168	4088	4424	
	Ratio of passengers[a](%)	–	–	–	–	0	107	104	102	97	101	
Jeonra	Annual Ridership (thousand people)	–	–	–	–	–	–	309	1771	1954	2244	
	Ratio of passengers[a](%)	–	–	–	–	–	–	101	99	91	95	

[a] The ratio of passengers is calculated by the number of given seats.
Source: Korea National Statistical Office, 2015

KTX has a large market share of passenger transportation compared to other modes such as conventional railway, car, bus and air transport for long-distance travel from Seoul to Daegu and Busan (Table 3). KTX market shares of about 60% on the Seoul-Daegu and Seoul-Busan routes imply a peak competitiveness of HSR on trips of approximately 300 km in South Korea. All airlines terminated service over the Seoul to Daegu route in 2007 after the competition of KTX in 2004. However, for long-distance travel exceeding 300 km, airlines compete with KTX due to the growth of low-cost airlines on the Seoul-Busan route (Jung and Yoo, 2014). The development of HSR in South Korea also has led to a significant increase of intercity travelers by train, but this achievement remains lower than the expected ridership before the construction of HSR (Table 3).

Table 3. Market share for the passenger travel along Gyeongbu KTX line.

Route	Distance (km)	Year	KTX (%)	Conventional Railway (%)	Car(%)	Bus(%)	Air(%)
Seoul - Daejeon	166	2003	0.0	14.7	70.4	14.8	0.0
		2008	28.1	5.4	54.5	12.0	0.0
Seoul - Daegu	306	2003	0.0	26.5	41.1	13.7	18.7
		2008	59.8	1.9	32.0	6.3	0.0
Seoul - Busan	360	2003	0.0	29.3	14.0	7.6	49.1
		2008	60.3	3.0	5.4	7.5	23.8

Source: Korean National Statistical Office, 2015

As a national transport infrastructure created by public investment, the overestimated ridership of KTX was a critical error requiring new strategies to address issue (Lim, 2005). For example, Gyeongbu KTX was predicted to carry 288,793 to 328,648 travelers per day in 2010, but the daily average ridership of 2010 was 94,088 (Korea Railroad Corporation, 2010). The predicted ridership error was partly explained by various flexible situations during the construction of KTX such as fare increases, a highly upgraded highway network, and insufficient travel time reduction by KTX to compete with other modes of transportation (Lim, 2005). The error of prediction in ridership also was due to business slowdowns during the construction of the KTX (Chang and Lee, 2008). These interpretations are reasonable, but not fully applicable to the case of the extended KTX network after 2010. There is reason to believe this problem is also influenced by the location of the new KTX stations, based on similar cases in Taiwan and Germany (Yin et al., 2015). Placing HSR stations outside city centers may reduce the potential for attracting ridership because of modal competition (Marti-Henneberg, 2015). On average, the new KTX stations of Gyeongbu KTX and Honam KTX on the two HSR routes are 15.86 km from the city halls of adjacent cities, compared to 4.06 km for upgraded KTX stations at the same location with conventional railway stations (Marti-Henneberg, 2015). Thus, KTX stations located more than 15 km from the urban center have disadvantages when attracting travelers into the stations from bus terminals in the nearby urban center or by private cars.

Ridership data are assessed from the perspective of supply and demand to evaluate the performance of each station (Fig. 3). Each performance value is calculated by the ratio of daily-averaged ridership (demand aspect) and daily stop frequency (supply aspect) of each station as of 2015. The result shows the different achievements of KTX stations in attracting passengers. Seoul, Yongsan (in Seoul), Busan, and Gwangjusongjeong stations show high scores in demand among KTX stations, but Gwangmyeong, Osong, Gimcheon, Shingyeongju, Gongju, Iksan, Jeongeup, and Naju are assumed to be less crowded stations, which means a relative deficiency of travelers in these stations (Fig. 3). The value of ridership by each KTX train is basically influenced by train-stop patterns composed of required stops (e.g., Seoul, Daejeon, Daegu, Busan, Iksan, Gwangjusongjeong, and Mokpo) and selective stops (e.g., Gwangmyeong, Osong, Gimcheon (Gumi), Gongju, and Naju). Some KTX stations, however, have imbalances between the supply of trains and travelers despite being a stop-required station. For instance, the Gwangmyeong station does not show enough ridership despite having the highest number of train stops among KTX stations. Likewise, the Iksan station has a relatively low ridership despite its high service frequency (Fig. 3).

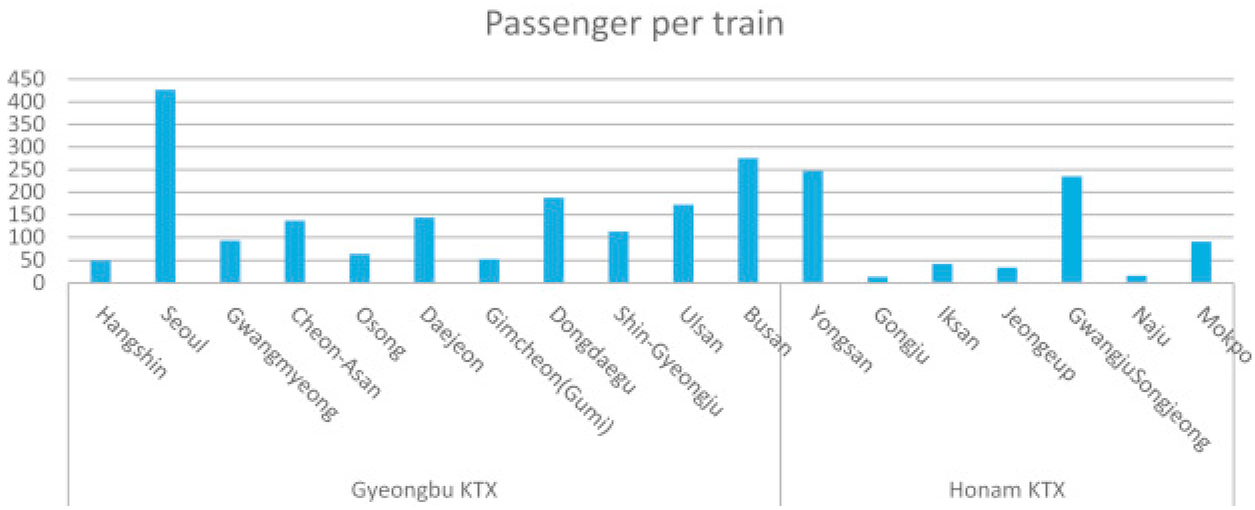

Fig. 3. Number of passenger per KTX train at each station in 2014.
Source: Korea National Statistical Office, 2015

Accessibility to existing urbanized areas is identified an important indicator for urban development around the KTX stations (Table 4). Since recently added KTX stations such as Osong, Gimcheon (Gumi), Shingyeonju, and Ulsan are located on the previously constructed dedicated HSR lines, these stations were in intermediate zones (e.g. targeted in small and medium--size cities) away from urban areas. Additionally, these smaller cities had less negotiation power when the line was designed (Garmendia et al., 2012, Vickerman, 2015). For this reason, the intermediate stations are located farther from the city centers compared to stations located in metropolitan cities that have populations of more than a million, such as Seoul, Daejeon, Dongdaegu (in Daegu), and Busan stations.

To investigate the present condition of KTX stations by distance, we classified the location of KTX station by modifying Marti-Henneberg's (2015) classification used to evaluate the capacity of HSR stations as a place expected to attract passengers. Based on the locational difference, the location of each KTX station is classified with various conditions (Fig. 4):

● **City center:** A) These stations are in the previous location of conventional railways. Some stations endure the reduction of train speed inside cities running on curved railways. Most of them are essential stops (Seoul, Yongsan, Daejeon, Dongdaegu, Busan, and Iksan), supported by high demand for railway service; B) These stations are part of the upgraded conventional railway through KTX service (Miryang, Naju, and Mokpo).

● **Suburban area:** A) These stations have a high demand for rail service, but there is insufficient space for HSR due to the already developed urban area (Cheonan-Asan). B) These stations were moved to suburban areas by upgrading conventional railways through KTX service (Changwonjungang, Jinju); C) These stations are part of the dedicated HSR, but they were constructed after high-speed operation began (Osong, Gimcheon (Gumi), Shingyeongju, Ulsan); D) These stations already are located in suburban areas for conventional railway services, and they were expanded for KTX service (Gupo, Incheon International Airport, Geomam) or maintenance for KTX trains (Hangshin).

Table 4. Proximity to urban center from KTX station.

Station	**City**	**Distance to city hall (km)**	**Travel time (min)**		**Built type**
			Car	**Public transportation**	
Hangshin	Goyang	6.2	17	35	Upgrade
Seoul	Seoul	2.2	8	13	Upgrade
Gwangmyeong	Gwangmyeong	7.9	18	36	New open
	Anyang	10.1	18	51	
	Siheung	13.1	14	51	
Cheonan-Asan	Cheonan	3.6	6	22	New open
	Asan	11.7	16	30	
Osong	Cheongju	17.1	28	40	New open
	Sejong	21.6	23	54	
Daejeon	Daejeon	6.9	17	24	Upgrade
Gimcheon(Gumi)	Gimcheon	10.2	15	30	New open
	Gumi	27.1	26	56	
Dongdaegu	Daegu	4.8	11	25	Upgrade
Shingyeongju	Gyeongju	15.1	23	46	New open
Ulsan	Ulsan	20.2	25	39	New open
Busan	Busan	8.5	19	27	Upgrade
Yongsan	Seoul	6.0	19	15	Upgrade
Gongju	Gongju	17.9	32	60	New open
	Nonsan	22.1	30	83	
Iksan	Iksan	1.7	4	13	Upgrade
Jeongeup	Jeongeup	1.6	4	10	Upgrade
Gwangjusongjeong	Gwangju	7.3	12	27	Upgrade
Naju	Naju	0.8	2	2	Upgrade
Mokpo	Mokpo	3.1	8	18	Upgrade

Overall, 43% of KTX stations are in city centers while 57% of KTX stations have lower accessibility from the city centers (Fig. 5). The stations located near the city centers are typically older stations, including Seoul, Daejeon, Daegu, and Busan. In contrast, stations such as Osong, Gimcheon (Gumi), and Shingyeonju are in the intermediate cities (between two large cities) on Gyeongbu KTX included in the category of “Suburban area-C” (Fig. 5). Even though these stations have a faster intercity connection by the dedicated HSR compared to many other cities served by KTX through the upgraded railways, they still have challenges of poor accessibility to nearby city centers.

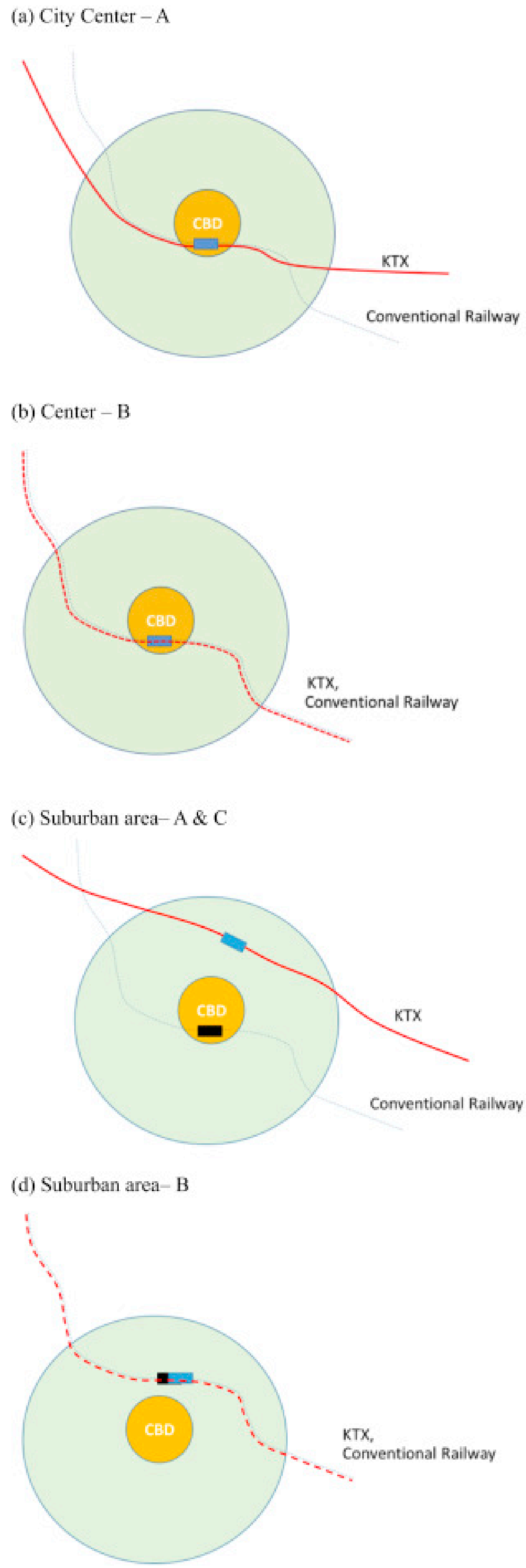

Fig. 4. Types of HSR station locations in South Korea. (a) City Center – A. (b) Center – B. (c) Suburban area – A&C. (d) Suburban area – B.

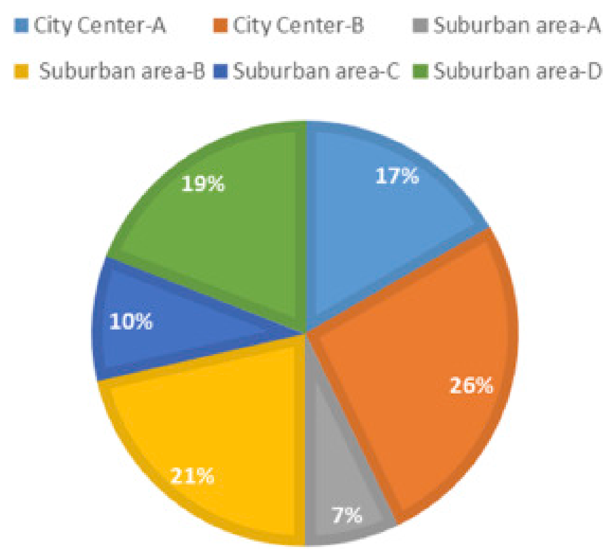

Fig. 5. Location types of KTX stations.

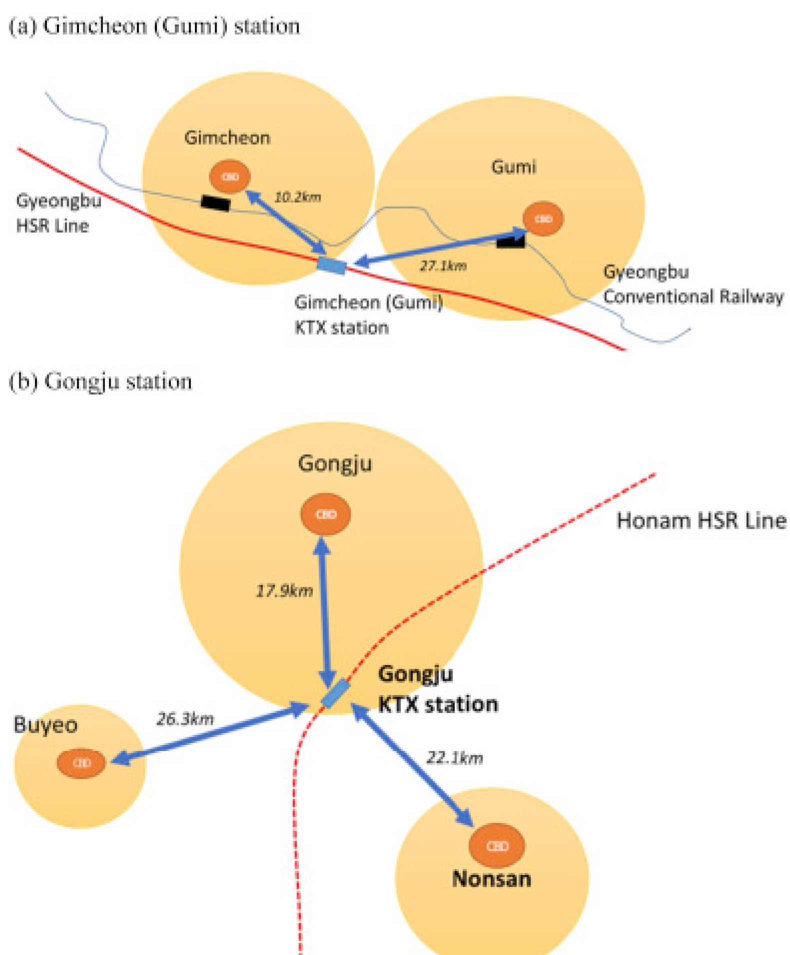

Fig. 6. Location of KTX stations targeting multiple cities. (a) Gimcheon (Gumi) station. (b) Gongju station.

We also evaluated the performance of KTX stations based on these locational differences (Fig. 6). These intermediate KTX stations such as Gimcheon (Gumi) and Gongju are situated between several adjacent cities with the purpose of extending HSR service to multiple cities with a single KTX station (Fig. 6). The strategy can expand the service range of KTX, but these KTX stations are notadjacent to urban centers, which poses severe challenges to integrate intermodal accessibility. Passengers using these stations require transfer to local transportation to reach an urbanized area, which decreases the merit of using HSR over other transportation modes. This disadvantage is more critical for KTX stations closer to Seoul in competition with bus and private cars. For example, travelers need an additional 40 min to reach the city center of Gongju from the Gongju station after 1 h of KTX train travel, while express buses depart the city center with one and one-half hours of travel time and charge 35% of KTX fares (Fig. 6).

Although the convenient transfer is important for KTX stations to be attractive, especially for stations outside the city center, local transportation depends on the size of cities surrounding a KTX station. Table 5 supports the difficulty of improving convenient access to urban centers from the intermediate KTX stations on the Gyeongbu corridor. Gimcheon (Gumi) station has 31 bus routes, but most of them operate less than five times per day except for limousine buses between Gumi and Gimcheon via this station. Conversely, Busan station connects to the metro line and has frequent daily bus service (more than 3000 times daily), which increases the accessibility of the station itself and makes it perform better as a place. Therefore, limited frequency of local transportation may cover the flow of KTX passengers, but it restrains the value of the station as a place due to reduced access to and from the station.

Table 5. Local transportation connectivity of Gyeongbu KTX stations.

	Metro	Bus routes	Parking space
Seoul	4	84	1 337
Gwangmyeong	1	19	2 247
Cheonan-Asan	1	12	1 094
Osong	0	10	1 351
Daejeon	1	27	353
Gimcheon(Gumi)	0	31	448
Dongdaegu	1	43	419
Shingyeongju	0	27	503
Ulsan	0	19	1 062
Busan	1	37	529

Source: Korea Railway Corporation, 2015a and Daum Maps website accessed November 11, 2015

3.3.2. Place perspective

The role of stations as an economic hub (i.e., place concept) can be evaluated by indirect indicators such as the population of cities connected with KTX, residents near a station, and business facilities. Relatively low ridership of some KTX stations such as Gimcheon (Gumi) and Shingyeongju is assumed to be related to the size of cities as a potential demand. Gimcheon (Gumi) station serves approximately 0.56 million people in Gimcheon and Gumi, and the city of Gyeongju surrounding Shingyeongju station has 0.25 million people (Korea National Statistical Office, 2015). Gyeongju's population is much less than other metropolitan cities on the Gyeongbu KTX corridor including Seoul, Daegu, and Busan, implying a population threshold is required for viable urban development around stations. Likewise, the remotely located stations of

Osong and Gimcheon (Gumi) also suffer from the lack of population thresholds (Table 4) and failed to play the role as economic hub. These stations principally serve as connectors, where passengers pass through them on their way to or from urbanized areas.

We investigated facilities inside station buildings (Table 6 and Fig. 7). Multipurpose stations have the advantage of promoting a railway station in a new central part of a city, but development of these has remained stationary in South Korea. Only Seoul and Dongdaegu stations were developed as part of multipurpose complexes with shopping malls and restaurants. While most other large stations in city centers provide multiple facilities such as meeting rooms for business to attract business travelers, the facilities within remotely located stations are limited to either convenience stores or restaurants that are mostly used by the travelers. However, some of the most recently developed stations in suburban areas are strategically located near population centers for attracting ridership. For instance, the Cheonan-Asan station has followed this strategy and shows significant annual ridership increases with more residents and businesses in the station area (Fig. 3). Unlike other rural KTX stations such Osong, Gimcheon, Shingyeongju, and Gongju, this station is relatively close (Table 4) to the existing urbanized area, and the new urbanized area around Cheonan-Asan station promotes the expansion of Cheonan, showing the synergy of the development of an HSR station. The location of department stores within the station shows the level of activity in the Cheonan-Asan station area. However, other intermediate stations do not have the same impact as Cheonan because of their distance from urbanized areas (Table 4). In this case, new towns are being developed around stations such as Gimcheon (Gumi) station, a city with a population of 26,000. The slow progress of station area development in intermediate stations located in mid-sized cities implies the limitation of being situated far from existing urban areas.

Table 6. Utility of station building (Gyeongbu KTX line).

Station	Building Type	Inside facilities	Surrounding Area
Seoul	Complex	Restaurants, convienence stores, Business meeting room, outlet, supermarket	CBD (skyscrapers, hotels, department store)
Gwangmyeong	Station only	Business meeting room, dining area	Large retail stores and High density residential zone (being developed)
Cheonan-Asan	Station only	Restaurants, convienence stores, business meeting room	Department store, Retail stores, multiplex cinema, Apartment complex
Osong	Station only	Restaurants, convienence stores	Bio-technology complex, Administration complex for public healthcare
Daejeon	Station only	Restaurants, convienence stores, business meeting room	Marketplaces, old CBD
Gimcheon(Gumi)	Station only	Restaurants, convienence stores	New town (being developed)
Dongdaegu	Complex[a]	Restaurants, convienence stores, business meeting room, department store[a], multiplex cinema[a], Aquarium[a]	Express bus terminal, CBD (≤3 km)
Shin-Gyeongju	Station only	Restaurants, convienence stores, business meeting room	Establishing development plan
Ulsan	Station only	Restaurants, convienence stores, business meeting room	Establishing development plan
Busan	Station only	Restaurants, convienence stores, business meeting room	CBD, Seaport, Waterfront (being developed)

[a] Opened in 2016.
Source: Korea Railroad Corporation, 2015b and Daum Maps website accessed November 10, 2015

FIGURE 7 IS OMITTED FROM THIS FORMATTED DOCUMENT.
Fig. 7. Multipurpose station building – Dongdaegu KTX staion.
Source: Kohn Pedersen Fox Associates (https://www.kpf.com/ko/projects/dongdaegu-transportation-hub)

3.4. Node-place balance and discussion

The performance of KTX stations on the major corridors and their relationship between transportation patterns and place functions from the selected indicators used in the node-place model indicates they function as a balance between nodes and places (Fig. 8). Seoul station is in the most favorably situated city center, but classified as a "stress" station with high values of node and place indices. Seoul's stress status as a station implies that it is overly crowded with travelers, cars, and trains. At the same time, the Seoul station area is highly developed with commercial and business facilities. Seoul station is an important transfer node in the national railway network as well as in the urban transportation network of Seoul. Other major KTX stations such as Daejeon, Dongdaegu, and Iksan experience similar conditions performing as stressed situation in terms of both node and place values (Fig. 8). All these stations have similar locational advantages in the transportation network and interaction with a large surrounding urban area. From the beginning, these stations were strategically located at nodal points not only in the conventional railway network but also in the KTX network. In addition, these stations are close to traditional urban suburban centers with high concentrations of economic activity and commercial and business facilities.

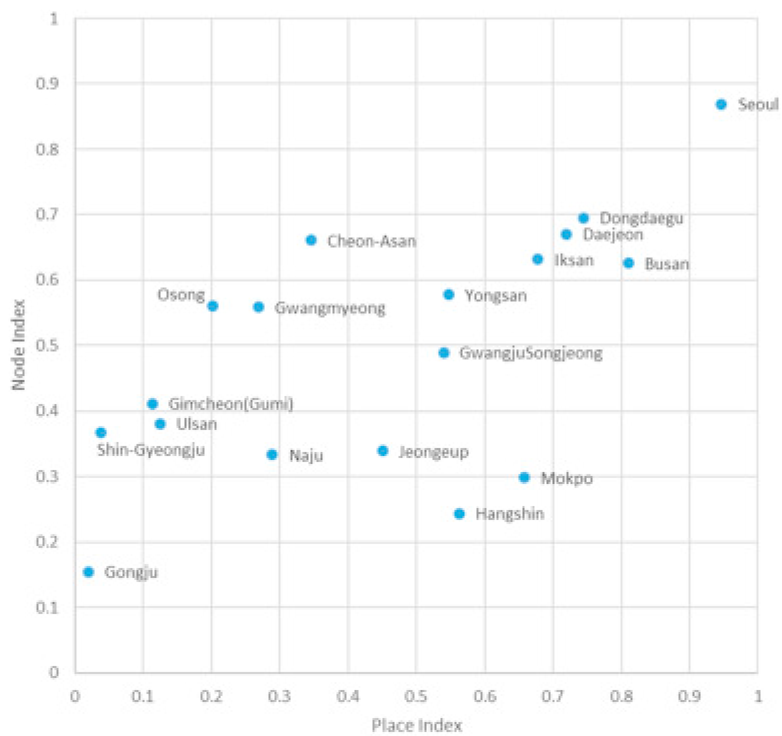

Fig. 8. Node-place model application to KTX stations.

The performance of Mokpo station in the old downtown is different from other downtown stations (e.g., Seoul). Mokpo station's performance as a business center is strong due to its location in the developed business district, yet this station is underperforming as a node (Fig. 8), as the station terminus is only connected with intermediate-level local transportation services. In contrast, the Hangshin station has a similar functional balance to Mokpo station—low node value and high place value—though it is located near a newly developed residential area where both train frequency and local connections are poor. Hangshin station's performance is likely influenced by its adjacency to the KTX Goyang Train Depot and thus, many trains return to this station for inspection and maintenance at the depot. These findings suggest that a multitude of locational factors such as city age and existing land use can determine the node-place balance.

Some KTX stations including Osong, Cheonan-Asan, and Gwangmyeong have higher node functionality, but function weakly as place. Hence, these stations are labeled as 'unsustained places' in the node-place model (Fig. 8). These stations perform well as transportation nodes because they are dedicated to HSR stations and have a relatively high frequency of KTX trains serving both Gyeongbu and Honam KTX lines. However, their suburban location hinders their development as economic hubs. Other stations functioning relatively weakly as 'places' are Gimchen (Gumi), Ulsan, and Shingyeongju, yet these perform well as 'nodes' despite their suburban location. These stations benefit from travel along a higher-density corridor sufficient to elevate ridership. Based on these findings, it is imperative that the station area plans need to be integrated with additional transportation connections to city centers. Gongju is the only 'dependent' station defined in this study as it is located in a rural setting (Fig. 8), but the status of this station may change. Gongju station is new, having opened in 2015, and its location between two cities and a town (Fig. 6) is intended to provide equal access to each city, which will require substantial investment in local services such as bus connections, business centers, and commercial stores (Lee, 2016).

4. Conclusions and policy implications

We evaluated KTX stations based on their performance as transportation nodes and places for economic growth in their surrounding areas. Overall, node and place indicators for each station show a positive role as catalysts for urban development. However, each KTX station has different conditions for performing as a nodal point and as a place. Our results suggest that the vitality of urban activities around stations depends on their spatial context. For example, KTX stations that followed the locational strategy of the conventional railway city centers perform better both in their roles of node and place. The newly built HSR stations, on the other hand, are underperforming in South Korea as economic catalysts. These stations are typically situated at locations remote from the urban centers and have only weak connectivity with local transportation services. Our results indicate stations located more than 10 km from city centers are lacking in urban economic activities even though there is some residential area around the station. In contrast, the intermediate HSR stations have less potential for making contributions to urban development because they are located on rail lines that bypass major urban areas. We do not expect this issue to be operative for a peripherally located station in large metropolitan areas because such stations are expected to extend urban-growth boundaries.

The use of the node-place model has limitations. First, detailed data representing economic activity are not easily collected for a small area. Also, specific information about economic activity is partially unavailable for a small number of stations. Thus, we used standardized scores of each variable in the basic node-place model to accommodate skewness. Additionally, timeseries data would improve the use of this model by providing the most influential factor for node-place balance change, yet are not available. Property value data around HSR stations can be utilized to show changes of attractiveness as an indicator of urban dynamics, but these data are unavailable at the micro-scale level for South Korea. Despite these limitations, our results provide a specific understanding of the current role of stations in regional development and have a significant policy implication for sustainable development by a rational diagnosis of the role of HSR stations (Chorus and Bertolini, 2011).

Our results suggest several strategies to address current major issues related to HSR and regional development. First, the proximity to central places should be the highest consideration for locating new stations in mid- and small-size cities for enhancing the impact of HSR on urban growth. Second, HSR stations built in suburban locations require a cautious investigation process in the planning stage to consider the various conditions that influence station performance. An integrated strategy of station and land-use plans is useful for this situation. Finally, stressed stations located near large city centers may revitalize the old CBD to release their stress status, such as demonstrated with the renovation of the Dongdaegu station to a multi-purpose HSR station and the redevelopment of the CBD area in Daejeon.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.tranpol.2018.02.008.

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