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RESEARCH ARTICLE

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# Interactive effects of high-speed rail on nodal zones in a city: Exploratory study on China



**Abstract** The arrival of the high-speed rail (HSR) era has accelerated the pace of urban development, but its broad socioeconomic impact remains subject to intense debates. This research aims to propose a model for measuring the impact of HSR operation on HSR stations and the surrounding areas, which this research call the HSR-based nodal zone (HNZ). The proposed model is composed of two variables (i.e., transportation situation and vitality) and three subsystems (i.e., economic, societal, and environmental). Data were collected in China through questionnaire survey. Results indicate that the effects of HSR operation on HNZ are multidimensional, transportation vitality has an intermediary role in the effects, and the effects on the physical environment are negative. This study presents an early examination of the impact of HSR operation on the HSR stations and relevant areas and contributes new evidence to academic debates on the contribution of HSR to urban development. Accordingly, urban development policies should be built on the mechanism of HSR in driving the growth of HNZ.

**Keywords** high-speed rail, nodal zone, interactive effects, sustainable urbanization, China

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## 1 Introduction

With the increasing use of high-speed rail (HSR), many cities around the globe have been experiencing new developments (Givoni, 2006; Yin et al., 2015; Lin et al., 2017). The operation of HSR produces an inflow of elements, such as capital, information, knowledge, and logistics, into cities (Bertolini, 1996; Kido, 2012). These elements are requisite to urban competitiveness, thereby suggesting that the impact of HSR on urban development is all-pervading. HSR stations and the surrounding areas, which are called HSR-based nodal zone (HNZ) in this study, are affected by the HSR operation (Pol, 2008; Hou et al., 2016). The impact spills over HSR stations or might appear somewhere in the city. Therefore, HNZ also refers to urban spaces that are directly or indirectly affected by HSR operation.

HNZ has become a window of local cities and a proxy for urban competitiveness (Bertolini, 1996; Kido, 2012). The prominence of HNZ in urban competitiveness embodies its role as a catalyst in boosting socioeconomic growth (Pol, 2008). For example, the *HSR New Towns* agenda was launched by China (Diao et al., 2017). This national agenda aims to maximize the substantial economic benefits that HSR induces, such as facilitating the expansion of the shopping, restaurant, and service industries (Stark and Uhlmann, 2009) and increasing the value of related properties (Zhuang and Zhao, 2014). However, the influence of HSR operation on urban development is not exclusively confined to economic performance (Geng et al., 2015). Hence, this situation implies that measuring such type of multivariate effects without adopting a considerably broad perspective is misleading (Yang and Sun, 2014; Martínez et al., 2016).

The relationship between HSR operation and urban development has received significant attention in previous studies. Geng et al. (2015) investigated the impact of HSR operation on the growth of the real estate industry and found that such an effect mirrors the increase in housing price. Wang (2015) addressed the layout of industries within the scope of HNZ and uncovered an intriguing circle of business distribution. Apart from HSR operation's contribution to transportation, this operation has the potential to fuel regional integration, reshape urban connection, and expedite population migration across regions (Murayama, 1994; Pol, 2008; Zhang et al., 2014). Nevertheless, the research on the relationship between HSR operation and HNZ is limited. Moreover, the effects of HSR on urban development remain unclear probably because of lack of sufficient effort (Zemp et al., 2011). Accordingly, the following questions should be answered: How will the operation of HSR impact HNZ? How can the operation of HSR determine HNZ development? Thus, this study aims to provide answers to the two questions through a case study of China. The popularity of HSR has stimulated many Chinese cities to address the urgency of HNZ development. Therefore, the research findings can support the formulation of effective strategies to achieve sustainable HNZ development. This study is of value because a case study on China's cities can serve as a reference for other countries in the same situation.

## 2 Literature review

Although many studies have stressed the vulnerability of cities to HSR operation (Wang, 2011; Yin et al., 2015), a consensus on the corresponding reasons has not been completely reached. Fundamentally, accessibility and labor division are indispensable to urban development. These two elements can be altered by HSR operation depending on the level of urban competitiveness (Levinson, 2012). The impact of HSR operation on local cities manifest immediately in station areas (Wang, 2011; Hou et al., 2016) where passengers arrive and depart (Pol, 2008). Previous studies have revealed that the impact are multi-layered and reflective of four dimensions, namely, transportation, economy, society, and environment (Givoni, 2006; Loukaitou-Sideris et al., 2012). The following discussion over these four dimensions favors the establishment of a model to describe the impact of HSR operation on HNZ.

First, transportation situation (TS) and transportation validity (TV) in HNZ are determined by HSR lines and the related networks. The HSR operation can enhance TS in the boundary of HNZ by expanding cities' linkages (Willigers, 2008) and replenishing traffic facilities (e.g., bus, taxi, and subway). As a result of the HSR operation, the outward and inward connectivity of transportation will be fortified (Trip, 2008; Hou et al., 2012) and local transportation can gain substantial efficiency (Brons et al., 2009; Kager et al., 2016). Furthermore, an increase in TS facilitates the enhancement of TV in terms of travel time and transportation cost (Nuworsoo and Deakin, 2009; Bertolini et al., 2012) and the influx of passengers into HNZ (Cascetta et al., 2011; Zhao et al., 2015).

Second, a high level of TV underpins the socioeconomic development of HNZ (Casserly, 2010). For example, savings in either travel time or transportation fees enable citizens to purchase properties, thereby accelerating the increase in housing price (Chen and Haynes, 2015). HNZ is a platform for local communities to map out connections with one another in terms of employment (Schuetz, 2015), household income (Loukaitou-Sideris et al., 2012), population, and culture (Murayama, 1994; Nuworsoo and Deakin, 2009; Yang and Sun, 2014). The convergence of travelers aggregates the speed of urban land utilization (Albrechts and Coppens, 2003) and supply of shopping, restaurant, and service facilities to HNZ (Stark and Uhlmann, 2009). Consequently, the competitiveness and efficiency of land development are enhanced (Zhuang and Zhao, 2014).

Third, HSR operation has considerable negative impact on the physical environment of a city. Although HSR is greener than other public transportation modes (e.g., aircraft), its environmental effects, including noise pollution (Nishida, 1977; Givoni, 2006; Loukaitou-Sideris et al., 2012) and electromagnetic radiation pollution (Geng et al., 2015), are comprehensive. Furthermore, the lifetime of buildings may be shortened owing to the vibration of trains and demolition of existing buildings (Nishida, 1977; Loukaitou-Sideris et al., 2012). These adverse effects weaken the attractiveness of HNZ to passengers, residents, and firms and inhibit the development of the TV and social entities of HNZ (Willigers, 2008).

HNZ plays an interlocking role in urban development (Zemp et al., 2011). Bertolini (1996) suggested that the role of HNZ in urban development is twofold: a node in the transportation network and a place in the local city. The former presents an essential function of interconnecting multiple transportation modes, while the latter outlines the capability of HNZ to accommodate different types of human activities. The dual characters of HNZ, namely, node in a network and place in an urban system, are complementary in the examination of how HSR operation can determine HNZ development. Figure 1 shows the proposed conceptual model.

The conceptual model is assumed to be built on three components, namely, economic sub-system (EcS), societal sub-system (SS), and environmental sub-system (EnS), for three reasons. First, the node function delineates the strength of an HSR line in enhancing cities' connectivity (Willigers, 2008), increasing passenger volume, and saving travel time (Bertolini, 1996; Albrechts and Coppens, 2003). TV causes an HNZ entity to be deluged with passengers and places it in an expansive transportation network (Oosten, 2000). To underscore the importance of HSR operation in HNZ development in terms of node function, TS (i.e., inward and outward connectivity) and TV should be included in the conceptual model. Second, the place function of HNZ is a snapshot of the multifaceted

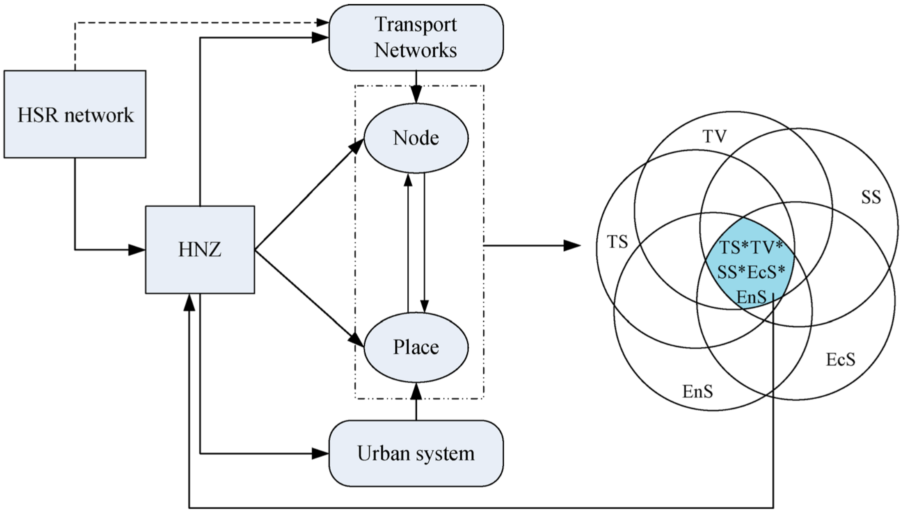


**Fig. 1** Conceptual model.

effects of HSR on relevant cities in terms of economy, society, and environment (Zemp et al., 2011). Third, these effects interact with one another. The interplay between socioeconomic functions is coupled with the flux of people, capital, and information via the HSR networks (Bertolini, 1996). The multidimensional effects are interdependent and the internal relationships are intensified by the HSR operation (Zemp et al., 2011).

## 3 Research methods

A literature review was first conducted to prepare a preliminary list of variables representing the effects of HSR on HNZ. Table 1 shows the resulting 20 variables. Thereafter, six senior professionals from China's major cities (i.e., Harbin, Beijing, Nanjing, Nanchang, Guang zhou, and Tianjin) were invited via email to evaluate the variables shown in Table 1. The professionals were contacted because of their extensive experience in this matter. Although they agreed to the 20 variables, they recommended the inclusion of two other variables, namely, light pollution (LP) and lifecycles of buildings (LCB).

Structural equation model (SEM) was adopted to detect the relationships among the aforementioned variables. SEM has gained increasing popularity in transportation and region-related areas (Ewing et al., 2014). Compared with other multivariate analysis methods, such as multiple regression and neural networks, SEM is capable of enabling the estimation of multiple and interrelated dependent relationships, offering unobserved concepts in these relationships, and using a model to explain an entire set of relationships (Wu, 2009). Moreover, SEM delineates the relationships between two types of variables, namely, latent and observed. Latent variables cannot be directly observed because of their general characteristics, whereas observed variables contain objective facts or use an item rating scale in questionnaires (Xiong et al., 2014).

Four professionals from Beijing and Chongqing were requested to convene and categorize all the variables into latent and observed groups. If at least three professionals agreed, then their opinions would be accepted. Consequently, all variables were classified into two groups (see Table 2).

A 5-point Likert scale (1 = extremely non-influential, 2 = non-influential, 3 = neutral, 4 = influential, and 5 = extremely influential) was used to collect the respondents' feedback on the importance of the variables. All variables were combined into a questionnaire with four sections. The first section introduces the background and objectives of the survey. The second section aims to gather demographic information on the respondents' professions, their main reasons for taking HSR, frequency of HSR travels in one year, their views on HNZ' functions, and time they consume in traveling from their dwelling places to an HSR station by public bus. The third section defines all the variables for the respondents. The last section enables the respondents to assess all the variables.

The questionnaire was delivered to experts in universities and city governments and HSR forum attendants by post, email, and online survey. A total of 175 questionnaires were returned within 1 month, in which 32 were excluded because of incomplete answers. Table 3 indicates that using a random approach for data collection is challenging if not impossible, but the diverse backgrounds of the participants help prevent bias and prejudice.

## 4 Data analysis

Cronbach's alpha is useful for testing the reliability of the sample. If Cronbach's alpha exceeds 0.7, then the collected

**Table 1** Preliminary variables on the effects of HSR on HNZ

| No. | Effects | Abbr. | References |
|---|---|---|---|
| 1 | Condition of outward connectivity among cities | OC | (Willigers, 2008) |
| 2 | Condition of inward connectivity in urban | IC | (Hou et al., 2012) |
| 3 | Service level of public facilities (transportation) | SPF | (Nuworsoo and Deakin, 2009; Kager et al., 2016) |
| 4 | Travel time to other places | TT | (Willigers, 2008; Vickerman, 2015) |
| 5 | Transportation cost to other places | TC | (Gargiulo and Ciutiis, 2010) |
| 6 | Passenger volume | PV | (Cascetta et al., 2011; Zhao et al., 2015) |
| 7 | Passenger structure | PS | (Hong and Yao, 2016; Lu et al., 2016) |
| 8 | Degree of traffic congestion | DTC | (Loukaitou-Sideris et al., 2012) |
| 9 | Cultural diversity of inhabitants | CD | (Hiroshi, 1994; Yang and Sun, 2014) |
| 10 | Population of permanent residents | PPR | (Zhuang and Zhao, 2014) |
| 11 | Crime rate | CR | (Geng et al., 2015) |
| 12 | Structure of employment | SE | (Bollinger and Ihlanfeldt, 1997) |
| 13 | Rate of employment | RE | (Hiroshi, 1994; Loukaitou-Sideris et al., 2012; Schuetz, 2015) |
| 14 | Household income | FI | (Loukaitou-Sideris et al., 2012) |
| 15 | Government revenue | GR | (Zhuang and Zhao, 2014) |
| 16 | Intensity of land development | ILD | (Loukaitou-Sideris et al., 2012) |
| 17 | Structure and layout of industries | SLI | (Nuworsoo and Deakin, 2009; Wang, 2015; Lu et al., 2016) |
| 18 | Values of real estate (e.g., house and land) | VRE | (Gargiulo and Ciutiis, 2010; Diao et al., 2017) |
| 19 | Electromagnetic radiation | ER | (Geng et al., 2015) |
| 20 | Noise pollution | NP | (Bertolini et al., 2005) |

data can be accepted because they have significant consistency. Therefore, the items measured in the five variables and the overall construct are sufficiently reliable (see Table 4).

An important step in developing SEM is to measure the goodness of fit (Wu, 2009). Several goodness-of-fit criteria are available for measurement, such as absolute, incremental, and parsimonious fit (Wu, 2009; Xiong et al., 2014). Consistent with the principle of SEM (Wu, 2009), the CR, CD and DTC variables were excluded based on the maximum change coefficient per indicator (see Table 5). Consequently, an SEM graph was derived (see Fig. 2), in which the observed variables are placed in rectangles and the latent variables are indicated in ellipses. The arrows between the observed and latent variables reflect the standardized regression weights and the arrows between the latent variables refer to the direction of the influence paths. The regression weights appear highly significant ($p < 0.05$), with values ranging from 0.55 to 0.90, thereby suggesting that good fitness is achieved.

**Table 2** Categorization of the variables

| Latent variables | Observed variables |
|---|---|
| TS | OC, IC, SPF |
| TV | TT, TC, PV, PS, DTC |
| SS | CD, PPR, SE, RE, FI, CR |
| EcS | GR, ILD, SLI, VRE |
| EnS | ER, LP, NP, LCB |

Figure 2 shows that the resulting model comprises seven direct effect paths, the effect coefficients of which range from 0.21 to 0.93. For example, TV is directly influenced by TS, with an effect coefficient of 0.93. Moreover, the model contains 14 indirect effect paths among the latent variables (see Table 6). The coefficients of the indirect effect paths vary from 0.01 to 0.38. In particular, nine indirect effect paths run through the variable of TV (e.g., TS → TV → SS), which accounts for 64%; and six indirect paths pass through EnS (e.g., TS → EnS → TV), which accounts for 43%. The coefficients of the variables (see Fig. 2) suggest that the model is acceptable and effective for illustrating the effects of the HSR operation on HNZ development.

## 5 Findings and discussion

The impact of the HSR operation on HNZ development changes with the inherent structure of a city and the urban environment that HNZ faces (Zemp et al., 2011). The data analysis results reveal the multiple dimensions of the effects as follows.

**Table 3** Details of the respondents

| Respondents' information | Groups | Number | Percent |
|---|---|---|---|
| Profession | Staff and related personnel | 24 | 17% |
| | Government officials | 18 | 13% |
| | Business or service persons | 16 | 11% |
| | Professionals and technicians | 60 | 42% |
| | Others | 25 | 17% |
| General purpose for using HSR | Travel | 22 | 13% |
| | Business trip | 14 | 10% |
| | Visiting relatives or friends | 40 | 28% |
| | Consumption and visiting families or friends | 1 | 1% |
| | Consumption and travel | 1 | 1% |
| | Travel and visiting families or friends | 23 | 16% |
| | Business trip and consumption | 1 | 1% |
| | Business trip and traveling | 9 | 6% |
| | Business trip, travel, consumption, and visiting families or friends | 2 | 1% |
| | Business trip, travel, and visiting families or friends | 21 | 15% |
| | Business trip and visiting families or friends | 9 | 6% |
| Average trip by HSR per year | Less than 2 times | 44 | 31% |
| | 3–6 times | 56 | 39% |
| | 7–10 times | 19 | 13% |
| | 11–14 times | 7 | 5% |
| | More than 15 times | 17 | 12% |
| Main function of HNZ | Traffic distribution | 109 | 76% |
| | Economic development | 21 | 15% |
| | Image promotion of the city | 13 | 9% |
| Time taking from dwelling place to HSR station by public bus | Less than 15 min | 7 | 5% |
| | 16–30 min | 34 | 24% |
| | 31–45 min | 20 | 14% |
| | 46–60 min | 34 | 24% |
| | 61–75 min | 2 | 1% |
| | 76–90 min | 7 | 5% |
| | More than 90 min | 5 | 3% |
| | None HSR station | 34 | 24% |

**Table 4** Reliability test of the questionnaire responses

| Variables | All | TS | TA | EnS | SS | EcS |
|---|---|---|---|---|---|---|
| Cronbach's alpha values | 0.926 | 0.777 | 0.826 | 0.902 | 0.875 | 0.848 |

### 5.1 Interactive effects of the HSR operation on HNZ

Figure 2 shows that the effects of the HSR operation on HNZ comprise five components, namely TV, TS, EcS, EnS, and SS. These components form a larger system, of which there are seven direct effect paths (e.g., TS → TV) and fourteen indirect effects paths (e.g., TS → EnS → TV) (Table 6). The system spells out effective ways to detect the sustainability of HNZ. Specifically, the higher the degree of TS, the better the TV. The results indicate that an increase in TV amplifies the flux of people, materials, information, and production factors into local cities. Thereby, the socio-economic development of HNZ can be realized (Matthias, 2014). While this finding concurs with the work by Zemp et al. (2011), which advocates a holistic approach to detecting the influence of HSR on

**Table 5** Results of goodness of fit

| Goodness of fit measure | Index | Criteria |
|---|---|---|
| CMIN/DF | 1.393 | $< 5.00$ |
| Absolute fit | | |
| RMSEA | 0.053 | $< 0.08$ |
| SRMR | 0.049 | $< 0.05$ |
| Incremental fit | | |
| CFI | 0.964 | $> 0.90$ |
| TLI | 0.957 | $> 0.90$ |
| Parsimonious fit | | |
| PNFI | 0.735 | $> 0.50$ |
| PGFI | 0.654 | $> 0.50$ |

**Table 6** Paths and coefficients of the model

| Direct effect path | Coefficient | Indirect effect path | Coefficient |
|---|---|---|---|
| TS → TV | 0.93 | TS → EnS → TV | 0.05 |
| TS → EnS | 0.21 | TS → EnS → SS | 0.06 |
| TV → SS | 0.40 | TS → TV → SS | 0.37 |
| TV → EcS | 0.41 | TS → EnS → TV → SS | 0.02 |
| EnS → TV | 0.22 | TS → TV → EcS | 0.38 |
| EnS → SS | 0.28 | TS → TV → SS → EcS | 0.21 |
| SS → EcS | 0.56 | TS → EnS → SS → EcS | 0.03 |
| | | TS → EnS → TV → EcS | 0.02 |
| | | TS → EnS → TV → SS → EcS | 0.01 |
| | | TV → SS → EcS | 0.22 |
| | | EnS → TV → SS | 0.09 |
| | | EnS → TV → EcS | 0.09 |
| | | EnS → SS → EcS | 0.16 |
| | | EnS → TV → SS → EcS | 0.05 |

urban development, the close relationships among the variables embrace some new thoughts in this area. That is, stressing one effect without considering others appears incapable of providing the entire view of the impact of the HSR operation on HNZ (Chen and Haynes, 2015). Furthermore, the evolution of an HNZ entity should be determined by measuring the inherent interplay among the components.

Geng et al. (2015) argued that housing price reflects the blend of environmental and societal impact caused by the HSR operation. The advantages of HSR in stimulating the growth of urban economies may attract many local governments to invest resources in an HNZ entity. Although the strategy of the *HSR New Towns* in China has been implemented nationwide for a long time, the majority of the cities have not achieved good sustainability performance (Diao et al., 2017). The reasons may be attributed to the reality that economic growth (e.g., industry development) cannot entirely reflect the multi-dimensional effects of the HSR operation on urban development (Loukaitou-Sideris et al., 2012). Therefore, a considerably comprehensive plan should be determined to utilize the role of HNZ as a catalyst to improve urban competitiveness.

Previous studies have determined the effects, which focus on the contributions of HSR to the HNZ spatial expansion. Nonetheless, the model (see Fig. 2) delineates the interactive effects of the HSR operation on HNZ and the HSR mechanism in driving urban development via the dual roles of HNZ (i.e., node and place). This type of interaction facilitates the understanding of the development process and accomplishment of the role of HNZ as catalyst. Hence, the finding provides new insights into the relationship between HSR operation and urban development.

### 5.2 Intermediary effects of TV

Table 6 lists two paths that describe the direct impact of TV on EcS and EnS, thereby accounting for 29% of the seven direct effect paths. The results suggest that TV determines the socioeconomic development of HNZ. In addition, 64% of the 14 indirect effect paths are via TV, thereby outlining its mediator role in determining the effects. The mediator role may be necessary because the factors caused by TV, such as people, capital, information, and logistics, are essential to the development of HNZs (Oosten, 2000). The increasing importance of TV in encouraging consumption and cultivating the prosperity of HNZ has been observed in recent years (Yin et al., 2013). For example, TV in the Lille HSR station led to the success of the city development in the European Union owing to a large volume of passengers (Trip, 2008). Another case is that the high travel cost in Suzhou City's (China) HNZ undermines its attractiveness for consumption, dwelling, and work, as well as hinders the organization of human activities in the city (Yin et al., 2013). By contrast, if the TV degree has some problems, such as high travel cost, firms or citizens may lose interest in HNZ (Willigers, 2008; Diao et al., 2017). Thus, TV can be inferred to be a key driver of the prospect of the HNZ entities.

The preceding finding complements those of previous studies on the impact of TV on the development of HNZ (Oosten, 2000; Trip, 2005; Zhang and Xu, 2005; Wang, 2011). Figure 2 shows that TV can be measured using such indicators as travel time, travel cost, passenger number, and passenger structure. Studies have claimed that passengers are the physical strand through which HSR pushes an HNZ entity to develop (Zhang and Xu, 2005; Wang, 2011). Therefore, the development of HNZ may be

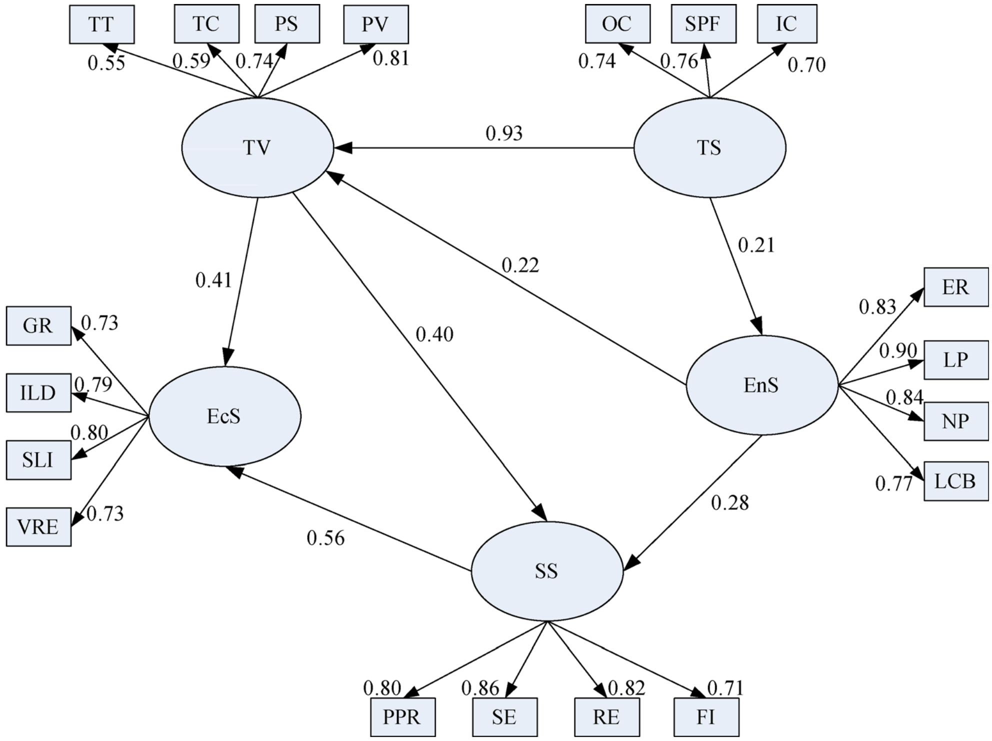


**Fig. 2** Results of the model exploration.

improved by TV related to HSR operation. Moreover, the effect of HNZ as a catalyst on urban development cannot be actualized by improving the outward connectivity of a station without fostering TV.

### 5.3 Negative environmental effects

Prior research has presented social concerns over the impact of high-speed trains on the urban physical environment in terms of radiation, noise, and waste (Loukaitou-Sideris et al., 2012; Geng et al., 2015). For example, residents along the *Shinkansen* line resisted the HSR operation because its vibration significantly reduces the life span of buildings (Nishida, 1977). Thus, how HSR changes the physical environment of HNZ and aids governments in mitigating the adverse impact should be identified (Loukaitou-Sideris et al., 2012).

Table 6 shows that 62% of the total effect paths are concerned with the EnS variable, thereby suggesting that the negative environmental effects penetrate many aspects of the HNZ development. EnS has a direct effect on TV (0.22) and SS (0.28). This result is partially caused by idea that the adverse effects (e.g., noise pollution) make local people reluctant to visit HNZ, thereby resulting in the low values of TV and SS (Willigers, 2008; Loukaitou-Sideris et al., 2012). The deterioration of EnS caused by HSR has knock-on effects on HNZ, thereby signifying that counter-measures to deal with the environmental impact should be built properly, in which HNZ is changed by the operation of HSR (Pol, 2008). Although controlling for the negative environmental effects favors the sustainability of HNZ, this finding can highlight the necessity of striking a balance between the variables and the three subsystems (see Fig. 2).

## 6 Conclusions

Evidence of the effects of the HSR operation on an HNZ entity is surfacing globally. Hence, an investigation should be conducted on how an HNZ entity is changed by the HSR operation to support the formulation of strategies for urban sustainability. Five variables are necessary to elaborate on the impact, namely, TS, TV, EcS, SS, and EnS. The interdependent relationships among these variables were simulated using SEM. The model is efficient in addressing the effects of the HSR operation on urban development through HNZ as a node in the transportation system and a place in the local urban system. Furthermore, the interaction among these variables lays a solid foundation for the development of HNZ, TV plays an intermediary role in determining the impacts, and the environmental performance brought by HSR can be a challenge to urban sustainability. The implication is that the highlighted economic benefits that an HSR line brings to a local city is incomplete. Hence, policies should be formulated to manage the multiple effects to realize the role of HNZ as a catalyst. These findings are new in the research area of HSR development and operation. Thus, the current study is limited owing to the scope of data collection. Lastly, the applicability of the proposed model in other contexts should be investigated in future studies.

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