An Extended Butterfly Model Application of Analytical Nodes and Places surrounding Nakhon Ratchasima High-speed Rail Hub

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Abstract: This research develops an empirical Nakhon Ratchasima high-speed rail (NKR HSR) hub assessment tool. This tool is rooted in node-place modeling literature, and more specifically in the tradition of empirical station assessment models that emerged from it. The first step is a methodological objective in that this research further develops strand of research by paying attention to improve the analysis. The second step applies the conceptual model to Nakhon Ratchasima province, Thailand. With analyzing NKR HSR hub in an extended butterfly model application, a score of 0.40 and a score of 0.28 over a maximum possible score of 1 can be considered as a moderate score (for node index) and a low score (for place index), respectively. Analyzing the placement of NKR HSR hub in the node-place diagram, this place can be classified as an unbalanced node.

Keywords: High-speed Rail, Nakhon Ratchasima High-speed Rail Hub, Node-place Model, Transit-oriented Development

1. INTRODUCTION

Transit-oriented development (TOD) has been described as a spatial planning approach that aimed to integrate transport and land use planning around transit stations. TOD aims to reduce the use of private transport and increase the use of public transit by ways of substantial catchment areas surrounding transit stations and improving transport accessibility. (Calthorpe, 1993; Bertolini, 1996; Bertolini and Spit, 1998; Dittmar and Ohland, 2014; Yin *et al*. 2015).

According to Dittmar and Ohland (2014), TOD projects need to achieve five main goals of location efficiency, a rich mix of choices, value capture, placemaking, and resolution of the tension between node and place. To achieve these goals and take benefits from them, it is necessary to ensure the urban development interacts with the transit system. In recent years, many studies have been conducted to determine how land use and transportation affect each other and how the development of one may influence the other. However, TOD is easier to be conceptualized than implement. This is to say, integration between land use and transport policies depends on numerous factors related to the practice of land use and transport planning.

The interaction between rail transportation and urban development has been studied using many approaches (e.g., Yin *et al*. 2015). Land use patterns determine the location of human activities, while the distribution of human actives requires the use of a transportation system (Dittmar and Ohland, 2014). More specifically, land use and transport planning need to be coordinated evaluation based on various factors such as density, diversity, design, and public transportation. A balance between transport functions (node index) and urban functions (place index) could be adopted as a key mechanism for development around transit stations.

Although several studies have explored the importance of TOD around stations, like rail-based public transportation, very few have focused on high-speed rail (HSR) hub, especially its automobile dependency and integration with adjacent areas and streets. With the HSR project connecting Thailand's capital Bangkok to Nakhon Ratchasima province (the HSR project) currently underway, it thus makes operational and economic sense to adopt and implement the general function of the HSR station (i.e. conceptual framework of the node-place model) that matched the needs of HSR hubs (SRT, 2016). The northeastern province of Nakhon Ratchasima (NKR) is the land transportation hub and serves the gateway to other northeastern provinces (NESDC, 2017a).

The objective of this paper is twofold. First, this is a methodological objective in that this research further develops strand of research by paying attention to three major considerations which will be further elaborated in section 4.1: (1) improving the analysis of some existing node and place indicators; (2) incorporating information about the people who use the public transportation to access HSR hub, which reflects the primary and secondary feeder services to HSR hub; (3) incorporating information about the people who pay the transport fare to access HSR hub, which reflects the willingness to pay for the primary and secondary feeder services to access the HSR Hub. Moreover, the methodological elegances to the literature, there is also, second, an empirical and related policies-support objective in that this research applies the model and designates strategic transport and land use for NKR HSR hub.

2. LITERATURE REVIEW

2.1 HSR Station Catchment Area

The HSR station catchment area was consisted of primary and secondary development zones (Oh *et al*. 2015). The primary development zone was described as a maximum acceptable walking distance to transit stations (Regional Plan Association 1997; Vuchic 2005). The secondary development zone was described as a distance between the city center and the farthest station or stop of the primary feeder (Murakami and Cervero, 2012; Zhong *et al*. 2014).

2.2 The General Function of Station Area

According to Bertolini (1999), the original node-place model was proposed 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 (Figure 1), the node index evaluated the connectivity, accessibility, and service quality of a station, and the place index evaluated the intensities and diversity of land uses resulting from various human activities around that station. Likewise, the node-place model could not predict these developments, but it could use to gain a better understanding of development dynamics.

Figure 1 showed five typical situations of the conceptual node-place model for a station area, labeled balance, dependence, stress, unbalanced node, and unbalanced place. The balance part in the middle area of diagram pointed out an intensive area for economic and transport activities. In other word, this scenario could be described as a key development of the station catchment area. On the contrary, stations in the dependence part had little demand for local land uses and less connected and infrequent transportation services.

The highest performance of a station was identified as a stress part, at the top right corner of the diagram, which indicated both a high supply of transportation and a strong place function of a station operating at capacity. In this situation, development around the station area was already saturated and further development of the station area would require more land, which might cause conflicts around the station area.

An unbalance node showed that a situation was in a position serving relatively strongly as a node with crowed rail services but played a relatively weak role in attracting economic activities. In contrast, unbalanced places had high economic activities, but an insufficient supply of rail transportation serviced.

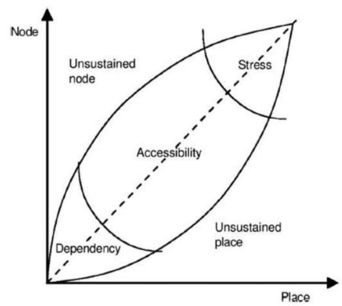

Figure 1. The conceptual node-place model (Bertolini, 1999)

2.3 Empirical Appraisal Model by Strategic Stations

The node-place model was modified and applied in various geographies to quantify TOD in terms of indexes. The models were examined from empirical node-place analyses and station typologies to conceptual models (Peek, 2006). Recent research on the node-place model generated station typologies and visualizing the performance of stations on different node and place criteria to compare between stations. The visualization was the shape of polar graphs for a set of criteria that plotted along axes with a common origin.

Figure 2 showed an overview of empirical station measurement models. Some more recent and well-known examples were derived from the node-place model and generated in the Dutch context. The kite model (Nijmegen, 2011) included that combined transit ridership and the presence of services at the station such as waiting rooms and shops. In a similar vein, the node-place-experience model (Groenendijk *et al.* 2018) added indicators reflecting the traveler's experience at the station in terms of comfort (e.g., Wi-Fi and sheltered waiting), ambient elements (type of architecture), and personnel presence. Vale *et al.* (2018) extended the model with design criterion in line with 3D's of TOD (Cervero and Kockelman, 1997). Design refered to the walkability of the built environment around the station.

The web diagram measured walkability and bikeability of the station, along with other additional criteria such as user-friendliness of the station and passenger load (Singh *et al*. 2018). The butterfly model included the proximity criterion, reflecting the travel distance to the nearest urbanized settlement (Province of North Holland Noor-Holland and Deltametropool Association, 2013). Finally, the butterfly model application was similar node index in the butterfly model to consider the different modes of transportation to and from the station. The design criterion was in line with Vale *et al*. (2018) on the combination between land use and travel behavior. Likewise, the place index was required to evaluate the geographical delamination of the station (Caset *et al*. 2018).

Depending on the context in which these models were developed and applied, how the models were conceptualized and operationalized varies (Peek, 2006). However, irrespective of the exact criteria included, the shared objective of these appraisal models remained to empirically inform policy discussions dealing with the identification of differentiated development opportunities for railway stations from a regional perspective.

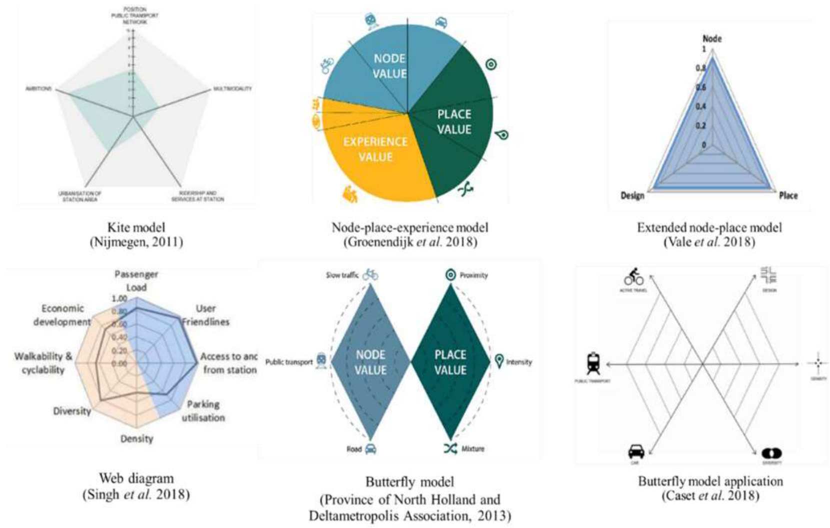

Figure 2. Overview of empirical station measurement models

2.4 The Multi-Criteria Decision Making (MDCA)

The MDCA was the making decisions that dealt with decision problems under the presence of multiple and conflicting criteria (Zardari *et al.* 2014). The MDCA was one of the most suitable methods for TOD in terms of the node-place model. Yang *et al.* (2008) mentioned that the method highlighted the identification of the evaluation criteria and the determination of the preference structure (e.g., ranking and weight).

With the MCDM process, each criterion (or indicator) was assigned a weight, which showed its importance to the evaluation of criteria and other criteria under consideration (Zardari *et al.* 2014). A criterion (or indicator) weight could be assigned either large or small scales. The more weight and the higher numbers, the more significant criterion (or indicator). Renne and Wells (2005) pointed out that evaluating the significance of the criterion (or indicator) depended on the perspectives of different stakeholders. While ideally, involvement of different stakeholder groups was desired, it was not often possible.

According to Malczewski (1991), there were four methods for assessing criterion weights comprising of ranking, rating, pairwise comparison, and trade-off analysis. Determination of the method selection depended on many factors (e.g., accuracy, decision makers, and ease of use). The ranking was a method, which arranged weight to be a preference for the decision's maker. Borda count was a type of ranking method, which was a method of election by order of merit and could be used to arrive at a combined rank (Reilly, 2002). This method was appropriate for experiential disciplinary experts in TOD analysis, which shared the same goal.

3. THE OVERVIEW OF THE CASE STUDY

3.1 Modes of Transport in NKR Municipality

NKR municipality is the socioeconomic center of Thailand's northeastern province of NKR. The province is the land transportation hub and serves the gateway to other northeastern provinces (NESDC, 2017a). The province of NKR has the largest gross provincial product (8.10 billion USD) of the northeastern region (NESDC, 2017b).

A 2020 study by MRTA on the current modes of transportation of residents in NKR municipality. Of a total of 1,800 respondents, private vehicles accounted for the largest proportion of the transport mode in the municipality (90.5 %), consisting of 42.5 % and 48 % for cars and motorcycles, respectively. The current modes of public transport in the municipality comprised songthaew shuttles (2.4 %), taxi and motorcycle taxi (1.1 %), chartered van (0.8 %), and others (0.6 %) including tuk-tuk, conventional diesel-run train, and tricycle rickshaw. Songthaew shuttles are modified from a pick-up or a larger truck with two rows of seats in the back carrying about 20 passengers (Tangphaisankun, 2010). Non-motorized transportation accounted for the rest (4.6 %).

The large disparity between the use of private and public transport in the municipality could be attributed to low levels of service of songthaew shuttles, e.g., low number and frequency of vehicles (OTP, 2016). Another reason was the accommodative policy on car ownership and subsidized fuel prices (Vikitset, 2014; Muthitacharoen *et al.* 2019).

The current modes of public transport in NKR municipality consist of songthaew shuttle, tuk-tuk, taxi service, motorcycle taxi, tricycle rickshaw, and conventional diesel-run train, while the future modes of public transport in NKR municipality consist of light rail transit (LRT) and HSR.

There are 363 songthaew shuttles serving the residents of the NKR municipality (DLT, 2020a). The songthaew service covers 20 routes with service time between 6 a.m. to 8:30 p.m. daily. The fare is flat (0.25 USD/trip), and passengers can conveniently access the shuttle service. However, the number of songthaew shuttles has been declining due largely to the accommodative policy on car ownership and subsidized fuel prices, resulting in lower levels of service of songthaew shuttle (DLT, 2020a).

Due to the accommodative car ownership policy, there are only 20 tuk-tuks for the entire municipality, with a starting fare of approximately 1.30 USD. There are 10 registered taxis serving the municipality, while the rest (118) are ride-sharing vehicles. The travel cost is distance-based and the starting fare is 1.30 USD. Likewise, there are more than 2,000 motorcycle taxis serving the municipality, and most motorcycle taxi stops are located near the songthaew shuttle stops. The motorcycle-taxi fare is distance-based with the starting price of 0.80 USD. There are fewer than 10 tricycle rickshaws serving local residents and tourists traveling a short distance. The fare is distance-based with the starting price of 0.70 USD (DLT, 2020b; MOT, 2016; MOT, 2017).

The NKR municipality has two conventional diesel-run train stations: Thanon Chira Junction railway station and NKR railway station. The train fare between the two stations is around 0.05 USD and the travel time is four minutes (SRT, 2020). The NKR railway station is located near (less than 30 m) the NKR HSR hub.

The green-line light rail transit project, currently in the detailed design phase, is expected to complete in 2024, which is the same year as the HSR project (MRTA, 2020). The LRT fare is distance-based and the fare structure is USD 0.33 + (0.033 × travel distance). The LRT service hours are from 6 a.m. - 11 p.m. and the frequency is every 10 minutes during peak hours (7:30 a.m. - 9 a.m. and 4:30 p.m. - 6 p.m.) and every 20 minutes during off-peak hours. The NKR LRT station is located around 50 m from the main entrance of NKR HSR hub.

3.2 NKR HSR Station Catchment Area

The study area is the catchment area surrounding the city center of NKR with a radius of 5.18 km. The catchment area includes the NKR municipality and parts of neighboring second-tier municipalities, as shown in Figure 3. The catchment area covers 84.33 km^2 with a population of 36,532, using ArcGIS version 10.1. The population in the catchment was calculated based on the registered total population of NKR province (NSO, 2019a). The NKR municipality is the socioeconomic center of the province, so there are a large number of (unregistered) residents from neighboring second-tier municipalities and provinces working and residing in NKR municipality.

The radius for the catchment area is the distance between the city center and the farthest station or stop of the primary feeder (Murakami and Cervero, 2012; Zhong *et al.* 2014). In this research, the primary feeder is the LRT. Furthermore, this study focuses on NKR HSR hub due to large gross provincial product, municipality size, travel distance from origin, ridership, vacant land around the hub, and availability of feeder services (Tissayakorn *et al.* 2019b).

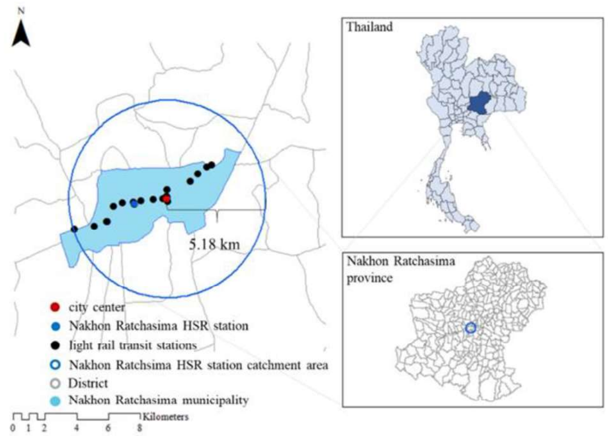

Figure 3. NKR HSR station catchment area

4. METHODOLOGY AND DATA

4.1 A Modified Station Assessment Model for NKR HSR Hub

Given the effectiveness of the node-place model for classifying the performance of station areas (e.g., Singh *et al.* 2017; Case *et al.* 2018), this research modified the methodology for evaluating the balance of node and place model in terms of strategic support for NKR HSR hub. In this way, the butterfly model developed and operationalized for all railway stations in the Dutch province offered a good starting point. This model was recently modified and applied to the Brussels Regional Express Network by Caset *et al.* (2018).

The original butterfly model consisted of two wings: a node wing (on the left-hand side), quantifying the accessibility of the station by active travel, public transport, and car; and a place wing (on the left-hand side), quantifying the proximity of the station by design, density and diversity (see Figure 2). The model qualified as a location-based accessibility instrument because it quantified accessibility characteristics of a location (Geurs, 2006). The node and place characteristics included in the model furthermore capture two of the accessibility components discerned by Geurs (2006): the transport and land-use components.

Accessibility to and from railway stations extended supply-side characteristics because the accessibility of railway stations involved the temporal constraints and individual needs and capabilities of travelers (Giannopoulous and Boulougaris, 1989). As Geurs (2006), temporal constraints involved differences in travel time and cost depending on the time of the day or day, whereas the individual component accounted for stratifications of the demographics. In the case of railway stations, the temporal component mainly involved the transport component. The individual component however required new information to be added to the empirical assessment models discussed above. It required relevant traveler-specific information which might improve particular insights about a station's functioning in the railway network. Hence, five accessibility components (light rail transit, songthaew shuttle, tuk-tuk, taxi service, and motorcycle taxi) might render a more comprehensive and diversified account of a station's level of accessibility, both from the perspective of the node and the place dimension, but also from the perspective of its travelers. In line with Oh *et al.* (2015), Yin *et al.* (2015) and Tissayakorn *et al.* (2019a), HSR hub should integrate with different feeder services and ranges.

The Thai government put forward an ambitious outlook on the future development of the land use and transport in NKR municipality by 2037 in the National Strategy for NKR spatial policy plan (NESDC, 2018) The policy papers put forward a renewed mid-long term vision extending most of the earlier spatial planning principles, even though rail transport is designed accessibility as the backbone for future spatial developments. This strategic vision was approved by the Thai cabinet and translated into relevant frameworks for the implementation of government agencies (e.g., MOT, 2017).

The objective of the policy paper was to design strategic public transport nodes which had the highest potential for allocation of additional urban development. This potential was determined by (1) the extent to which a location was accessible by public transportations, and (2) the extent to economic development and amenity. Both criteria recently mapped and operated by Oh *et al.* (2015), Verachtert *et al.* (2016), and Singht *et al.* (2017). Drawing on this research, the policy paper put forward a conceptual NKR HSR hub.

The assessment model that resulted from these considerations took the shape of an extended butterfly model application (see Figure 4). Below, the structure of the diagram was described, after which the operationalization of the criteria (dimensions) and indicators was detailed. In the process, this research would discuss how to improve the analytical strength of indicators.

Each criterion and indicator were normalized to vary between 0 and 1. MDCA was conducted in which all normalized criteria and indicator scores were concluded and normalized per dimension. MDCA scored from transport experts, urban experts, public and policy experts, and economic experts in Thailand in local viewpoint and national viewpoint. The experts were electronically received a short report detailing out the purpose of the research, the expected outcomes, and the need for weight exercise. A detailed calculation of weight could be found in Reilly (2002). The high scores for criteria or indicators showed high weights, while the low scores for criteria or indicators showed low weights.
281 A descriptive code was given to each indicator detailing its field (N for node, including active travel (AT), HSR, feeder services (FS), automobile (AM), and P for place, including density (DEN), design (DES), diversity (DI), and economic development (ED)).

4.2 Operationalization

4.2.1 Node index

1) Active travel criterion

This criterion measured the accessibility to and from the HSR hub for active modes of travel (i.e. walking and cycling) that were used by Caset *et al.* 2018. In Table 1, N_AT_1 measured the bike parking capacity within the catchment area. The indicator was measured by digitizing the bike parking using shapefile from DPT (2015), and by consulting Google Earth (GE) and NOSTRA map for the cases in which confusion about a bike parking presence and capacity arose. N_AT_2 was a binary variable indicating the presence of bike sharing facilities within the catchment area. This indicator was obtained the raw data from Yokohama National University (YNU) (2020) where conducted for “determinants of primary and secondary access mode choices to NKR HSR hub” at the end of February through early March 2020.

2) HSR criterion

The first five indicators analyzed characteristics of the HSR service at the station as was rarely done in node-place analyses. In this research, all indicators were adapted from the original indicators that were used by Bertolini (1991). Regarding indicators N_HSR_1 to N_HSR 5, calculations are based on the HSR project data that was obtained from SRT (2017). This government agency was accountable for inter-city railways in Thailand. The timetable of operation in a workday was parallel,

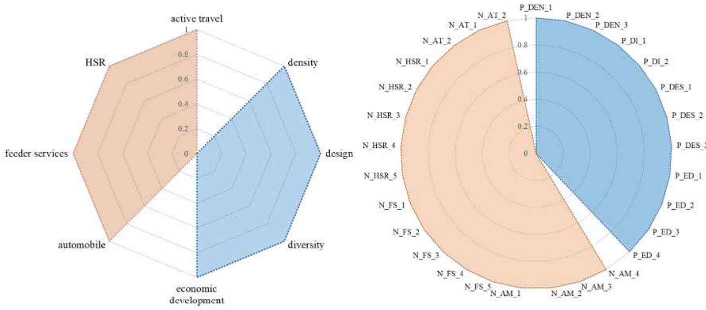

Figure 4. An extended butterfly model application (orange color for node index and blue color for place index): overall criteria (left) and indicators (right)

while the timetable of operation on holiday was paired. N_HSR_1 indicated the number of directions served at NKR HSR hub based on all available routes listed in the data for the HSR project. N_HSR_2 presented the number of end stations reachable by NKR HSR hub. N_HSR_3 was the total number of trains serving the hub (stop or start at NKR HSR hub) on a workday, while N_HSR_4 was the same indicator but replaced holiday with the workday. Indicator N_HSR_5, counting the number of passengers per day by NKR HSR hub could be predicted in the first year of operation.

3) Feeder services criterion

In this research, the feeder services criterion conformed to the HSR criterion and also developed the more specific accessibility indicators which accessed NKR HSR hub from primary and secondary feeder services and willingness to pay (WTP). Below, the sample size, questionnaire survey, conceptual models, access transport modes to the HSR hub, and descriptive analysis were explained, after which the calculation of the indicators was detailed.

First, this research analyzed access transport modes to NKR HSR by using raw data from YNU (2020). The population in the catchment area of NKR HSR hub was 36,532. The sample size for a survey of access mode choice to the HSR hub was determined by using Krejcie and Morgan formula because of the finite population (Krejcie and Morgan, 1970). The calculated sample size for survey data collection was 377. The locations for data collection included green-line LRT stations with high ridership (OTP, 2016) and civic and economic centers inside the catchment area, e.g., educational institutions, shopping malls, places of worship, hospitals. Figure 5 shows the locations (L1 - L20) where the survey data collection was undertaken by in-person interview using a questionnaire, and 50 - 60 samples were randomly selected from each location. The number of respondents were 1,108 individuals to avoid missing data. The survey participants had residences inside the catchment area and were of working age or university students because these age groups were prospective customers of the HSR service.

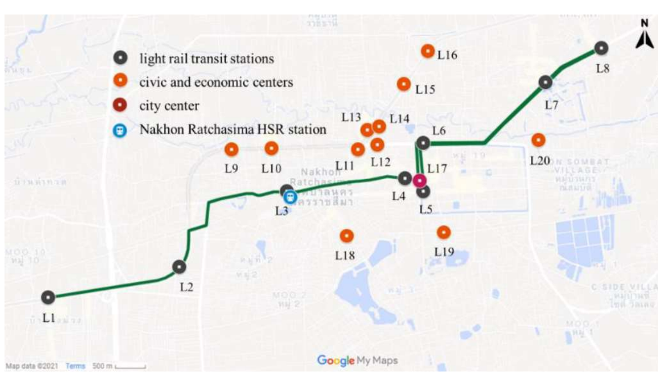

Figure 5. The locations of survey data collection (L1 - L20)

The survey questionnaire consisted of three parts. (1) demographics; (2) purpose of HSR travel and travel characteristics of access/egress transport modes; and (3) facilities and infrastructure to access NKR HSR Hub. The first part was concerned with the respondents' demographics, including gender, occupation, education, income, car ownership, and motorcycle ownership. The second part was involved the mode of transport, fare, travel distance, timing (peak/off-peak) from the origin of journey to the HSR hub, and the purpose of travel. The responses on travel distance were validated against Google Map.

The third part is comprised of two groupings of questions: (1) the satisfaction levels with the facilities and infrastructure surrounding the HSR hub; and (2) the availability of songthaew shuttle routes and future LRT line near the origin of journey. In the first grouping, the questions on the levels of satisfaction with facilities and infrastructure surrounding the HSR hub asked about the connectivity and fare integration, walking amenity, and designated parking area. The satisfaction-level questions were of 4-point Likert scale. In the second grouping, the questions on the songthaew shuttle service and future LRT asked about the availability of songthaew shuttle routes and LRT line within a 500 m radius from the origin of journey (Regional Plan Association 1997; Vuchic 2005). This research assumed that the HSR passengers used the same mode of transport to access and egress the HSR hub. Prior to data collection, the questionnaire was electronically sent to and validated by a panel of experts in the area of urban and transport planning.

Second, the conceptual model was consisted of multinomial logit (MNL) model and Tobit model to determinant of primary and secondary access mode choice to NKR HSR hub. The first model (MNL model) was used to determine influencing factors of access mode choice to NKR HSR hub via the primary and secondary feeder services. The influencing factors were categorized into three groups: demographics; purpose of HSR travel and travel characteristics of primary and secondary feeders and private vehicles; and facilities and infrastructure. The purposes of travel under study included work and business, leisure, and education, excluding family visit and medical-related travel. As a result, the actual number of respondents used in the MNL model was 793 respondents, excluding 315 respondents for family visit and medical-related travel. The reason for exclusion was that these two groups of travelers infrequently used the HSR service, in comparison with the three other groups.

Private transport was a reference mode of transport in MNL because of the aim of TOD (Cervero and Sullivan, 2010). The MNL model in STATA version 15 was used for analysis. The MNL-based choice modeling was typically used to evaluate consumer preferences in relation to transport alternatives (Feng *et al.* 2014; Yang *et al.* 2019).

To control for multicollinearity between travel cost, travel distance, and length of travel time, this research thus replaced the length of travel time with timing. Furthermore, the influencing factors under the three groups of factors were tested for multicollinearity by a variance inflation factor (VIF). The VIF of the influencing factors was less than 2 %, given that a VIF < 2 % was statistically acceptable (Marquaridt, 1970).

The second model (Tobit model) was used to estimate the WTP of 793 survey respondents by using the maximum likelihood estimation (MLE) technique (Whitehead, 2003). In the Tobit analysis, it was assumed that substantial improvements would be made to the facilities and infrastructure around the NKR HSR hub. The independent variables in the Tobit model were the demographics in the survey questionnaire (e.g., gender, occupation, and car ownership). The Tobit model in STATA version 15 was used for analysis. The expected WTP value could be calculated by following Whitehead (2003).

Third, as the access transport modes to the HSR hub, the LRT was the most preferred access mode choice as 32.19 % of the questionnaire respondents on average would select this access transport mode. The main reason given by the respondents was the ability to plan and manage commute time. Likewise, certain locations which were the civic and economic centers also had large proportions of respondents who preferred the LRT. As a result, this research selected the LRT service as the primary feeder to access NKR HSR hub.

Despite the LRT service, the proportion of private vehicle used on average was still as high as 48.08 %, consisting of 23.64 % and 24.44 % for private cars and private motorcycles, respectively. This could be attributed to the country's accommodative policy on car ownership and subsidized fuel prices. The songthaew shuttle service accounted for 11.76 % of the survey respondents. The low proportion was attributable to the limited number and frequency of vehicles. The songthaew shuttle service was currently the main public transport in the NKR municipality. Upon the completion of LRT, the songthaew shuttle service would become the secondary feeder of the municipality to access the HSR hub. As a result, the local government had planned to modernize the songthaew shuttle service, including the availability of shuttles, frequency, safety, personnel, and regulations.

Walking as the access mode accounted for 4.43 % of the survey respondents. The very low percentage was attributable to the country's tropical climate with an average temperature of 35 °C. The other modes of transport consisted of tuk-tuk, conventional diesel-run train, bicycle, and taxi service, accounting for 3.54 %.

Fourth, determinants of access mode choice, MNL analysis of access mode choices, and Tobit analysis of willingness to pay were shortly explained in descriptive analysis. Determinants of access mode choice to NKR HSR hub were categorized into three groups: demographics; the purpose of HSR travel and travel characteristics of primary and secondary feeders and private vehicles; and facilities and infrastructure. The purposes of HSR travel included work and business, leisure, and education, excluding family visit and medical-related travel because these two groups of travelers infrequently used the HSR service, vis-à-vis the three other groups.

The results show that 40.04 % of the respondents chose the LRT as the access mode of transport to the HSR hub, followed by private car (23.14 %), private motorcycle (21.63 %), and songthaew shuttle (15.19 %). Education was the most cited reason as the purpose of HSR travel (37.59 %), followed by leisure (36.56 %) and work and business (25.85 %). The respondents who were students accounted for the largest proportion (42.42 %) and private and public employees the second largest (41.97 %).

Around two-thirds of respondents had a bachelor's degree (67.51 %) and would choose public transport over private vehicle use to access the HSR hub. Slightly over half the respondents (53.25 %) were in the low-income bracket, while the respondents in the middle-income bracket accounted for 41.06 %. The share of respondents with car and motorcycle ownership who used songthaew shuttle to access the HSR hub are 25.83 % and 84.77 %, and those who chose the LRT service are 29.15 % and 87.19 %.

On the travel characteristics, the average travel distance from the origin of journal to the HSR hub was 3.08 km, with an average travel cost of 0.28 USD. Over two-thirds (68.80 %) of respondents traveled to the HSR hub during off-peak hours (68.80 %), while those travelling during peak-hours accounted for 31.20 %.

On the facilities and infrastructure, the results on four-point Likert scale were reclassified into two classes prior to the MNL analysis to establish the relationship between the dependent variable (access mode choice) and independent variables (three groups of influencing factors). Class I consisted of satisfied and very satisfied (3 and 4 on the Likert scale) and Class II of very dissatisfied and dissatisfied (1 and 2 on the Likert scale). The two-class classification of the variables (i.e., connectivity and fare integration, walking amenity, and designated parking area) was derived through trial and error in MNL analysis.

The access mode choices in the MNL analysis included LRT and songthaew shuttle service, while private vehicle use was the reference. The influencing factors of access mode choice were comprised of demographics; purpose of HSR travel and travel characteristics of primary and secondary feeders and private vehicles; and facilities and infrastructure. The purposes of travel include work and business, leisure, and education, excluding family visit and medical-related travel.

The significant variables of the primary feeder were travel distance ($p < 0.01$), travel cost ($p < 0.01$), and the availability of LRT line ($p < 0.05$). The significant variables of the secondary feeder were middle- and high-income brackets ($p < 0.01$), car ownership ($p < 0.05$), travel distance ($p < 0.01$), travel cost ($p < 0.01$), the availability of songthaew shuttle routes ($p < 0.05$), and the availability of LRT lines ($p < 0.01$).

The MNL analysis results also indicated the travel distance, travel cost, and the availability of LRT line as the common significant variables for both the primary and secondary feeder services. As a result, to successfully convince motorists to switch from private vehicle use to the LRT and songthaew shuttle services, policymakers and concerned government agencies should attach greater emphasis to the travel distance and travel cost of access mode choices as well as the adequacy of the LTR service.

The WTP was the maximum amount of money a commuter would sacrifice to use the feeder service. Given that substantial improvements were made to the facilities and infrastructure surrounding NKR HSR hub, the Tobit analysis results showed that the significant demographic variables were income ($p < 0.001$), car ownership ($p < 0.05$), and motorcycle ownership ($p < 0.05$). The expected WTP for the primary and secondary feeder services to access the HSR hub was 1.094 USD/trip/person

Indicators N_FS_1 and N_FS_2 represented the total number of feeder services serving the hub on workday and holiday, respectively. In order to calculate the accessibility to and from the HSR hub by songthaew shuttle, tuk-tuk, taxi service, motorcycle taxi, tricycle rickshaw, conventional diesel-run train, and LRT were filtered from publicly available NKRPTO (2020), MRTA (2020), and YNU (2020) data. N_FS_3 indicated the number of directions served by LRT. Indicator N_FS_4, measuring the number of stations that could be reached within 14:22 min of travel by primary feeder. This research adapted the travel time from 45 min to 14:22 min because of the average travel time of HSR passengers to NKR HSR hub. N_FS_5 was an additional indicator in research because fare was significant variable for the primary and secondary feeder. This indicator was also a part of accessibility indicators for transport planning (Tuan and Son, 2015; Litman, 2016). As a corollary, WTP to access NKR HSR hub could be set 1.094 USD/trip. It was important to note that all five indicators were calculated within the catchment area.

4) Automobile criterion

The first automobile criterion focuses on the parking capacity for private cars and private motorcycles. In order to calculate the accessibility to and from the HSR hub by automobile, the stops considered around HSR hub were filtered from publicly available DPT data using ArcGIS 10.1, and consulting GE and NOSTRA map for the cases in which confusion about the automobile parking presence and capacity. N_AM_2 was a binary variable indicating the presence of automobile sharing facilities within the catchment area. The indicator was checked by consulting YNU (2020) data. N_AM_3 and N_AM_4 were measured in ArcGIS 10.1 using OSM data and DPT data, respectively, and indicated the position of the station in the national and regional road network. N_AM_3 indicated the road network distance between the HSR hub and its closest motorway access, while N_AM_4 provided the total length of structural roads within the station catchment area. The structural roads included the following DPT road categories: primary, secondary, and tertiary.

4.2.2 Place index

1) Density criterion

This criterion referred to the concentration of residents, accommodations, and jobs. Its contribution to the walkability of TOD was detailed in Cervero and Kockelman (1997). P_DEN_1 reflected the density of residents. This data was provided by NSO, on the basis of the geographical coordinates of the official residential address in the national register. P_DEN_2 used a measure of accommodations density. This data was provided by DPT, on the basis of the geographical coordinates of the official accommodative address in the national register. In this research, accommodations were included houses, dormitories, apartments, and condominiums. P_DEN_3 provided the measure of jobs density that were located and disaggregated by the employment sector. This research focused only industrial sector for consideration because of available data. The data was calculated and provided by the Department of Industrial Works (DIW), on the basis of the types of industrial works. The official registered employment and industrial works were subsequently obtained from the DIW. A limitation of the data (residents and jobs) was the people and industrial works who were not registered in DIW.

2) Diversity criterion

This diversity (or land-use mix) criterion was a principal ingredient of walkability (Dovey *et al*. 2017). In general, it was often operationalized by the functional mix indicator used by Bertolini (1999). This measure captured functional land-use mix, but it did not capture the spatial configuration of the land-use types (Hess *et al.* 2001). Given this, this research adapted the work of Hess *et al.* 2001 in which the landscape ecology approach to measuring path diversity was applied within the context of land use and transport interaction. Shannon's diversity index was measured by ArcGIS 10.1 which considered the fundamental and spatial diversity of land-use types within each catchment area. P_DI_1 increased as the number of different land-use types increased and/or the proportional distribution of area among types became more equitable. The data was calculated in ArcGIS 10.1 using DPT data.

An additional indicator P_DI_2, measuring the density of land prices that could be showed the substantial economic activity and attractiveness of land use and transportation. Although the land prices were derived from several factors, the actual land prices could be reached external economic benefits (Suzuki *et al*. 2015; Yin *et al*. 2015). The data was calculated in ArcGIS 10.1 using data from the Treasury Department (TD).

3) Design criterion

This criterion aimed to measure the walkable and bikeable access by urban morphology of public space and by the built environment. All indicators were calculated in ArcGIS 10.1 using OSM data. P_DES_1 measured the pedestrian shed ratio of the catchment area. It revealed the actual area that might be covered by walking within a radius of 1.90 km from NKR HSR hub, which was the maximum acceptable walking distance to the HSR hub (Vuchic 2005). The ratio of the total area could be drawn based on the walkable street network from the station, divided by the area of a circle with the same radius. The larger the value, the larger the walkable area around the station. P_DES_2 provided the number of street network intersections with three or more links in the catchment area, as it was an indicator of the connectivity of the street network (Handy *et al*. 2003). The larger the indicator, the more walkable the neighborhood. P_DES_3 measured the total length of an accessible street network for walkability, excluding bikeable lanes. This was the study area uses shared lanes between public transportation, automobile, and bicycle. P_DES_3 slightly differed from P_DES_1 because it was not dependent on the algorithm setting to create the walkable catchment area.

4) Economic development criterion

This criterion referred to the private investment per land-use type and the number of service and retail establishments within catchment area (Rene and Wells, 2005). P_ED_1 to P_ED_3 were available (amenities) data at the district level, while P_ED_4 were available (tax earnings) data at the municipality level. All indicators were calculated in ArcGIS 10.1 using data from DPT and NKR municipality data, and consulting open sources for the case in which confusion about the places. In this research, the amenities were emphasized the significant facilities to generate economics and regional specialization (Oh et al. 2015). P_ED_1 measured the important places for daily life (e.g., hospital, pharmacy, restaurant, school, and temple). P_ED_2 measured the larger place to serve in a different area (e.g., shopping mall, department store, and office). P_ED_3 measured the largest place to serve the travelers (e.g., touristic attractions, university, museum, conference center, and exhibition center). P_ED_4 measured the tax earnings of municipalities (house and land tax, local maintenance tax, and signboard tax). This indicator was measured by using a shapefile from NKR municipality with ArcGIS version 10.1.

Table 1. Criteria, indicators, and weights for an extended butterfly model application

Criterion	Weights	Code: Indicator description	Weights	Source (year)
Node index				
Active travel	0.03	N_AT_1: bike parking capacity (km^2)	0.57	DPT (2015) GE (2020) NOSTRA Map (2020)
		N_AT_2: presence of bikes-sharing service (yes/no)	0.43	YNU (2020)
HSR	0.19	N_HSR_1: number of directions served at NKR HSR hub	0.22	SRT (2017)
		N_HSR_2: number of end stations reachable by NKR HSR hub	0.20	
		N_HSR_3: total number of trains serving the hub (arrival and departure/day) on workday	0.21	
		N_HSR_4: total number of trains serving the hub (arrival and departure/day) on holiday	0.14	
		N_HSR_5: number of passengers per day by NKR HSR hub (passengers/day)	0.23	
Feeder services	0.17	N_FS_1: total number of feeder services serving the hub (arrival and departure/day) on workdays	0.22	NKRPTO (2020) MRTA (2020) YNU (2020)
		N_FS_2: total number of feeder services serving the hub (arrival and departure/day) on holiday	0.18	
		N_FS_3: number of directions served by LRT	0.15	MRTA (2020)
		N_FS_4: number of stations that can be reached within 14:22 min of LRT	0.20	
		N_FS_5: WTP (USD/trip)	0.25	YNU (2020)
Automobile	0.06	N_AM_1: automobile parking capacity (free and paid service)	0.25	DPT (2015) GE (2020) NOSTRA Map (2020)
		N_AM_2: presence of automobile sharing facilities (yes/no)	0.18	YNU (2020)
		N_AM_3: road network distance between the HSR hub and its closest motorway access (km)	0.34	DPT (2015) OSM (2020)
		N_AM_4: total length of structural roads (km)	0.23	
Place index				
Density	0.12	P_DEN_1: density of residents (people/km^2)	0.35	NSO (2020)
		P_DEN_2: density of accommodations (units/km^2)	0.30	DPT (2015)
		P_DEN_3: density of jobs (people/km^2)	0.35	DIW (2020)
Diversity	0.12	P_DI_1: Shannon's diversity index	0.43	DPT (2015)
		P_DI_2: density of land prices (USD/km^2)	0.57	TD (2020)
Design	0.09	P_DES_1: pedestrian shed ratio	0.39	OSM (2020)
		P_DES_2: number of street network intersections with three or more links	0.25	
		P_DES_3: total length of an accessible street network for walkability (km)	0.36	
Economic development	0.22	P_ED_1: density of basic amenities	0.16	DPT (2015)
		P_ED_2: density of regional amenities	0.27	
		P_ED_3: density of metropolitan amenities	0.26	

Criterion	Weights	Code: Indicator description	Weights	Source (year)
		P_ED_4: tax earnings of municipalities (million USD)	0.31	NKR municipality (2019)

5. RESULTS

5.1 Node index

NKR HSR hub scores are shown in Figure 6. Using the results, FS criterion is the highest score at 0.63 followed by HSR (0.48), AM (0.19), and AT (0.01) criterion, respectively. An average score of 0.40 over a maximum possible score of 1 can be considered as a moderate score for node index. This means that node functionality surrounding hub should focus on substantial improvement, especially AT, AM, and HSR criteria.

In terms of indicators, the high scores are consisted of N_FS_5 (0.94), N_FS_1 (0.91), N_HSR_3 (0.88), N_FS_2 (0.82), and N_HSR_5 (0.71). The moderate score is N_HSR_3 (0.59), while the rest are low scores.

Although NKR HSR hub has only one way to travel at the first stage of the HSR project, the ridership is expected to increase by 7.88 % during 2024-2050 (SRT, 2017). This ridership ranks the second largest among the HSR project as well.

According to SRT (2017), the total length of the HSR project is 252.3 km which was expected to can make a difference in gaining market share to the private vehicle (private cars) and public transportation (bus and conventional diesel-run train). The location of NKR HSR hub also plays competitiveness among HSR hubs because of travel distance (Gleave, 2014).

Although the convenient transfer is important for NKR HSR hub, especially neighboring municipalities and cities, feeder services depend on the size of cities. NKR municipalities has one line with two directions for primary feeder service and two routes for secondary feeder service, however, most of them operate less frequencies. Hence, limited frequency of primary and secondary feeder services may cover the flow of NKR HSR hub passengers, but it restrains the value of the station as a place because of reduced access to and from the station

The number of songthaew shuttles due largely to the accommodative policy on car ownership and subsidized fuel prices, resulting in lower levels of service of songthaew shuttle (DLT, 2020a). This performance can be expanded the service and the challenge to integrate fare structure of public transportations and improve the songthaew shuttle service. The urban morphology needs to strategically reshape for investment in public transportations.

Accessibility to the existing urbanized area is identified a crucial indicator for urban development around NKR HSR hub. This hub is now in progress in constructing dedicated HSR lines, while it is located in NKR municipality and large city. The large city had more negotiation power when the line was designed (Yin et al 2015). Hence, the large hub is located around the city center compared to Seoul HSR hub located in metropolitan cities that increased populations of more than a million (Kim et al 2018).

Most of other indicators (in active travel criterion and automobile criterion) are low scores. The bike parking capacity is remarkably low and automobile parking is also scarce. This is a good illustration of the strategy to reduce congestion, delay, and carbon emissions by providing parking capacity.

The hub provides less bike-sharing and automobile-sharing services. This performance can be expanded the development and challenge to increase the ride-sharing services for reducing private vehicle ownership, traffic congestion, and carbon emissions.

5.2 Place Index

NKR HSR hub scores are shown in Figure 6. Using the results, ED criterion is the highest score at 0.52 followed by DES (0.25), DEN (0.24), and DI (0.23) criterion, respectively. An average score of 0.28 over a maximum possible score of 1 can be considered as a low score for the place index. This means that spatial quality surrounding hub should focus on substantial improvement, especially DES, DEN, and DI criteria.

In terms of indicators, the high scores are consisted of P_ED_2 (0.84) and P_ED_1 (0.61). The moderate scores are P_DES_3 (0.57), P_ED_4 (0.46), and P_DI_2 (0.44), while the rest are low scores.

The role of NKR HSR hub as an economic hub can be evaluated by indirect indicators, e.g., population and business abilities. Relatively high ridership is assumed to be related to the size of cities as a potential demand. NKR HSR hub serves approximately 2.42 million people in 2024 (SRT, 2017). NKR's population is much more than other cities along the corridor, implying a population threshold is required for viable urban development surrounding hub. However, the remotely located hub suffers from the lack of population threshold and fails the role as an economic hub.

In parallel, P_DI_1 and P_DI_2 is a low score and moderate score, respectively. These results mean that a balance of path diversity required improvement. The types of land use are converted from polygon to point because of the size of the station area and identifying points of interest. The residential area is more than half of a proportion (52.07 %), while the accumulation of commercial area and industrial area (17.35 %) and the accumulation of public utility and public assistance are small proportions (20.64 %). These results possible result in neighborhood TOD when compared results with Associates (1992).

The walkable area around this hub fails a remarkable functional and spatial diversity of the functions living, working, and visiting. This result contrasts with NKR province (2018) that aimed to switch the use of the private vehicle to the use of public transportation or non-motorized transportation.

The strong economic activities with basic and regional amenities are consistent with the NKR plan (NESDC, 2017) and Boonlert et al (2019), but the recent economic developments are concentrated in NKR municipality. Conversely, metropolitan amenities are a low score since the functions are spread from NKR municipality to the neighboring municipalities. Tax earnings are moderate score with house and land (5.76 million USD), local maintenance (0.09 million USD), and signboard (0.90 million USD) in 2019. The development around the hub evolves from the initial phase of the HSR project because of the limitation of legislation and regulation to support TOD planning (Chalermpong and Ratanawaraha, 2016; JICA *et al*. 2017). The local government also faces fiscal autonomy and self-reliance from the federal government (Wongpreedee and Mahakanjana, 2011; Metasuttirat and Wangkanond, 2017).

Although this hub is located beside the central business district (CBD), NKR municipality's economic stagnation get down. Up to this point, this result does not support Hall (2009) that the hub would improve attractiveness for CBD. It depends on urban spatial and morphological strategy.

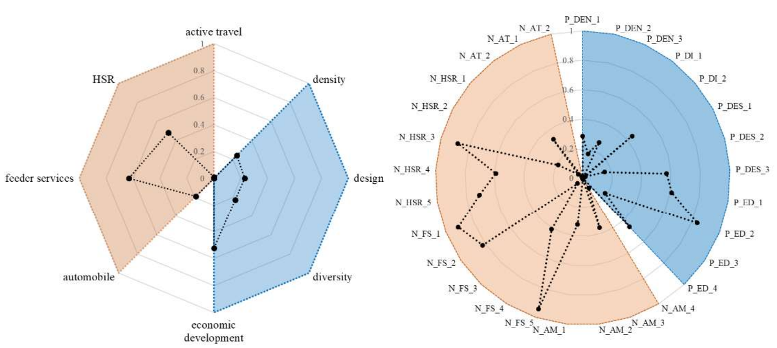

Figure 6. NKR HSR hub scores (left: criteria, right: indicators)

Note: low scores are 0-0.39, moderate scores are 0.40-0.60, and high scores are 0.61-1.00

5.3 Balancing Node and place functions and sensitivity analysis

Analyzing the placement of the hub in the node-place diagram, this place can be classified as an unbalanced node. This implies that it was overly crowded with feeder services, economic development, and HSR criteria. At this time, this hub is highly developed with commercial and business facilities. This hub is also an important transfer hub in the northeastern provinces by conventional diesel-run train or local transportation network of NKR.

This analysis is a well-established fact that investment policies and plans were not sufficient to support TOD planning and required to implement by specific actions and tools. Figure 6 can hint in identifying those criteria and indicators that scored low and can be improved. Given the standardized score is one for evaluation and the LRT project operates with the same year of the HSR project. Based on the information in an extended butterfly model application, these are identified that can be improved, if need be, and are shown in Figure 6. For example, the TOD policy could be to improve active travel, automobile, density, design, and diversity criteria in the catchment area. Any increase in the latter should mean an increase in the number of jobs and improve the accessibility and higher densities in the station area. Parking capacity can be improved to increase parking supply and reduce traffic by distributing trips across different modes of transportation. This research can make a policy decision on the need for improving existing criteria and indicators. The planners need to consider the local components (e.g., local conditions) before the detailed proposal for TOD planning.

Since this research does not expect any uncertainty in the data and weight exercise, sensitivity analysis is adopted to incorporate this uncertainty. The weight for each eight criteria was changed by ± 10 %, one at a time, while others were equally increased or decreased, thereby generating 16 scenarios for this research. The node index ranged from 0.36 to 0.41 and the place index ranged from 0.32 to 0.37. The results are not significantly affected by sensitivity analysis. It should be noted that the results of the sensitivity analysis could notice if the number of criteria and indicators were fewer as it would mean that the total weight of 1 gets spread over fewer criteria and indicators.

6. CONCLUSION AND POLICY IMPLICATIONS

This research had two relevant objectives. First, the methodology developed a strand of research by drawing on the node-pace model. This model was suggested and implemented strategies for the analytical strength of some standard node and place measures. Based on a discussion, an extended butterfly model application was produced visible and knowledge about NKR HSR hub-specific accessibility and spatial development, some of which are not captured in standard node-place analyses.

Second, the empirical and related policies-support objective in that this research included in the model to the NKR HSR hub. This research discussed how to provide the strategic HSR hub put forward in the static vision. Given the LRT project in NKR municipality included in comprehensive analysis and operated with the same year of the HSR project and an extended butterfly model application is calculated using MDCA with experts' involvement and which expresses the TOD planning around the hub. A sensitivity analysis was also carried out to study how the results are affected by changes in weights or indicator values.

This analysis of node-place of NKR HSR hub reveals that had a node index higher than place index. This hub can be classified as an unbalanced node. Inferences were drawn from an extended butterfly model application results to recommend areas for improvement (see Figure 6) based on the low scores of criteria and indicators. Given the standardized score is one for evaluation. All scenarios in sensitivity analysis are not significantly affected. The scores reflect the existing situation from the government strategies and plans which required substantial investment to guide the TOD proposal for NKR HSR hub.

As the node perspective, although the convenient transfer is important for NKR HSR hub, especially neighboring municipalities and cities, feeder services depend on the size of cities. NKR municipalities have one line with two directions for LRT and two routes for songthaew shuttle service, however, most of them operate less frequencies. The limited frequency of LRT and songthaew shuttle service may cover the flow of NKR HSR hub passengers, but it restrains the value of the station as a place because of reduced access to and from the station

The number of songthaew shuttles due largely to the accommodative policy on private vehicle ownership and subsidized fuel prices, resulting in lower levels of service of songthaew shuttle. This performance could integrate fare structure with modes of transportation, while the urban morphology needs to strategically reshape for investment in public transportations. Given the low level of service of songthaew shuttles, concerned agencies need to modernize the songthaew service, improve safety, and provide training to the drivers to successfully convince private vehicle users to switch to this mode of public transport.

The parking capacity (for bikes and private vehicles) is scarce around the hub. The parking management needs to implement by local governments or personal businesses in response to specific parking and traffic problems. The general problems could be addressed (e.g., parking congestion, traffic congestion, and poor pedestrian environments) and the geographic areas are considered how to switch the use of private vehicles to mass transit services or non-motorized transportation.

Ride-sharing services are an alternative to substitute for private vehicle ownership and reduce carbon emissions. The vehicles are located in a residential area, priced by travel time, with convenient pick-up and drop-off procedures. This makes occasional use of an automobile affordable, even for low-income households. The bike-sharing service could be considered as well.

As the place perspective, NKR's population is much more than other cities along the corridor, implying a population threshold is required for viable urban development surrounding hub. However, the remotely located hub suffers from the lack of population threshold and fails the role as an economic hub.

With the intensive land use in the catchment area, a balancing different priorities of path diversity should require to increase with change in community composition in a way that reflects what is valued. The station area development of this hub looks like neighborhood TOD (local activity node), but it should design to access residents' perceptions about the neighborhood and opinions about potential TOD opportunities.

The walkable area surrounding the hub suffers a remarkable functional and spatial diversity of the functions living, working, and visiting. The clearer definitions should examine for urban design because places vary substantially between definitions leading to substantially different designs. Create, use, and develop put forward frame options for understanding the multiple perspectives.

The HSR hub located less than 5 km from the city center is lacking in densities of metropolitan amenities even though there are some commercial and business facilities around the hub. This area of economic development needs particular development strategies to accumulate information and the explanation for the achievement of economies of agglomeration.

Stimulating TOD through tax incentives would provide the incentive to utilize the station area development more intensively by improving legislation and regulation. TOD needs tax to provide services to generate through retail and commercial properties and to support population moving in viable areas as well as benefit the municipal government. For more discussion, see Chalermpong and Ratanawaraha (2016).

Balancing node and place functions in NKR HSR hub need improvement in many perspectives (e.g., strategic planning, financial supports, actors, and legislation and regulation). TOD planning for in the Thai context is a simplified representation of an even more complex constellation of actors and institutions. However, there is little discussion on the intuitional perspectives and financial support of station area development, especially the planning process and stakeholders. Further is needed to analyze the interaction between socioeconomic needs and quality of places and identify and select planning process approached that can respond to the complexity of the development process.

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