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Which Variables are Influential to Evaluate Rapid-Transit Systems in China's Cities?

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ABSTRACT

Purpose: This study aims to determine important variables to evaluate rapid-transit systems on urban central areas, which can help establish an assessment framework to forecast and evaluate intended planning proposals. **Method:** Multi-criterion analysis is conducted based on the Delphi approach. Relevant variables regarding evaluating rapid-transit systems that influence urban central areas are collected according to strategies such as archival investigation of previous relevant studies and suggestions of experts. Forty-nine variables are established and placed into eight categories, and their significance is measured via the principal component analysis (PCA) and the analytic hierarchy process (AHP). **Result:** Thirteen major variables are determined and classified into five variable sets (consumption; building and land use; transportation; travel accessibility; and neighborhood and community) and four categories (social; economic; land use and transportation; and accessibility). The 13 major variables with ranks and weights can be used to establish an assessment framework for evaluating the ability of rapid-transit systems to regenerate city centers in China.

KEYWORD

Rapid-Transit
Delphi
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1. Introduction

Due to the rapid urbanization in China, many cities have faced rapid urban expansion and large-scale population migration. Among the most attractive areas in a city, city centers have demonstrated unchanging spatial forms and land use patterns [1]. As industrial zones have moved out, many new commercial and residential properties have been placed in city centers. Rapid urban renewal and new developments have resulted in the destruction of social structures and environments. In China, city center regeneration has aroused academic attention since the 1990s. Researchers have investigated the strategies involved in city center regeneration in China according to aspects such as history and theory [1]; physical, material and environmental regeneration [2]; and the social, economic and cultural concerns involved [3].

Facing the negative effects of decentralization and suburbanization, scholars have investigated issues related to city center regeneration since the 1970s [4]. Discussions of city center regeneration have considered the development of a compact and functionally mixed city that combines commercial, residential and leisure usages, which are among the popular urban renewal policies for enhancing activities in city centers [5]. Recent studies of city center regeneration have demonstrated that the concept of sustainable development can promote city center revival and evolution [6]. However, the urban renewal boom may have an adverse effect on social structures and the urban fabric via gentrification [7]. For example, cooperation and collaboration can shorten gaps and solve problems between stakeholders during city center regeneration [8].

Although investment forecast, land use, policy and economic issues are frequently discussed, systematic analysis of the effects of rapid-transit systems is rarely conducted. In China, recent redevelopment projects have focused on economic profits rather than the various social and spatial effects on a region. A holistic assessment framework is necessary to identify major variables that can be adopted to forecast and evaluate intended planning proposals. This study aims to determine these variables that help evaluate rapid-transit systems on urban central areas. The major variables should help identify the significant elements involved in the early stages of rapid-transit-system adoption in city centers. These systems are usually adopted to promote smart and sustainable urban development and should be evaluated in advance.

2. Background

2.1. Effects of rapid-transit systems

Given the large-scale rapid-transit construction, an increasing amount of researchers are realizing that rapid-transit systems have

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important direct and indirect effects on urban development. The primary aims of rapid transit are to promote less pollution and conjunction and to decrease travel times and average expenditures [9]. Furthermore, it obviously raises ridership around the transport corridors [10]. Meanwhile, rapid-transit development may lead to changes in population, land use patterns and real estate. Rapid speeds and inexpensive costs have encouraged significant increases in population densities around transportation systems [9]. Some case studies of Western cities have demonstrated that although the effect of land use on rapid-transit systems is small, that of other significant public factors such as planning policies is significant [11]. However, commercial usage tends to replace residential and industrial usages around metro stations [12]. In addition, time series and cross-sectional data analyzed using hedonic price and repeat sales models illustrate that rapid-transit systems normally affect housing and commercial property values. The price of property is higher around transport corridors than in unaffected areas and changes with the property's proximity to a metro station [13].

2.2. Methods of assessing effects and determining major variables

In recent years, assessment methods have been developed to evaluate the economic and sustainability effects of urban development. Gospodini [14] evaluated five main indirect effects on urban development, redevelopment and regeneration. Mejia-Dorantes and Lucas [15] constructed a typology of the successful factors of economic effects from two rail transit projects to make the economic and developmental effects of major transport infrastructure more transparent. Vermote et al. [16] developed an analytic multi-actor multi-criterion assessment instrument to assess the sustainability of alternative regional light-rail scenarios by all of the involved stakeholders. Researchers have paid more attention to the benefits and positive effects of rapid-transit systems than the negative effects.

According to Linstone and Turoff [17], the Delphi approach is a structured communication technique that was originally developed as a systematic, interactive forecasting method that relied on a panel of experts. Although early studies implementing the Delphi approach focused on scientific and technological forecasting, the approach has been expanded to include the forecasting of many social circumstances [18]. The Delphi approach has recently been adopted to integrate expert opinions in the fields of urban policy [19], corporate real estate [20] and sustainable urban regeneration [18]. In 1901, Karl Pearson introduced PCA (Principal Component Analysis), a type of multivariate statistical analysis that selected a few important variables from a field of many via linear transformation [21]. PCA is suitable for removing redundant data and transforming a set of correlated variables into uncorrelated factors [22]. Moreover, it is a widely used method in the fields of urban simulation and land use planning [22] and urban sprawl [23]. The Analytic Hierarch Process (AHP) is a structured technique used to organize and analyze complex decisions based on mathematics and psychology [24]. It uses quantitative and qualitative data given by experts to analyze local problems [25]. In addition, the AHP is a useful multi-criterion decision-making method widely adopted in urban allocation [26], project design [27] and sustainable urban renewal practices [18].

3. Methods

This study uses the Delphi approach, PCA and the AHP, all of which are widely used in decision-making analysis, to determine important variables required to evaluate rapid-transit systems on urban central areas. The investigation process follows three steps: informing, developing and weighting.

3.1. Informing

Before establishing the multi-hierarchy model, it is necessary to collect data of variables to evaluate rapid-transit systems on urban areas. In the first step, this study investigates previous relevant studies, including books, papers and newspapers; relevant urban development and transportation policies; and urban renewal standards and guidelines. Following the presentation of data from expert interviews, a set of 49 variables is listed to support the establishment of a multi-criterion model. These variables are divided into eight categories, including physical, ecological, political, social, economic, cultural, land use and transportation, and accessibility.

3.2. Developing

Based on the Delphi approach, 20 experts with more than 10 years of working experience in the fields of architecture, urban planning, urban design and transportation were invited to participate in this study. The two Delphi rounds conducted for this study were designed to determine the major variables and measure their significance.

PCA is conducted to measure the significance of the 49 variables and order them based on composite scores. The objective of this study is to collect data and conduct analysis according to four steps. The first step involves the administration of a survey to collect the participants' basic information and identification in addition to other data. In this study, the participants were asked to assign scores to the 49 variables based on the given standard I.e. 1 to 5 as no-effect to very strong effect.

The second step is to test the reliability of the survey data. As the participants' evaluations were subjective, it is necessary to use Cronbach's alpha to test the reliability of the data. Cronbach's alpha is distributed around 0 to 1, with higher values indicating more reliable data. If $\alpha > 0.9$, the data exhibit excellent reliability, and if $0.7 < \alpha < 0.9$, they exhibit good reliability [28]. In this case, Cronbach's alpha is 0.899, so the survey data exhibit excellent reliability. The third step is to apply the Kaiser-Meyer-Olkin (KMO) measure and conduct Bartlett's test to assess whether the data can be analyzed via PCA. They produce a ratio that compares the simplicity index with the correlation index of the variables [29]. The KMO measure is between 0 and 1, and demonstrates whether the variables can be calculated via PCA. Table 1 evaluates the factorial simplicity index levels. In this case, the data can be analyzed via PCA.

Table 1. KMO measure and Bartlett's test

Test		Value
Kaiser-Meyer-Olkin measure of sampling adequacy		0.707
Bartlett's test of sphericity	Approx. chi-square	505.649
	Df	190
	Sig.	0.000

The fourth step is to calculate the composite scores and rankings. The purpose of PCA is to synthesize the representative factors from many initial variables. Solving the load factor matrix is the key point of PCA. The eigenvalue and variance contribution rates are generated via sample data analysis. Moreover, the composite scores of each variable are obtained based on a series of algorithms. Each initial variable is ranked according to the composite scores and major variables can be put forward.

3.3. Weighting

In the second Delphi round, the AHP is used to measure the significance of the major criteria and variables. According to Saaty [24], the variables are analyzed as follows. First, the hierarchical structure is formed. The hierarchy model of the assessment of major variables consists of several levels. The variables at the topmost level are divided into sub-variables at the second level. Those sub-variables are divided again at the third level and so forth. Second, the judgment matrix is established. The AHP uses pairwise comparison to determine the relative priorities of the different variables at every level. In particular, each participant is required to make comparative judgments on every two variables using a 9-point scale. After the process, the judgment matrix is expressed as follows:

$$A = (a_{ij})_{n \times n}; i, j = 1, 2, ..., n \qquad (1)$$

where A is the judgment matrix; and a_{ij} refers to the judgment given by the participants.

Third, the priority weights of each variable are calculated. Based on Satty's eigenvector procedure [24], the judgment matrix can be analyzed to measure the absolute priority weights of each variable. Fourth, the consistency ratio is measured. This step verifies whether the participants are make consistent judgments about the relative significance of the variables. As subjectivity is one-sided, it is difficult to require absolutely consistent judgment on behalf of the participants. According to Satty [24], if the consistency ratio is 0.10 or less, then the judgment is considered acceptable. Otherwise, the participants must conduct a pairwise comparison again. Fifth, the overall weights of each variable are synthesized. The final priority weights of each variable at every level of the hierarchy are calculated into the geometric mean of the judgments received from individual participants. The overall weights are calculated as follows:

$$W = (w_1 \times w_2 \times ... \times w_n)^{\frac{1}{n}} \qquad (2)$$

where W is the overall weight of each variable, w_n refers to the priority weight of each variable given by the participants and n is the number of participants.

4. Determining Variables to Access Effects

A number of possible factors are reviewed and considered to determine the major variables, including their positive and negative effects. Previous studies including Gospodini [14], the U.S. Green Building Council [30], Yigitcanlar and Dur [31] and Wang [32] provide significant criteria for evaluating urban developments. Combined with the participants' suggestions, 49 possible effects are established for further analysis in Table 2. A document and archival analysis was conducted to figure out the variables of individual factors. After PCA, 13 major variables are determined and their component scores are given in Table 3. These variables are classified according to five variable sets (neighborhood and community; consumption; building and land use; transportation; and travel accessibility) and four categories (social; economic; land use and transportation; and accessibility).

Table 2. 49 variables to access effects
(13 selected major variables)*

Factor categories	Factor sets	Individual factors	No.
Physical	Topography	Slope gradient	1
	Geology	Incidence of seismic hazards	2
Ecological/ environmental	Vegetation	Greening rate	3
	Environmental impacts	Air quality	4
		Air ventilation	5
		Groundwater quality	6
		Noise level	7
		Light pollution level	8

Political/legal	Legal properties	Land ownership	9
Social*	Local population	Working/resident population	10
		Average personal income	11
	Local employment	Employment types	12
		Employment quantity	13
	Neighborhood / Community*	Original community characteristics	14
		Place attachment*	15
Economic*	Production	Local domestic product	16
	Consumption*	Investments in reconstruction of buildings	17
		Public investments in development, redevelopment and renewal of public open space	18
		Real estate prices*	19
		Real estate rents*	20
Cultural/historic	Local built environment	Urban texture	21
	Historical features	Historical buildings	22
Land use and transportation*	Building and land use*	Residential*	23
		Commercial*	24
		Industrial	25
		Government, institutional and community factors	26
		Open space	27
		Mixed uses	28
		Plot ratio*	29
		Building density	30
		Number of retail and service facilities*	31
	Transportation*	Road density	32
		Traffic flow*	33
		Parking capacity	34
		Number of bus lines	35
		Convenience for bicycle users	36
		Convenience for pedestrian	37
		Main working transportation mode*	38
		Main leisure transportation mode*	39
Accessibility*	Travel accessibility*	Access to CBD/BCCs*	40
		Access to cultural facilities	41
		Access to recreation facilities	42
		Access to medical center	43
		Access to school	44
		Access to civic and public spaces	45
		Access to airport*	46
		Access to railway stations/MTR	47
		Access to bus terminus	48
		Access to trunk roads*	49

Table 3. Composite scores and rankings of 13 major variables

Variable	Composite-score	Ranking
Real estate rents	3.10	1
Real estate prices	2.86	2
Main working transportation mode	2.39	3
Commercial	2.25	4
Access to CBD/BCCs	2.08	5
Place attachment	1.75	6
Number of retail and service facilities	1.61	7
Access to airport	1.57	8
Plot ratio	1.53	9
Main leisure transportation mode	1.43	10
Access to railway stations/MTR	1.42	11
Traffic flow	1.28	12
Residential	1.03	13

The final weights of each variable at every level of the hierarchical model are measured by synthesizing the absolute judgments made by the 20 participants. Figure 1 illustrates the hierarchical model along with the weights of the major variables, which can be used to evaluate rapid-transit systems on urban central areas.

5. Discussion

Based on the hierarchical model of the important variables, the "Land use and transportation" variable category occupies the largest proportion and has more variable sets and individual variables than the others in Figure 1. Although "Economic" has only one variable set and two individual variables, its significance is only 13% less than the significance of "Land use and transportation." Furthermore, rapid-transit systems directly affect "Accessibility," which has one variable set and three individual variables. Although "Social" has only one variable set and one individual variable, it occupies an important position in the model.

In the second level, the "Consumption" variable set, which includes two variables ("Real estate prices" and "Real estate rents"), has a larger weight than the others in Figure 1. These two individual variables occupy the top two positions. Compared with other variables, it is normally agreed that rapid-transit systems significantly affect property values. Many case studies conducted in both Western and Asian cities have found that accessibility to transport remains an important determinant of housing prices [27,49]. In addition, distance from subway stations has a statistically significant effect on property values before the opening of a subway line [34].

"Building and land use" is placed at the second position and is composed of four individual variables: "Residence land," "Commercial land," "Plot ratio" and "Number of retail and service facilities." According to analysis of cross-sectional and time series data, commercial usage tends to replace residential and industrial usages near transit stations [35]. The addition of commercial properties has been promoted to increase the number of retail and service facilities. The boom in rapid-transit operations also encourages underground commercial streets. As rapid-transit construction promotes the compact and mixed use of a city, rapid-transit systems have indirectly raised the plot ratio of blocks along corridors [35].

Rapid-transit systems also directly affect "Transportation," which comprises "Traffic flow," "Main working transportation mode" and "Main leisure transportation mode." In major cities, drivers frequently complain about traffic congestion and long commute times. An increasing number of people are choosing

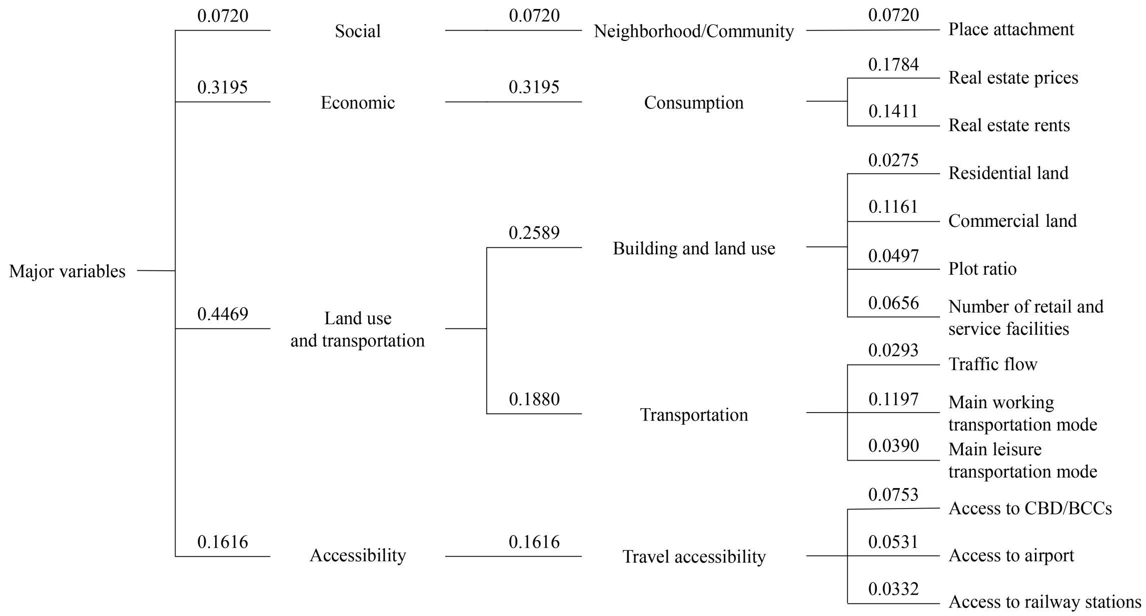

Fig 1. Hierarchical model to evaluate rapid-transit system on urban central areas in China

rapid-transit systems as their main transportation modes due to the rapid speeds offered and the appeal of being on time. In particular, when heavy traffic jams occur during rush hour and parking spaces are limited in shopping malls, a metro system can gradually become a main working and leisure transportation mode. Traffic flow can also be controlled as rapid transit ultimately replaces some vehicle usage.

Rapid-transit systems can directly affect “Travel accessibility” and particularly decrease the time spent travelling from corridor catchment areas to airports, commercial business centers (CBDs) and subway stations. In China, many cities have opened airport subway lines, such as Airport Express in Beijing and Hong Kong and Luobao Line in Shenzhen. A CBD is usually an important transfer station at which many metro lines are concentrated. Footbridges and underpasses are commonly developed to promote access to subway stations.

Although “Neighborhood/community” has the smallest weight at the second level and only one individual variable, it is nevertheless affected by rapid-transit systems. The operation of transit systems raises the amount of human movements, promotes city center regeneration and increases the attractiveness of affected areas.

6. Conclusion

Additional rapid-transit systems are opening in major cities as China's urbanization becomes more rapid. The boom in rapid-transit construction has inevitably affected peoples' lives and behavior. Because rapid-transit systems affect various aspects of urban development such as real estate value, urban transportation, economic and urban renewal, it is important to identify their major effects, particularly in China.

This study synthesizes a framework that determines the major variables involved in evaluating rapid-transit systems in city centers. A combined method involving the Delphi approach, PCA and the AHP is applied to establish a hierarchical model and evaluate rapid-transit systems on urban central areas. Experts in related fields were invited to participate in two Delphi rounds. Forty-nine variables divided into fifteen sets under eight categories are identified as the significant effects of rapid transit. PCA is conducted to determine the major variables, and the AHP is applied to measure the significance of each variable based on the participants' opinions. Finally, a hierarchical model, which contains three levels consisting of the 13 major variables divided into 5 sets (consumption; building and land use; transportation; travel accessibility; and neighborhood and community) under 4 categories (social; economic; land use and transportation; and accessibility), is established to evaluate rapid-transit systems on urban central areas. This hierarchical model framework is useful for stockholders or participants to evaluate the operations of rapid-transit systems and city center regeneration proposals. It is expected to improve China's rapid development and make it more sustainable.

This study helps develop a holistic framework to evaluate the effects of rapid-transit development in city centers. In particular, reviewing the extensive related literature and policies and administering surveys to experts permitted the evaluation of the significance of various aspects of rapid-transit development and the relationships between rapid-transit systems and urban development. To realize the full potential of this framework, the relationships between the variables and effects must be continuously evaluated. As urban contexts continuously change, the continuous monitoring of these changes can enhance the framework and allow it to adapt, particularly in China, where a large amount of rapid-transit systems are being constructed in various cities.

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Reference

[1] Guan, Yu. Comparison of the development in the central area of old cities in China and Western countries and renewing theory, Shanxi Architecture, 2008;34(25):36-7.
[2] Zuo, Fuqiang. Conservation and rehabilitation on urban core historic site, Urban Studies, 200;11(5):21-5.
[3] Duan, Xianfeng; Wang, Chaohui. The value of the planning of old city center regeneration: A case study of Liwan District renewal planning in Guangzhou, Urban Planning Forum, 1998,4:46-9.
[4] Bromley R.; Tallon A.; Thomas C. City centre regeneration through residential development: Contributing to sustainability, Urban Studies, 2005;42(13):2407-29.
[5] Department of the Environment, Transport and the Regions, London (United Kingdom). Our Towns and Cities: The Future, Delivering an Urban Renaissance, Her Majesty's Stationery Office London, 2000.
[6] Lehmann, S. Towards a sustainable city centre: Integrating ecologically sustainable development (ESD) principles into urban renewal, Journal of green building, 2006;1(3):83-104.
[7] Uzun, C. The impact of urban renewal and gentrification on urban fabric: Three cases in Turkey, Tijdschrift voor economische en sociale geografie, 2003;94(3):363-75.
[8] Williams, G. Collaborative partnerships and urban change management: The renewal of Manchester city centre, International Journal of Sociology and Social Policy,2006;26(5/6):194-206.
[9] Guerra, E. Mexico City's suburban land use and transit connection: The effects of the Line B Metro expansion, Transport Policy, 2014;32:105-14.
[10] Gutiérrez, J.; Cardozo, O.D.; García-Palomares, J.C. Transit ridership forecasting at station level: An approach based on distance-decay weighted regression, Journal of Transport Geography, 2011;19(6):1081-92.
[11] Handy, S. Smart growth and the transportation-land use connection: What does the research tell us?, International Regional Science Review, 2005;28(2):146-67.
[12] Cervero, R.; Landis, J. Twenty years of the Bay Area Rapid Transit system: Land use and development impacts, Transportation Research Part A: Policy and Practice, 1997;31(4):309-33.
[13] Bowes, D.R.; Ihlanfeldt, K.R. Identifying the impacts of rail transit stations on residential property values, Journal of Urban Economics, 2001;50(1):1-25.
[14] Gospodini, A. Urban development, redevelopment and regeneration encouraged by transport infrastructure projects: The case study of 12 European cities, European Planning Studies, 2005;13(7):1083-111.
[15] Mejia-Dorantes, L.; Lucas, K. Public transport investment and local regeneration: A comparison of London's Jubilee Line Extension and the Madrid Metrosur, Transport Policy, 2014;35:241-52.
[16] Vermote, L.; Macharis, C.; Hollevoet, J.; Putman, K. Participatory evaluation of regional light rail scenarios: A Flemish case on sustainable mobility and land-use, Environmental Science & Policy, 2014;37:101-20.
[17] Linstone, H.A.; Turoff, M. The Delphi method: Techniques and applications, Addison-Wesley Reading, MA, 1975.
[18] Hemphill, L.; McGreal, S.; Berry, J. An aggregated weighting system for evaluating sustainable urban regeneration, Journal of Property Research, 2002;19(4):353-73.
[19] Coombes, M.; Wong, C. Methodological steps in the development of multivariate indexes for urban and regional policy analysis, Environment and Planning A, 1994;26(8):1297-316.
[20] Carn, N.G.; Black, R.T.; Rabianski, J.S. Operational and organizational issues facing corporate real estate executives and managers, Journal of Real Estate Research, 1999;17(3):281-99.
[21] Pearson, K. Principal components analysis, The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, 1901;6(2):559.
[22] Li, X.; Yeh, A. Principal component analysis of stacked multi-temporal images for the monitoring of rapid urban expansion in the Pearl River Delta, International Journal of Remote Sensing, 1998;19(8):1501-18.
[23] Ewing, R.; Schmid, T.; Killingsworth, R.; Zlot, A.; Raudenbush, S. Relationship between urban sprawl and physical activity, obesity, and morbidity, in Urban Ecology, Springer, 2008, p. 567-582.
[24] Saaty, T.L. The Analytic Hierarchy Process, McGraw-Hill, New Yok, 1980.
[25] De Montis, A.; De Toro, P.; Droste-Franke, B.; Omann, I.; Stagl, S. Criteria for quality assessment of MCDA methods, Third Biennial Conference of the European Society for Ecological Economics, Vienna, May, 2000, p. 3.
[26] Cook, T.; Falchi, P.; Mariano, R. An urban allocation model combining time series and analytic hierarchical methods, Management Science, 1984;30(2):198-208.
[27] Cheng, E.W.; Li, H.; Yu, L. The analytic network process (ANP) approach to location selection: A shopping mall illustration, Construction Innovation, 2005;5(2):83-97.
[28] Cronbach, L.J Coefficient alpha and the internal structure of tests, Psychometrika, 1951;16(3):297-334.
[29] Kaiser, H.F. An index of factorial simplicity, Psychometrika, 1974;39(1):31-6.
[30] U.S. Green Building Council. LEED 2009 for neighborhood development, Washington, DC, 2009.
[31] Yigitcanlar, T.; Dur, F. Developing a sustainability assessment model: The sustainable infrastructure, land-use, environment and transport model, Sustainability, 2010;2(1):321-40.
[32] Wang, H. A GIS-based framework for supporting sustainable land use planning in urban renewal projects., Ph.D. dissertation, The Hong Kong Polytechnic University, 2013.
[33] So, H.; Tse, R.Y.; Ganesan, S. Estimating the influence of transport on house prices: Evidence from Hong Kong, Journal of Property Valuation and Investment, 1997;15(1):40-7.
[34] Bae, C.C.; Jun, M.; Park, H. The impact of Seoul's subway Line 5 on residential property values, Transport Policy, 2003;10(2):85-94.
[35] Vessali, K.V. Land use impacts of rapid transit: A review of the empirical literature, Berkeley Planning Journal, 1996;11(1).