Transport Policy 69 (2018) 179–192

Contents lists available at ScienceDirect

Transport Policy

journal homepage: www.elsevier.com/locate/tranpol

Pricing policy of floating ticket fare for riding high speed rail based on time-space compression

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ARTICLE INFO

Keywords:
High-speed rail
Time-space compression
Time-space map
Pricing policy
Operations management
Passenger perception

ABSTRACT

The Taiwan high-speed rail (HSR) markedly reduces the travel time from the north of Taiwan to the south, or vice versa, relative to other modes of public overland transportation. The HSR is faster than those modes, but also more expensive to ride. The pricing of HSR tickets has gained limited public acceptance because it lacks justification, indicating the need for a theoretical method for objectively justifying the ticket prices. With continuing improvements in data analytics, the computational capacity of computers, and visualization techniques, constructing a time–space model of a long-distance transportation system has become increasingly feasible, and such a model can be used to examine the time–space compression of the HSR. The first part of this investigation uses multidimensional scaling to obtain fitting coordinates based on travel times for various combinations of departure/destination HSR stations, and a geographic information system to generate time–-space maps of the relative locations of those stations. Through these maps, we can directly estimate the traveling time between pairs of stations. The second part constructs a floating ticket-pricing model that accounts for the riding costs of the HSR. The model's power to explain the prices of HSR tickets is evaluated. Based on the analytical results, suggestions to the current HSR ticket fare were proposed to set the feasible rate concerning the operating, passenger-perceived, and time-space compression costs. Recommendations for future research are made.

1. Introduction

The implementation of the "one fixed day off and one flexible rest day" working-day reform policy has had profound effects on domestic economic development, individual attitudes toward leisure, and company leave benefits. Partially as a result of the policy, the Taiwanese public has become increasingly eager to improve their standard of living and engage in leisure activities; the perceived value of time and the quality of transportation services has also been growing. Accordingly, the service quality, convenience, safety, comfort, punctuality, travel time, and ticket fares of transportation services warrant investigation (Andersson et al., 2010; Jen and Hu, 2003; Sumaedi et al., 2012).

The service portfolio of the Taiwanese middle- and long-distance transportation industry started with buses and trains, and it has recently incorporated the high-speed rail (HSR). Although the HSR considerably reduces overland travel time, its construction and operation have entailed substantial costs, so its ticket fares make it more expensive than other modes of public overland transportation (Huang et al., 2018). In October 2013, HSR fares were raised for the first time since the operation of the rail system began in 2005 (by 9.69%), causing public disdain. In the knowledge economy of the 21th century, HSR operation managers should develop business strategies that satisfy the needs of their customers.

With multiple transportation services to choose from, travelers place a growing emphasis on service quality, safety, and punctuality (Lam and Huang, 2003). The HSR has the unrivalled advantage of reducing travel time, but it may attract merely passengers seeking to experience the rail service as a novelty if its managers fail adequately to respond to customer needs. In addition to exploiting the advantages of its trains and meeting customer needs, the HSR operator must sufficiently address public concerns about its rail service, enabling its operation.

HSR trains expedite travel among regions of Taiwan, altering the socioeconomics of space (Banister and Givoni, 2013; Bullock et al., 2009; Givoni, 2006; Hall and Pain, 2006). Therefore, the HSR in Taiwan has caused time–space compression of varying uniformity in the geographical areas along its route. A map can compare the effects of time–space compression before and after the construction of the HSR. Increasing the ridership of the HSR necessitates an investigation into the behavioral intentions of passengers.

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https://doi.org/10.1016/j.tranpol.2018.06.006
Received 15 October 2017; Received in revised form 23 May 2018; Accepted 19 June 2018
Available online 06 July 2018
0967-070X/

Many empirical investigations have shown that service quality directly influences customers' behavioral intentions (Brown et al., 1993; Zeithaml et al., 1996). However, some researchers have argued that perceived value is a more relevant predictor than service quality, suggesting that perceived value and customer satisfaction indirectly affect customers' behavioral intentions (Cronin et al., 2000).

Ticket fare has been demonstrated to influence passengers' choice behavior (Wu, 2007). Zeithaml (1988) proposed that perceived value is directly determined by service quality and an antecedent factor in purchase decision-making, suggesting that it affects purchase intention (Chen and Chang, 2008; Zeithaml, 1988). Based on these findings, the HSR operating company in all instances should ensure that its service coverage meets passengers' needs and that its service quality meets their expectations, building customer trust and loyalty. It should also revisit the prices of its tickets, which affects passengers' perceived value of its service, to promote profitability.

The HSR has refined the transportation network of Taiwan, increasing the accessibility of the regions it serves. It is faster than other modes of public land transportation but more expensive to ride (Banister and Berechman, 2001; Cheng, 2010). In particular, the varying pricing of HSR tickets lacks a solid, convincing rationale, indicating a need to assess objectively the time value of the pricing of the tickets. A theoretical method is required to justify their prices. Fig. 1 depicts the current HSR map of Taiwan.

For the above reason, a time–space map is constructed in this work to emphasize the advantage of social and economic effects by the construction of HSR. A floating ticket-pricing model (TPM) (Voss, 2015) is proposed, which may inform the adjustment and customization of HSR ticket fares in the future (Fearnley, 2013; Jansson, 1993). It can be used to review existing ticket fares for other forms of rail transportation by replacing the input data. Overall, this study emphasizes the advantage and the influence of time–space compression that is associated with the HSR, by proposing the time-space maps for diverse Taiwan HSR transportation strategies, and developing a floating TPM that is tailored to it.

The rest of this paper is organized as follows. Section 2 reviews HSR ticket pricing in other countries, as well as theories and methods that are applied in the construction of time–space maps and TPM; it also considers factors that affect a floating TPM. Section 3 describes the methodology that is utilized herein to establish a time–space map and determines the structure of the proposed floating TPM. Section 4 demonstrates the application of the TPM and the time-space map to the HSR and the results thereof. Section 5 draws conclusions and suggests avenues for future research.

Fig. 1. Current HSR map of Taiwan (adapted from https://www.google.com.tw/maps/).

2. Literature review

Ticket pricing is a critical factor in the competitiveness of transportation operations because it determines the extent to which the operators can leverage the technical and economic strengths of their transportation services to improve their operating efficiency. Reasonable ticket pricing may help to balance the market shares of various modes of transportation, satisfy the transportation needs of travelers, and allow operators to improve service quality.

This section discusses HSRs in different countries. It considers the relationship between the pricing of tickets and the business performance of the operators, studies of ticket-pricing models, the conceptual framework and variables of the ticket-pricing model that is reviewed in this study, the economic implications of time–space compression, and theories and methods that are used in time–space map construction.

2.1. Theoretical basis and construction of HSRs ticket-pricing models

HSRs around the world serve mostly metropolitan areas, helping to reduce unnecessary investments in public transportation infrastructure (Bullock et al., 2009; Little et al., 2011; Xu et al., 2012). Often, railway tracks are adapted for use by HSR trains. However, HSRs in countries such as Taiwan, South Korea, and Spain are intended to facilitate the development of less well connected, under-resourced parts of those nations (Cheng, 2010; Kim and Sultana, 2015; Monzón et al., 2013; Moyano and Coronado, 2018).

The Asian countries with HSR systems are China, Japan, South Korea, and Taiwan. Ticket fares for the HSR in China and Taiwan depend on the number of kilometers traveled (Cheng, 2010; Zheng and Liu, 2016). Fares for the high-speed railway in Japan, called the Shinkansen, are not only based on the number of kilometers traveled but also include a surcharge for express service, which depends on the distance traveled, based on a series of bands (Taniguchi, 1992). Fares for South Korea's HSR or Korea Train Express, decrease as the number of kilometers traveled increases.

The European countries that have HSR systems are France, Germany, Spain, Italy, Sweden, and Switzerland (Campos and de Rus, 2009; Fu et al., 2012). Ticket fares for the TGV (French: Train à Grande Vitesse, “high-speed train”) in France and AVE (Spanish: Alta Velocidad Española, “high-speed rail”) in Spain differ from those for HSRs in Asian countries because they vary with the time of purchase, distance traveled, the type of train car, and the time of riding. Fares for the ICE

Table 1
Survey of factors affecting HSR ticket price.

No.	Country	Factors				
		D_t	E_s	T_p	T_c	T_r
1	China	●	–	–	●	–
2	Japan	●	●	–	●	–
3	South Korea	●	–	–	●	–
4	Taiwan	●	●	●	●	●
5	France	●	–	●	●	●
6	Germany	●	–	●	●	●
7	Spain	●	–	●	●	●
8	Switzerland	●	–	●	●	●
9	United Kingdom	●	–	●	●	●
10	United States	●	●	●	●	●

Note: D_t: Distance traveled; E_s: Express service; T_p: Timing to purchase; T_c: Type of train car; T_r: Time of riding.

(Dutch: Intercity-Express, "high-speed rail") in Germany depend on the distance traveled. Fares for the Eurostar in the United Kingdom, start at the price of a single trip and vary depending on the time of the ticket reservation and the time of the train booked (Fu et al., 2012; Sun et al., 2017). In the United States, Acela (the only rail service that meets the HSR standards set by the U.S. Department of Transportation) sells tickets at floating rates, which vary according to the time of purchase.

In summary, the pricing of HSR tickets varies among countries. Most HSR ticket fares in Asia comprise a base rate that is multiplied by the number of kilometers traveled and vary with the ridership of public transportation in the country, while Europe and the United States use floating fares. Based on the above reviews, Table 1 summaries the survey result of factors that affect HSR ticket prices in various countries.

Owing to these differences in the pricing of HSR tickets, this investigation proposes a floating ticket-pricing model that is based on existing theories. This approach can be used to conduct future research into HSR ticket pricing or to examine the feasibility of ticket-pricing schemes in countries where HSR construction is underway (such as Australia and Mexico, or the early phases of the high-speed train system in the United Kingdom).

Ticket pricing has been widely studied. The ticket pricing of urban rail transit concerns various groups in society, and reasonable ticket fares may allow urban rail systems to develop robustly (Zhang and Li, 2009). Hence, the rationale and methodology for ticket pricing must be clearly specified. Factors that typically influence ticket prices are transportation costs, profit margin, passenger capacity, and comparisons with fares for other modes of transportation (Liu, 2010).

Shao et al. (2010) utilized low-peak fares as average ticket fares, based on the theory of congestion pricing, and analyzed the ticket-pricing of urban rail transit on the basis of Ramsey pricing theory (Shao et al., 2010). Wang and Zhou (2012) developed a multi-time-period pricing model for urban rail based on Ramsey pricing theory (Wang and Zhou, 2012).

Some researchers have developed generalized cost functions that consider five service attributes (safety, speed, economy, comfort, and convenience), and have used these functions to establish two-level programming models that respectively account for benefits to HSR operators and passengers (Wei et al., 2015; Zhou et al., 2016).

Zhao and Ren (2015) presented a method for benchmarking HSR ticket fares that accounts for fixed and variable costs and a combination of upper and lower finance accounts. The ticket fares for urban rail transportation are directly related to passenger traffic (Zhao and Ren, 2015).

Zhang and Li (2009) used a logit model to estimate the distribution rate of urban rail transit passenger traffic with a view to increasing it (Zhang and Li, 2009). Therefore, they established a multiobjective programming model that maximizes the interests of consumers, businesses, and the government to optimize ticket fares.

Tang et al. (2007) developed a method for urban rail transit pricing that the life-cycle cost of urban rail transit to passengers (Tang et al., 2007). Zhang et al. (2014) developed a generalized cost function for the service attributes of various modes of transportation to examine the relationship among ticket income, the distribution rate of passenger traffic, and ticket fare, and proposed a floating pricing model for the purpose of maximizing the revenues of rail companies (Zhang et al., 2014).

Although researchers globally have investigated ticket pricing for urban rail transit, time–space compression that is associated with HSRs and passenger satisfaction has not been studied in relation to ticket-pricing models. This investigation addresses this gap in the literature by drawing on relevant findings from previous studies; examines the effects of time–space compression and passenger satisfaction on HSR ticket fares, and proposes a floating ticket-pricing model that accounts for the operational, passenger-perceived, and time–space costs of the HSR operations.

2.2. Perceived prices and satisfaction

Price perception refers to a consumer's perception of the value of a deal and his or her attitudes toward the deal (Lichtenstein et al., 1991); it pertains to the consumer's feelings about price and is a critical factor in evaluating the value of a good or service and purchase decision-making (Voss et al., 1998). Jacoby and Olson (1976) divided price into consumer-perceived price and objective price (Jacoby and Olson, 1976); the former refers to the consumer's subjective perception of whether the price of a good or service should be lower or higher (Erevelles et al., 1999); the latter is the actual price of a good or service, which is set by the seller. Normally, consumers recall the perceived price rather than the actual price of a purchase (Dickson and Sawyer, 1990; Zeithaml, 1988).

The ticket fare and the quality of a rail transportation service strongly affect its consumer-perceived price (Wen et al., 2012). Therefore, the proposed floating ticket-pricing model was designed to account for the passenger-perceived price of HSR tickets. Based on that research, there are five characteristics of service quality that influence the passenger-perceived price of HSR tickets-safety, comfort, convenience, punctuality, and passenger satisfaction. High service quality helps to justify increased ticket fares (Zhang et al., 2014). Each component is detailed at section 3.1.2.

Real economic growth depends on the productivity of economic resources and the quality of the products that are made from these resources. Marketing researchers and neoclassical economists measure economic growth by utility or the satisfaction of consumers. Some scholars have described customer satisfaction as an economic asset of a company. For example, the American Customer Satisfaction Index (ACSI) is related to market capitalization. Others have established that customer satisfaction significantly affects the revenues and profits of a firm (Fornell et al., 2006).

The passenger satisfaction index (PSI), which was developed by Chou et al. (2011) on the basis of the ACSI, is expressed as follows (Chou et al., 2011).

$$\mathrm{PSI} = \frac{\sum_{i=1}^{n} W_i \overline{Y}_i - \sum_{i=1}^{n} W_i}{(r-1) \times \sum_{i=1}^{n} W_i} \times 100 \tag{1}$$

where $\overline{Y}_i$ is the mean value of ith measurement indicator for passenger satisfaction, W_i is the standard weight, and r is the level of measurement.

2.3. Time–space compression and its economic implications

Time–space compression (or time–space convergence) refers to a process in which temporal and spatial experiences change as technologies of transportation and communication advance. It is both a theoretical concept and an observed phenomenon in real life.

The geographer David Harvey introduced the concept of time–space compression in *The Condition of Postmodernity* in 1989. Harvey (1990) referred to time–space compression as a consequence of capitalist commodity production and capital accumulation, suggesting that capitalism accelerates the pace of life, helps to overcome spatial barriers, causes the distances between places to shrink, and therefore provides the impression that "the world is being compressed" (Harvey, 1990).

Not only does time–space compression reduce travel time and spatial distances; it also facilitates political, economic, and cultural exchange internationally, favoring globalization. Additionally, it strengthens as the efficiency of transportation improves. Time and space can both be regarded as computable objects. The effects of time–space compression vary depending on social class, income level, and consumer culture (Givoni, 2006; Harvey, 1999).

The HSR network improves the accessibility of all of the regions it serves, causing socioeconomic changes. For example, populations and employment rates grow faster in the regions of Japan that are served by the Shinkansen than in those that are not. Furthermore, the time saved by riding HSR trains has economic benefits, contributing an estimated 3.7 billion euros to the Japanese economy annually (Okada, 1994).

The advent of HSR technology in the latter half of the twentieth century has ushered in "the second railway age" (Banister and Hall, 1993), causing an unprecedented compression of time and space (Spiekermann and Wegener, 1994). Studies of accessibility following time–space compression have used either the "spatial-layout approach" or the "isochronous-ring approach." The spatial-layout approach describes changes in the overall efficiency of a network, but unlike the isochronous-ring approach, it does not consider the size and direction of time–space compression at nodes or in regions of interest.

However, the isochronous-ring approach provides an incomplete picture of phenomenon. Time–space compression due to transportation requires a redefinition of the spatial proximity between served regions on account of changes in travel distance or time to generate a complete and continuous space (Zhou et al., 2014).

In the field of metacartography, which delineates the accessible geographic ranges of different modes of transportation, Tobler (1961) was the first to propose a method for plotting "time–space maps," which converts Euclidean distance into a network or temporal distances to derive fitting plots for new spaces, depicting time–space compression and distortion that are associated with changes in traffic conditions in the region of interest (Tobler, 1961).

Spiekermann and Wegener (1994) used a time–space map to examine the time–space effects of cross-European HSR networks during the years 1993–2010 (Spiekermann and Wegener, 1994). Ahmed and Miller (2007) examined time–space compression that was induced by transportation systems in Salt Lake City, Utah, in the United States between 1992 and 2001; they utilized Multidimensional Scaling to analyze the compression, and studied the related time–space maps that were produced using a geographic information system (Ahmed and Miller, 2007).

Zhu et al. (2010) drew on previous investigations to estimate the rail-travel time and distance between the cities of Fuzhou and Shanghai in China, recalculated the travel distance between both cities, and visualized the recalculated distance on a map (Zhu et al., 2010). Chen and Hall (2011) examined the time–space relationship of towns that were served by high-speed trains (HST) and those that were not, suggesting that towns within a 2-h HST travel time of London experienced economic growth (Chen and Hall, 2011). Lu et al. (2013) selected five Chinese cities as HSR economic zones, establishing the spatial layout of those zones based on principles that are used to generate 2D distorted time–space maps (Lu et al., 2013).

Since neither the spatial-layout approach nor the isochronous-ring approach provide a complete picture of time–space compression, Zhou et al. (2014) acquired distance data matrices from online navigation services; estimated and assessed fitting errors, superimposed both fitting and geographical spaces, analyzed changes in fitting spaces, and summarized the characteristics of time–space compression (Zhou et al., 2014).

3. Methods

This section provides descriptions of two methodologies that are utilized in this study, *i.e.*, floating ticket-pricing model, and time-space map generation.

3.1. Construction of proposed floating ticket-pricing model

The literature review reveals that HSR ticket pricing varies among countries, and various theories and methods concerning HSR ticket-pricing have been developed around the world. The proposed floating ticket-pricing model is based on studies on HSR ticket pricing and involves the operating, passenger-perceived, and time-space compression costs of HSR. It is detailed in the following subsections.

3.1.1. Operating costs

The operating costs of a rail line can be divided into labor, material, energy, replacement, and other expenses. Labor costs are the sum of salaries paid to all employees, plus employee benefits such as wages for seconded and temporary staff, pension payouts, and labor and health insurance. Material costs comprise expenses for materials, facilities, tools, as well as other physical items that are used to support the operation of a rail line. Energy costs consist of include the cost of the electricity that is required to run the rail line. Replacement costs cover the replacement of fixed assets. Other costs include loan interests and advertising expenses.

In this study, the operating costs of a rail line are classified into four categories, following Zhao and Ren (2015) (Zhao and Ren, 2015).

C_1: Annual expenditure for the replacement and maintenance of rail stations and the lines, as well as other fixed equipment.

C_2: Annual expenditure for the operation of rail stations, and annual wages and benefits for technicians that are responsible for rail lines maintenance.

C_3: Annual expenditure for the operation of rail stations and lines.

C_4: Miscellaneous expenses (including loan interest, advertising, wages for seconded and temporary staff, pensions, and labor and health insurance).

All four categories of operating costs were apportioned among the trains in operation. Accordingly, the operating cost that is apportioned to each operating train for each kilometer traveled by it is estimated using

$$C_{total} = \frac{C_1 + C_2 + C_3 + C_4}{2 \times 365 \times \sum_{i=1}^{N} L_i} \tag{2}$$

where N is the number of trains in operation, and associated with a particular mode of transportation, and L_i is the operating distance of the i^{th} mode of transportation (km).

3.1.2. Perceived costs

(1) Safety

The operation of public transportation entails different risks, and safety is paramount. Safety is also a factor in the selection of public transportation services (Papadimitriou and Yannis, 2014). It can be quantified by safety credibility (Saf_i), where Saf_i is 1 if the casualty rate is 0, or 0 if the casualty rate exceeds a certain level. Saf_i is estimated as

$$Saf_i = \frac{1}{\gamma_i e^{\alpha_i \beta_i}} \tag{3}$$

where γ_i is the casualty rate of the i-th mode of transportation and $e^{\alpha_i \beta_i}$

is a coefficient to be determined, in which α_i is the recovery time after a ride in a vehicle of the i^{th} mode at t= 0; namely, the minimum amount of recovery time ($\frac{H}{1+\alpha_i}$). Physiologically, the recovery time required increases to a certain limit, which is defined herein as "H." The recovery time varies with the internal environment of the train and the duration of the ride (Shi et al., 2004; Wei et al., 2015; Zhang and Peng, 2006). β_i is the "strength coefficient", which gives of the recovery time per unit of travel time (a higher strength coefficient indicates a greater amount of time).

(2) Comfort

Comfort can be quantified by the time required to recover from fatigue after a train ride. Poor comfort corresponds to a longer recovery time for a passenger. The recovery time (g_i^{AB}) is given by Eq. (4) (Welding, 1957), and the monetary value of the recovery time (Com_i) is calculated using Eq. (5).

$$g_i^{AB} = \frac{H}{1 + \alpha_i e^{-\beta_i\left(\frac{d_{AB}^i}{\bar{v}}\right)}} \tag{4}$$

$$Com_i = g_i^{AB} \times V_t^{AB} \tag{5}$$

Here, d_{AB}^i is the distance from place A to place B using the i^{th} mode of transportation; $\bar{v}$ is the average speed of HSR from A to B.

The primary purpose of most transportation improvements is to reduce the time it takes to get from one place to another. The valuation of that time in terms of commensurate with the improvement costs is a critical issue. Time is regarded as an opportunity cost because travelers are presumed to have other activities they would prefer to engage in if they weren't traveling. The time value depends upon the travelers willingness to pay to shift the time from travel to another activity (Lee, 2000). Therefore, a formula of estimating time value is proposed as Eq. (6).

$$V_t^{AB} = \frac{GDP}{(P_e \times t_e)} \tag{6}$$

V_t^{AB} is the passenger time value; GDP is gross domestic product; P_e is regional employment number; and t_e is average working hours.

(3) Convenience

A more convenient mode of transportation is more likely to be used. In this investigation, measures of convenience are the time taken to purchase a ticket and the waiting time for a train (Guevara, 2017). Convenience is given by

$$Con_i = (t_b^i + \omega^i) \times V_t^{AB} \tag{7}$$

where t_b^i is the time taken to purchase a ticket and ω^i is the waiting time, which can be estimated based on the previous study (Luo et al., 2016), as follows:

$$\omega^i = \frac{h}{2}\left(1 + \frac{\sigma^2}{h^2}\right) \tag{8}$$

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2 \tag{10}$$

where h is the average between train departure times; σ^2 is the population variance of departure time.

(4) Punctuality

Delays in a public transportation service can disrupt passenger itineraries, causing unnecessary losses to passengers (Wang et al., 2014). Punctuality is quantified mainly by the average delay of journey in a given transportation mode, which is estimated as,

$$Pun_i = t_l^i \times V_t^{AB} \tag{11}$$

where t_l^i is the average delay of journey in the *i*-th transportation mode.

(5) Passenger satisfaction

In their study on the relationship between price and customer satisfaction, Anderson et al. (1994) demonstrated that customer satisfaction is a function of price (Anderson et al., 1994), and reported a positive relationship between customer satisfaction and price tolerance (Zeithaml et al., 1996), suggesting that a 1% increase in customer satisfaction corresponds with a 0.6% decrease in price sensitivity, in which the variation of passenger satisfaction index, PSI (Chou and Yeh, 2013), can be estimated periodically by Eq. (1).

3.1.3. Time costs

Savings in travel time are a key element in the economic evaluation of transport projects (Román et al., 2014). Continued advances in transportation technology increasingly expedite travel between regions, carrying passengers farther in much shorter times. Therefore, the Euclidean distance can be converted into a temporal distance that is related to transportation advances, and estimated according to passengers' perceptions of reductions in travel time due to transportation advances (Liu and Zhou, 2014).

Janelle (1973) measured the speed of physical objects to estimate the rate of time–space convergence (Janelle, 1973). The reduction in travel time (V_{TS}) given by

$$V_{TS} = \frac{\Delta T_{AB}}{\Delta T} = \frac{\text{Travel time between Places A and B}}{\text{Timeframe}} \tag{12}$$

The change in travel time between A and B as a result of the operation of the HSR is subsequently calculated [using Eq. (13)], and the effects of time–space compression are measured from reductions in travel time between both places due to transportation advances [using Eq. (14)].

$$T = T_{before} - T_{after} \tag{13}$$

$$Compression_i = T \times V_t^{AB} \tag{14}$$

where T is the change in travel time between A and B due to the construction of the HSR.

Perceived and time costs are related to time value, so the passenger-perceived and time-space compression costs are combined in Eqs. (15) and (16).

$$Model_i1 = \theta_1 Com_i + \theta_2 Con_i - \theta_3 Pun_i + \theta_4 Compression_i \tag{15}$$

$$Model_i2 = Model_i1 \times 1.006 \times \Delta PSI \times Saf_i \tag{16}$$

where $\theta_m (m = 1, 2, 3, 4)$ is the weight of each service attribute. Since safety (Saf_i) and passenger satisfaction differ from other service attributes in that they cannot be converted into monetary value, each is multiplied by a weighted sum of attributes to yield the passenger-perceived and time-space compression costs ($Model_i2$).

Thus, the proposed floating ticket-pricing model (TPM) is given by

$$TPM = C_{total} \times \text{ Number of kilometers traveled by HSR train} + Model_i2 \tag{17}$$

3.2. Procedure for constructing a time–space map

Relevant numerical data were collected, input into statistical software, and analyzed using Multidimensional Scaling (MDS); the results of the analysis were then visualized using a geographic information system, yielding a time–space map.

3.2.1. Data preparation

The construction of the time–space map starts with the collection of

Table 2
Relationship between Stress-I and goodness of fit.

Stress-I	Goodness of fit
0	Perfect
(0, 0.025)	Excellent
(0.025, 0.05)	Good
(0.05, 0.1)	Fair
> 0.1	Poor

data on travel time between pairs of departure/destination HSR stations. In this study, the travel times for different combinations of departure/destination HSR stations in Taiwan was estimated from schedules on the official HSR website. A matrix of these travel times was generated.

3.2.2. Multidimensional scaling analysis

MDS is a statistical technique that uses N subjects to estimate M objects in accordance with P principles. An MDS problem can be solved by metric or nonmetric methods (Borg and Groenen, 1997; De Leeuw and Mair, 2009). Because of dealing with nonmetric data, this investigation adopts nonmetric ones.

The primary objective of MDS is to develop perceptual maps by converting multivariate data into fewer dimensional spaces. A perceptual map typically has two axes of reference and is a spatial positioning map. The meanings of both axes on the map depend on the distributions of observed values.

An MDS analysis involves specifying an appropriate number of dimensions and ensuring their explanatory power and goodness of fit. In this study, the pressure coefficient was used to establish the reasonableness of a specified number of dimensions. Table 2 shows the goodness-of-fit results of the dimensions (Kruskal, 1964). Lower pressure coefficients indicate higher goodness of fit and, accordingly, smaller differences between fitted plots and given data.

This investigation uses IBM SPSS Statistics, which offers two MDS procedures- ALSCAL and PROXSCAL (an extension of ALSCAL). It also uses PROXSCAL, which uses generalized least squares to describe multidimensional data in low-dimensional spaces; moves multiple times on coordinates to obtain the optimal fitting space, and ensures that the distance between all pairs of points in the space and the sum of squares of the Euclidean distance converges to the minimum (Zhou et al., 2014).

The matrix was input into SPSS, and PROXSCAL was used to generate a nearly complete MDS map of the relative positions of HSR stations. MDS estimates error coefficients to assess the goodness of fit of the space that is obtained by MDS transformation. In Eq. (18), σ is a standardized initial level of stress; a lower σ corresponds to a higher goodness of fit. Equation (19) describes a validity evaluation method that is commonly used in MDS.

$$\sigma^2 = \frac{1}{m}\sum_{k=1}^{m}\sum_{i<j}^{n}\omega_{ijk}\left[\hat{d}_{ijk} - d_{ij}(X_K)\right]^2 \tag{18}$$

$$\text{Stress} - \text{I}= \sqrt{\frac{\sum_{k=1}^{m}\sum_{i<j}^{n}\left[\hat{d}_{ijk} - d_{ij}(X_K)\right]^2}{\sum_{k=1}^{m}\sum_{i<j}^{n}\left[\hat{d}_{ijk}\right]^2}} \tag{19}$$

where $k = 1, 2, 3, \ldots, m$; $i = 1, 2, 3, \ldots, n$; $j = 1, 2, 3, \ldots, n$; σ is the fitting error (a standardized initial level of stress); n is the number of HSR stations; ω_{ijk} is the distance weight; $\hat{d}_{ijk}$ is the distance of the fitted space; and $d_{ij}(X_k)$ is the Euclidean distance.

3.2.3. Visualization

IBM SPSS Statistics was used to conduct MDS to identify hidden structures in any data (i.e., the relative coordinates of the fitting space). ArcGIS, a geographic information system, was employed to visualize the results from IBM SPSS Statistics. The system uses spatial adjustment tools to visualize dimensional fitting spaces. To enable the superimposition of fitting spaces and actual maps, regions that were readily accessible by public transit were designated as anchors, and two regions whose map and network distances were almost the same were used as reference points.

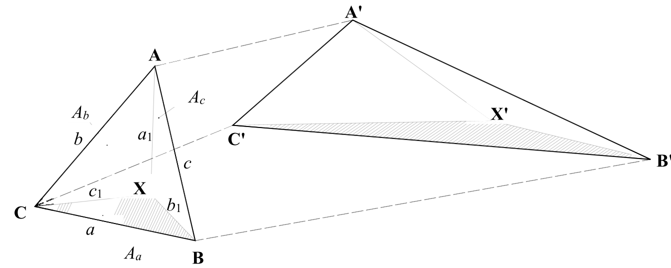

Fig. 2. New coordinates of each point.

Triangle barycentric coordinate has been known for many centuries (Coxeter, 1989; Meyer et al., 2002; Möbius, 1827). This method is used to calculate the new coordination of each point in the maps after calculating coordination of each station.

When the triangle $\mathbf{T} \subset \mathbf{R}^2$ has vertices **A**, **B**, and **C**, any point **X** in **T** partitions it into the three sub-triangles indicated in Fig. 2, and the coordinate of **X** is the ratios of the areas A_a, A_b, A_c of the sub-triangles to the area A of **T**, that is,

$$\mathbf{X} = \alpha\mathbf{A} + \beta\mathbf{B} + \gamma\mathbf{C} \tag{20}$$

where

$$\alpha = \frac{A_a}{A} \tag{21}$$

$$\beta = \frac{A_b}{A} \tag{22}$$

$$\gamma = \frac{A_c}{A} \tag{23}$$

Heron's formula gives the area A of a triangle with the lengths of sides are a, b, c is

$$A = \sqrt{p(p-a)(p-b)(p-c)} \tag{24}$$

where p is the semi perimeter of the triangle; that is,

$$p = \frac{a+b+c}{2} \tag{25}$$

Follow Eq. (24)

$$A_a = \sqrt{p_a(p_a-a)(p_a-b_1)(p_a-c_1)} \tag{26}$$

$$A_b = \sqrt{p_b(p_b-a_1)(p_b-b)(p_b-c_1)} \tag{27}$$

$$A_c = \sqrt{p_c(p_c-a_1)(p_c-b_1)(p_c-c)} \tag{28}$$

where p_a, p_b, p_c are the semi perimeters of the sub triangles with the length of sides presented in Fig. 2.

From Eqs. (21)–(28), we can calculate α, β, γ

$$\alpha = \frac{A_a}{A} = \frac{\sqrt{p_a(p_a-a)(p_a-b_1)(p_a-c_1)}}{\sqrt{p(p-a)(p-b)(p-c)}} \tag{29}$$

$$\beta = \frac{A_b}{A} = \frac{\sqrt{p_b(p_b-a_1)(p_b-b)(p_b-c_1)}}{\sqrt{p(p-a)(p-b)(p-c)}} \tag{30}$$

$$\gamma = \frac{A_b}{A} = \frac{\sqrt{p_c(p_c-a_1)(p_c-b_1)(p_c-c)}}{\sqrt{p(p-a)(p-b)(p-c)}} \tag{31}$$

According to Eq. (20), interpolation of the new coordinate **X'** of **X** when new coordinate of vertices **A**, **B**, **C** are **A'**, **B'**, **C'** is

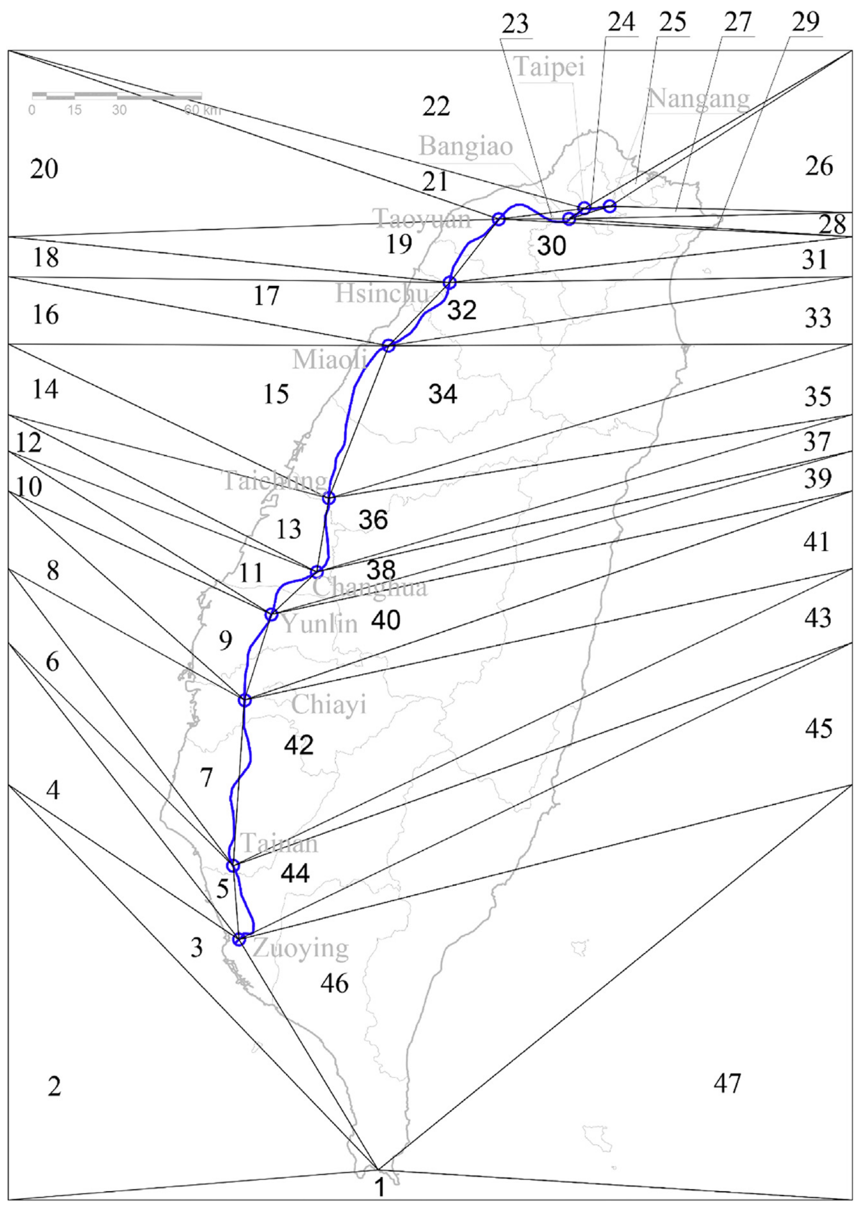

Fig. 3. Triangle meshes.

$$\mathbf{X}' = \alpha\mathbf{A}' + \beta\mathbf{B}' + \gamma\mathbf{C}' \tag{32}$$

Fig. 3 displays the triangle meshes to calculate the new coordinates of each point on the time-space compression map.

4. Ticket-pricing model application

The travel time between HSR stations in Taiwan varies. A time–-space map is utilized to determine the time–space compression before and after HSR construction and a floating ticket-pricing model is used to calculate HSR ticket prices. This section introduces HSR ticket pricing, proceeds to the construction of the time–space map and the application of the ticket-pricing model, and ends with the verification of the model.

4.1. HSR in Taiwan

In 1980, the Taiwanese government formulated the nation's first build–operate–transfer infrastructure project to establish an HSR network that linked the north, central, western, and southern parts of the island, in response to surging demand for transportation across western Taiwan. The project cost a total of NT$480.6 billion. The Taiwan High Speed Rail Corporation (THSR) oversaw the construction of the HSR network and now operates it. The company's concession for the rail network took effect in 1998 and is due to expire in 2067.

The HSR began formal operations in 2007. It spans about 349.5 km along the west coast of Taiwan from the northern city of Taipei to the southern city of Kaohsiung, and serves 12 stations. HSR trains run up to 300 km/h from the northernmost station of Nangang to the southernmost station of Zuoying in 96 min, which is much less time than that, 3 h and 47 min, taken by the Tzu Chiang Limited Express, which is the fastest train operated by the Taiwan Railways Administration. Eight stations (Taipei, Banqiao, Taoyuan, Hsinchu, Taichung, Chiayi, Tainan, and Zuoying) were in service as of December 2015; three (Miaoli, Changhua, and Yunlin) were inaugurated on December 1st that year, and one (Nangang) was opened in July 2016.

The Bureau of High Speed Rail, a government entity, that is tasked with planning and supervising the operation of the HSR, has laid down the following guidelines for HSR ticket pricing (BOHSR, 2014):

No limit is imposed on the setting of fares and discounts for business-class tickets. However, standard-class tickets must be priced as follows:

Table 3
F_G and F_G, 2007–2017.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
$\mathbf{F_G}$ (NTD/passenger-km)	3.655	3.655	3.875	3.875	3.875	3.875	4.009	4.009	4.009	4.009	4.134
$\mathbf{F_B}$ (NTD/passenger-km)		4.386 (=3.655×120%)					4.8108 (=4.009×120%)				4.9608
Price (NTD) (Taipei to Zuoying)		1490 (=4.386× 340)					1630 (=4.8108× 340)			1490	1490

(1) The THSR shall specify a base fare (F_B) within 120% of the government-stimulated base fare (F_G). That is, $F_B \leq F_G \times 120\%$.
(2) Average revenues from a standard seat sold (calculated by dividing gross revenues by the total number of passenger kilometers) shall not exceed 120% of the government-set base fare.
(3) The Ministry of Transportation and Communications (MOTC) shall review the government-set base fare (F_G) according to the rate of change in the General Index of Consumer Price (GICP) in Taiwan and publish the results of the review on April 1 each year, based on which the THSR sets its base fares (F_B).

If the annual rate of change in the GICP reaches 3% or if the cumulative rate of change of the GICP reaches 3% when the most recent adjustment of F_G occurs, then F_G is expressed adjusted follows.

$$F_{G,t+1} = F_{G,t} \times (1 + X_t\%) X_t\ \% = \frac{GICP_t - GICP_{t-1}}{GICP_{t-1}} \tag{33}$$

Table 3 shows government-set and THSR-specified base fares in various years. The MOTC set F_G in 2007 (when the HSR began formal operations) at NT$3.655 per passenger-kilometer. In 2009 and 2013, when the GICP reached a level that necessitated the adjustment and review of the government-set base fare, F_G was changed to NT$3.875 and NT$4.009 per passenger-kilometer, respectively.

In 2016, F_G remained at NT$4.009 per passenger-kilometer, because the GICP had exhibited a −0.31% annual change earlier in the year and compounded annual rate of change in all instances from the most recent adjustment of $F_G$in 2013 to its review in 2016 was 1.69%. The THSR passed a financial improvement measure in 2015 and reduced the fare for a standard-class adult ticket from Taipei to Zuoying to NT$1490 the following year. In March 2016, the MOTC increased F_G to NT$4.134 per passenger-kilometer.

Table 4 presents the detail of ticket fares of other Taiwan train modes for the comparison. Although HSR is the most expensive transportation mode, HSR still is the top choice for traveling because of its rapid traveling time, frequency of trains, and ease of accessibility.

4.2. Constructing a time–space map

4.2.1. Taiwan HSR data collection

THSR operates three types of train service, which are express (train numbers starting with 1), skip-stop (train numbers starting with 6 or 16), and all-stop (train numbers starting with 8). An express train stops at the stations of Nangang, Taipei, Banqiao, Taichung, and Zuoying, and its total journey time is 105 min. Skip-stop trains serve different combinations of stations (usually including Nangang, Taipei, Banqiao, Taoyuan, Hsinchu, Taichung, Chiayi, Tainan, and Zuoying), and each of these trains operates for a total of 130 min. An all-stop train stops at each station along the HSR line and has a total travel time of 145 min. This study presents the time-space maps of these three HSR trains.

Table 4
Ticket fare of Taiwan train modes.

	HSR	Tze-Chiang Express Train	Chu-Kuang Express Train	Local Train
Taipei - Banqiao	40	23	18	15
Taipei - Taoyuan	160	66	51	42
Taipei - Hsinchu	290	177	137	114
Taipei - Miaoli	430	255	X	164
Taipei - Taichung	700	375	289	241
Taipei - Changhua	820	415	320	267
Taipei - Yunlin	930	527	407	339
Taipei - Chiayi	1080	598	461	385
Taipei - Tainan	1350	738	569	X
Taipei - Zuoying	1490	824	635	X

Amounts in NT dollars.

4.2.2. Multidimensional scaling for the space maps

To perform the PROXSCAL procedure, data on the total travel time for the three HSR trains, detailed in the previous subsection, were input into IBM SPSS Statistics. An MDS analysis was subsequently conducted on the data. Data were defined to generate individual datasets and coordinates in more than two dimensions that reveal the relative positions of all HSR stations (the coordinates of corresponding fitting spaces), and to derive the stress values of different common space maps (Table 5).

The MDS analysis revealed the goodness of fit of common space maps from the stress values. Based on the comparison showed in Table 2, all Stress-I values were < 0.025 indicating high goodness of fit. In the time–space map, express trains had optimal dimensionality in the 3D MDS analysis, whereas the skip-stop and all-stop trains had optimal dimensionality in the 2D MDS analysis.

4.2.3. Visualization of time–space compression

The data applied for visualization include maps of Taiwan, HSR stations, and routes that were acquired from an online GIS administered by the MOTC. For comparison of subsequent analyses, the MDS results were presented at the 2D level. Fig. 4 presents common space coordinates that are based on the 2D MDS results.

Common space maps were converted into a format that can be read by ArcGIS. They were subsequently superimposed on the maps of HSR stations after “Fit to Display” was selected from the Georeferencing toolbar. “Add Control Points” was then selected from the tool bar to add shapefile point features, giving attributes (HSR station names) to the coordinate system.

Taipei HSR station was used as the reference point based upon which time–space maps were generated using spatial adjustment tools. Fig. 5 displays the aforementioned time–space maps, which suggest that time–space compression for express trains is greater than that for all-stop ones. Since train operations differ in the number of stations and travel time, they induce time–space compression with various degrees of intensity.

4.3. Application to determination of HSR ticket fare

This investigation involves several assumptions. First, the proposed

Table 5
Stress test results.

Dimension		2	3	4	5	6
Stress-I	Train number (xxx = daily)					
	1xx	0.02478	0.02418	0.02418	–	–
	6xx, 16xx	0.01784	0.02270	0.02234	0.02387	0.02260
	8xx	0.02044	0.02216	0.02385	0.02451	0.02424

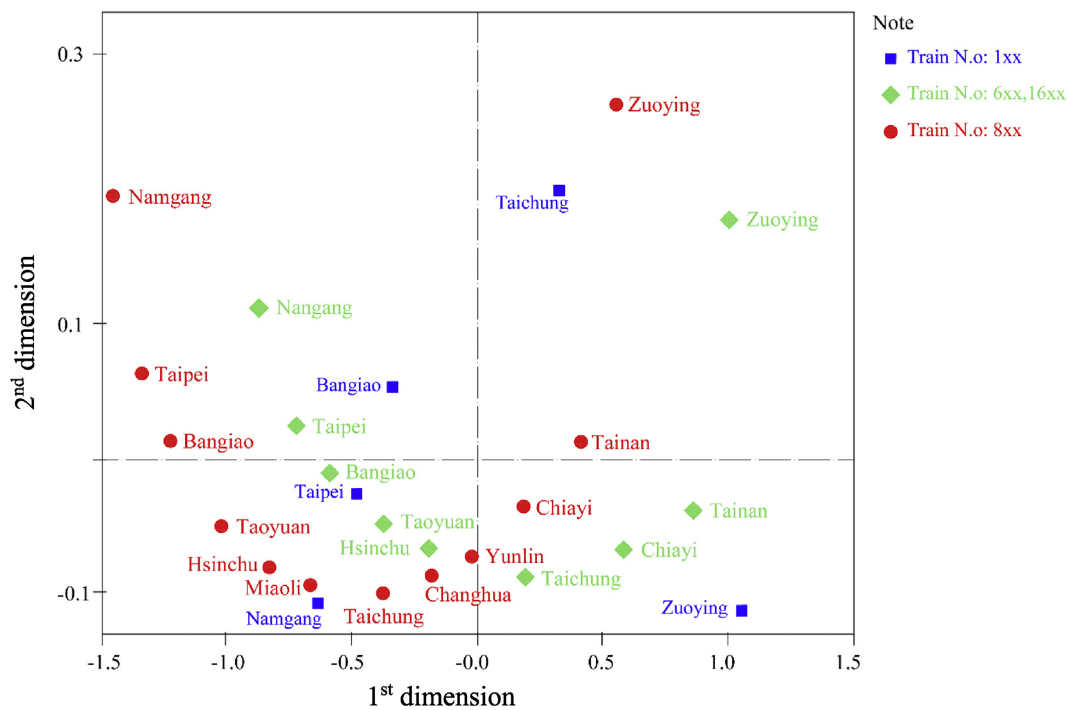

Fig. 4. Common space.

pricing model for HSR tickets does not account for any pricing guidelines, discounts, or subsidies on HSR ticket fares. It does not assume that each passenger has the same time value. Moreover, the model is applicable only to the ticket-pricing of HSR trains in Taiwan. Second, the weight of all service attributes was estimated using a study that was conducted in a foreign country (Tang et al., 2007). Third, T_{before} in the calculation of $Compression_i$ was the travel time for different pairs of departure/destination railway stations that are in the same location as or close to the HSR stations.

4.3.1. Operating costs

In Section 3.3.1, the operating costs of an HSR network fall into four categories ($C_1 - C_4$), which are used in the annual financial reports of the THSR. Accordingly, Eq. (2) is rewritten as Eq. (34):

$$C_{total} = \frac{C}{2 \times 365 \times \sum_{i=1}^{N} L_i} = \frac{\text{Operating costs} + \text{operating expenses} + \text{other operating costs}}{\text{Annual total seat kilometers traveled}} \tag{34}$$

Data collected from the THSR website showed that, in 2016, the operating costs were NT$25,973,173,000, the operating expenses were NT$938,237,000, other costs were NT$8,375,559,000, and the annual total seat kilometers traveled were 16,513,000,000. Thus, C_{total} of the HSR for the year was NT$2.137. Table 6 presents the operating costs of the HSR between different pairs of departure/destination HSR stations.

4.3.2. Passenger-perceived costs

(1) Safety

Like any other transportation service, the HSR is exposed to risks from natural and man-made disasters, and climate change increases its exposure to natural disasters. However, the HSR has so far maintained high safety performance, with no casualties since it began operating in 2007. Thus, the safety credibility (Saf_i) of the HSR equals 1 since the casualty rate is 0.

(2) Comfort

The maximum time that is required to recover from fatigue after an HSR ride (H) was 15 h (Shi et al., 2004). Based on the THSR official website, the average speed of HSR trains in Taiwan is 250 km/h. The minimum recovery time (α_i) was estimated at 59, and the strength coefficient of the recovery time per unit of travel time (β_i) was 0.28. The recovery time after a ride on an all-stop HSR train (g_i^{AB}) between Nangang and Zuoying (distance: 345.19 km) was estimated using Eq. (4) to be 0.37 h.

The gross domestic product of Taiwan in 2016 is NT$ 15,875,635,000,000. The Ministry of Labor estimated that in 2016, the total regional employment number was 11,267,000 people, and the total work hours per person per year in Taiwan was 2034 h. Accordingly, the time value of traveling on the HSR in Taiwan was estimated using Eq. (6) to be NT$ 693/h. The monetary value converted from the time required to recover from fatigue after traveling on an HSR train from Nangang to Zuoying (Com_i) was estimated using Eq. (5) to be NT$ 252.94.

(3) Convenience

HSR tickets can be purchased at ticket booths inside HSR stations, on the Internet and mobile apps, at convenience stores, and through EasyCard cobranded credit cards. The amount of time taken to purchase a ticket (t_b^i) was excluded. The waiting time for each station was retrieved from HSR official website. The passenger time value was afore-estimated (NT$ 693/h). The convenience costs of the HSR between different pairs of departure/destination HSR stations was estimated using Eq. (7), as presented in Table 7.

(4) Punctuality

The official website of THSR has published that an HSR train has a punctuality rate of 99.43% in 2016. From that rate, the average delay time for HSR was calculated to be 0.00433 h, and thus the punctuality of the HSR (Pun_i) was estimated using Eq. (11) to be NT$3.00 to the passenger.

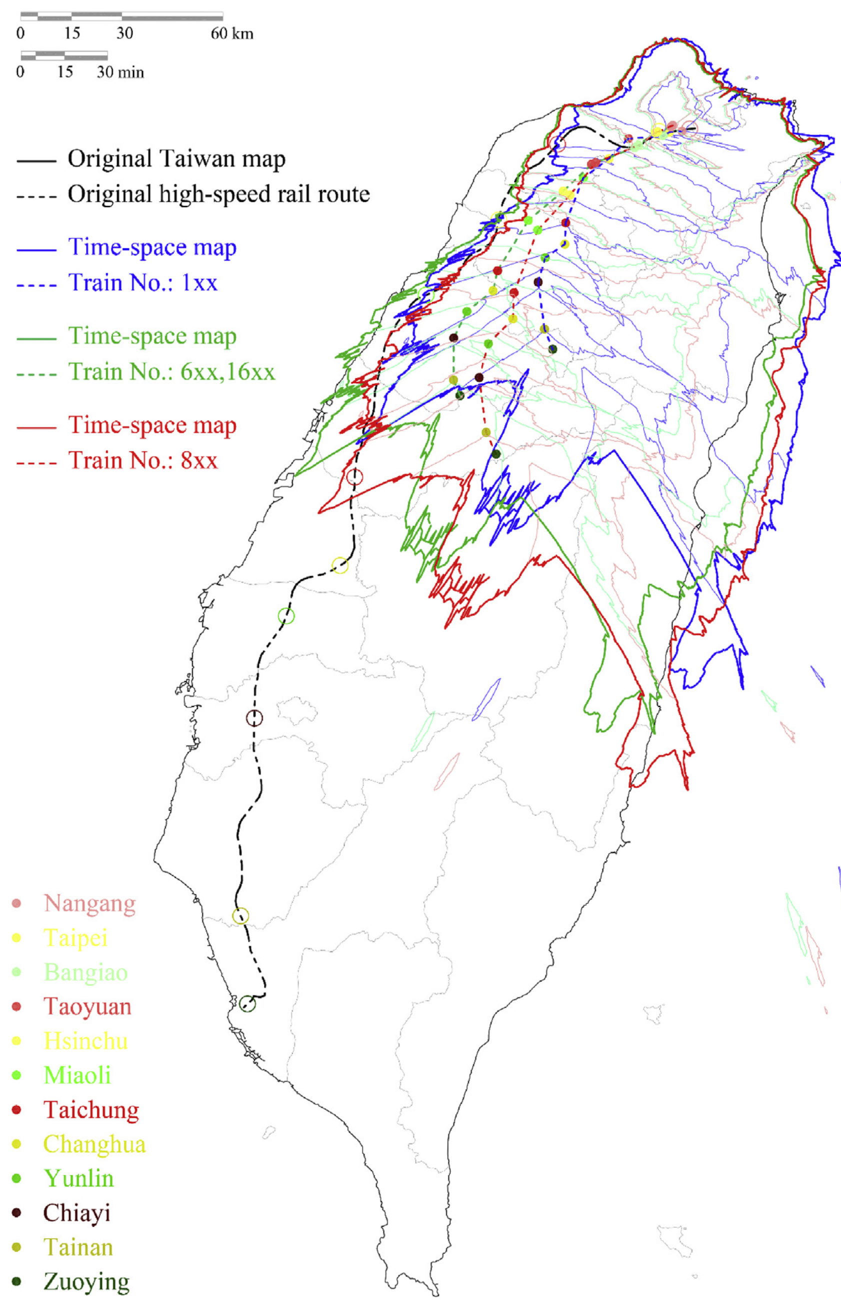

Fig. 5. Time-space maps of Taiwan HSR.

Table 6
Matrix table of operating costs.

	Nangang	Taipei	Banqiao	Taoyuan	Hsinchu	Miaoli	Taichung	Changhua	Yunlin	Chiayi	Tainan
Taipei	12.61										
Banqiao	28.03	15.42									
Taoyuan	90.36	77.74	62.32								
Hsinchu	154.24	141.62	126.20	63.88							
Miaoli	224.09	211.47	196.05	133.73	69.84						
Taichung	354.17	341.55	326.13	263.80	199.92	130.07					
Changhua	414.33	401.71	386.29	323.97	260.08	190.23	60.16				
Yunlin	466.89	454.27	438.85	376.52	312.64	242.79	112.72	52.55			
Chiayi	537.63	525.02	509.59	447.27	383.39	313.54	183.46	123.30	70.74		
Tainan	670.71	658.10	642.68	580.35	516.47	446.62	316.54	256.38	203.82	133.08	
Zuoying	737.66	725.04	709.62	647.30	583.42	513.57	383.49	323.33	270.77	200.02	66.94

Amounts in NT dollars.

Table 7
Matrix table of convenience cost.

	Nangang	Taipei	Banqiao	Taoyuan	Hsinchu	Miaoli	Taichung	Changhua	Yunlin	Chiayi	Tainan
Taipei	68.51										
Banqiao	69.40	68.93									
Taoyuan	85.83	85.36	86.26								
Hsinchu	96.35	95.88	96.77	113.20							
Miaoli	140.46	139.98	140.88	157.31	167.82						
Taichung	72.44	71.97	72.86	89.29	99.81	143.91					
Changhua	207.47	207.00	207.89	224.32	234.84	278.94	210.93				
Yunlin	208.61	208.14	209.03	225.46	235.97	280.08	212.07	347.10			
Chiayi	95.62	95.15	96.04	112.47	111.15	167.09	99.08	234.11	235.24		
Tainan	83.78	83.31	84.21	100.63	111.15	155.26	87.24	222.27	223.41	110.42	
Zuoying	73.71	73.24	74.13	90.56	101.07	145.18	77.17	212.20	213.33	100.34	88.51

Amounts in NT dollars.

Table 8
Matrix table of Compression$_i$.

	Nangang	Taipei	Banqiao	Taoyuan	Hsinchu	Miaoli	Taichung	Changhua	Yunlin	Chiayi	Tainan
Taipei	15.56										
Banqiao	23.34	7.78									
Taoyuan	97.25	81.69	73.91								
Hsinchu	159.49	143.93	136.15	62.24							
Miaoli	225.62	210.06	202.28	128.37	66.13						
Taichung	357.88	342.32	334.54	260.63	198.39	132.26					
Changhua	427.9	412.34	404.56	330.65	268.41	202.28	70.02				
Yunlin	478.47	462.91	455.13	381.22	318.98	252.85	120.59	50.57			
Chiayi	490.14	474.58	466.8	392.89	330.65	264.52	132.26	62.24	11.67		
Tainan	676.86	661.3	653.52	579.61	517.37	451.24	318.98	248.96	198.39	186.72	
Zuoying	653.52	637.96	630.18	556.27	494.03	427.9	295.64	225.62	175.05	163.38	155.6

Amounts in NT dollars.

Table 9
Matrix table of Model$_i$1.

	Nangang	Taipei	Banqiao	Taoyuan	Hsinchu	Miaoli	Taichung	Changhua	Yunlin	Chiayi	Tainan
Taipei	56.09										
Banqiao	59.39	53.44									
Taoyuan	91.50	85.55	82.73								
Hsinchu	117.88	111.92	109.09	85.80							
Miaoli	154.84	148.88	146.04	122.71	102.01						
Taichung	186.67	180.68	177.82	154.42	133.65	120.44					
Changhua	249.45	243.46	240.59	217.15	196.34	183.10	114.85				
Yunlin	269.05	263.06	260.18	236.71	215.87	202.59	134.28	144.37			
Chiayi	244.31	238.31	235.42	211.91	187.83	177.70	109.30	119.35	100.53		
Tainan	311.38	305.36	302.45	278.85	257.87	244.46	175.90	185.87	166.99	131.12	
Zuoying	301.79	295.76	292.84	269.19	248.16	234.70	166.06	175.99	157.07	121.16	112.88

Amounts in NT dollars.

Table 10
Matrix table of Model$_i$2.

	Nangang	Taipei	Banqiao	Taoyuan	Hsinchu	Miaoli	Taichung	Changhua	Yunlin	Chiayi	Tainan
Taipei	78.52										
Banqiao	83.14	74.82									
Taoyuan	128.10	119.77	115.82								
Hsinchu	165.03	156.69	152.72	120.12							
Miaoli	216.78	208.43	204.45	171.79	142.81						
Taichung	261.33	252.96	248.95	216.19	187.10	168.62					
Changhua	349.23	340.84	336.83	304.01	274.88	256.34	160.79				
Yunlin	376.67	368.28	364.25	331.39	302.21	283.63	188.00	202.11			
Chiayi	342.04	333.63	329.59	296.67	262.96	248.77	153.03	167.09	140.74		
Tainan	435.94	427.51	423.43	390.39	361.02	342.24	246.26	260.22	233.78	183.57	
Zuoying	422.51	414.06	409.97	376.86	347.43	328.58	232.48	246.39	219.90	169.63	158.03

Amounts in NT dollars.

Table 11
Matrix table of Pricing Model.

	Nangang	Taipei	Banqiao	Taoyuan	Hsinchu	Miaoli	Taichung	Changhua	Yunlin	Chiayi	Tainan
Taipei	91.13										
Banqiao	111.17	90.24									
Taoyuan	218.46	197.51	178.14								
Hsinchu	319.27	298.31	278.92	184.00							
Miaoli	440.87	419.90	400.50	305.52	212.65						
Taichung	615.50	594.51	575.08	479.99	387.02	298.69					
Changhua	763.56	742.55	723.12	627.98	534.96	446.57	220.95				
Yunlin	843.56	822.55	803.10	707.91	614.85	526.42	300.72	254.66			
Chiayi	879.67	858.65	839.18	743.94	646.35	562.31	336.49	290.39	211.48		
Tainan	1106.65	1085.61	1066.11	970.74	877.49	788.86	562.80	516.60	437.60	316.65	
Zuoying	1160.17	1139.10	1119.59	1024.16	930.85	842.15	615.97	569.72	490.67	369.65	224.97

Amounts in NT dollars.

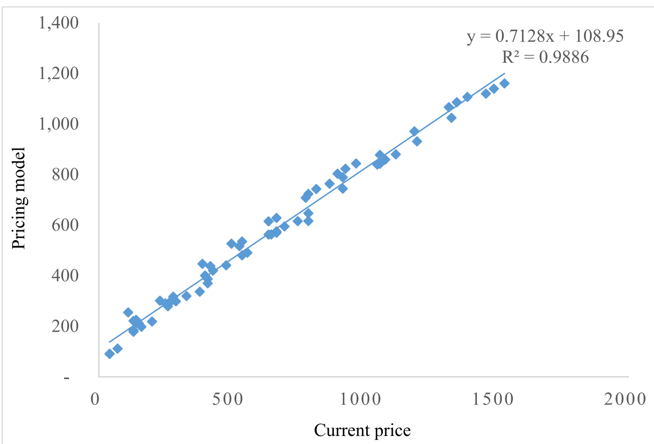

Fig. 6. Linear regression between the current price and proposed model.

(5) Passenger satisfaction

The PSI for the HSR increased from 54.03 in 2007 to 68.50 in 2010 and 78.28 in 2013 (Chou and Yeh, 2013).

4.3.3. Time-space compression costs

The shortest travel time from Taipei to Zuoying by the Tzu Chiang Limited Express is 285 min, whereas that by an HSR train is 105 min. Even an all-stop HSR train, which completes the same trip in as little as 145 min, compares favorably to the Tzu Chiang Limited Express. Equation (12) was used to estimate the rate of time–space compression for the three HSR trains, yielding 16.36 min/year for the express train, 14.09 min/year for the skip-stop train, and 12.73 min/year for the all-stop train. Moreover, the change in travel time from Nangang to Zuoying as a result of the construction of the HSR was estimated to be 168 min. The monetary value of time–space compression owing to the construction of the HSR (Compression_i) was NT$653.52 in 2016. Table 8 presents the monetary value of time–space compression.

4.3.4. Ride fare discussion

The PSI of 78.28 that was obtained from the results of a 2013 survey of HSR customers (Chou and Yeh, 2013), was used herein to represent the PSI of the HSR for 2016, and was 1.4% higher than that in 2010. In Eq. (15), perceived and time costs are combined, and the weights of service attributes denoted by θ_m (m = 1, 2, 3, 4) were respectively set to $\theta_1 = 0.1805$, $\theta_2 = 0.2692$, $\theta_3 = 0.1896$, and $\theta_4 = 0.3607$ (Zhang et al., 2014). Based on Eq. (15), Table 9 shows the perceived and time costs (Model_i1) for different combinations of departure/destination HSR stations.

As mentioned in the literature review, a 1% increase in customer satisfaction corresponds to a 0.6% decrease in price tolerance. This fact is used in Eq. (16), which yields an estimate of Model_i2 of NT$ 422.51. Table 10 displays the estimates of Model_i2 for different combinations of departure/destination HSR stations.

The total number of kilometers that are traveled by an HSR train between Nangang and Zuoying is 345.188 km. The proposed ticket-pricing model was estimated using Eq. (17) to be NT$ 1160.17. Table 11 summarizes the respective ticket-pricing models for different pairs of departure/destination HSR stations.

A linear regression analysis between the fares estimated using the ticket-pricing model and the current HSR ticket fares was carried out to elucidate their relationship. The regression equation (35) was derived from the linear regression analysis. Fig. 6 plots the linear regression relationship fares estimated using the ticket-pricing model and the current HSR ticket fares.

$$\text{Ticket fare estimated using the proposed ticket pricing model} = 0.7128^*(\text{current HSR ticket fare}) + (\text{NT\$ } 109) \tag{35}$$

The regression pattern shows that the proposed ticket fare is higher than the current one for the short-distance traveling and is lower than the current one for the long-distance traveling. According to the time-space compression theory, the analytical comparison herein implies the current pricing policy encourages passengers to ride THSR for longer distance service, whereas implicitly pushes passengers to take regular transportation modes for short-distance trip.

5. Conclusions

This investigation confirms that the rail system has caused noticeable time-space compression across the nation. The time-space maps for three types of HSR train service were examined. This study finds that the time–space compression rates of Taiwan as a result of the HSR are 16.36 min/year for the express train, 14.09 min/year for the skip-stop train, and 12.73 min/year for the all-stop train, respectively.

In particular, a floating ticket-pricing model was developed based on the prior literature. The ticket-pricing model comprises 67% operating costs, 11% passenger-perceived costs and 22% time-space compression costs. The proposed model not only considers the profit margin, but also takes into account the safety, comfort, convenience, punctuality, and satisfaction of passengers. This study also identifies that the passenger satisfaction is the most important factor in determining the perceived cost. Accordingly, THSR can increase revenue and improve operations performance by increasing passenger satisfaction.

An interesting discrepancy between the current HSR price and the time-space compression value of HSR is discovered. The price determined by the proposed pricing model is higher than the actual one for pairs of stations with short distance. According to our best knowledge, the inconsistency is the imposing adjustment by the authority committee though the current HSR price for long-distance trip is higher than its time-space compression value. Nevertheless, HSR remains the best choice of passengers for a long-distance traveling because of its convenience, frequency and rapidity.

The ticket-pricing model can be used to inform the adjustment of ticket fares for Taiwan's HSR. The pricing framework could be useful to form up the rationale of fares for other modes of public transportation or for HSR lines in other countries to the potential passengers. The systematic approach offers the government officials to budget the public transit infrastructure to be planned, constructed, or under operations, by determining a referential basis of HSR riding fares for financial feasibility.

The model that is developed in this study accounted for time value based on the average monthly salary and the average annual number of work hours in Taiwan. However, owing to the substantial wealth inequality in the nation, the model may have overestimated the perceived and time costs. Further studies should conduct comprehensive surveys to evaluate the qualitative value of time-space compression. Another research direction is to define the value of saved traveling time so as to improve the validity of the ticket-pricing model.

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