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Development of a Structural Equation Model for ride comfort of the Korean high-speed railway

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ABSTRACT

This study is aimed at developing a Structural Equation Model for the ride comfort of the high-speed railway launched in South Korea (KTX: The Korea Train eXpress). The Structural Equation Model (SEM) was used to systematically explain passenger ride comfort and quantify the impacts and values of various factors found to be related to the ride comfort of a high-speed train. In order to develop the ride comfort model of the high-speed railway, both the qualitative and quantitative factors were investigated using an on-board passenger questionnaire. The influence of the qualitative factors such as fatigue (physical and visual) and medical symptoms was considered together with various interior design factors such as seat, cabin layout, cabin ambience and tunneling effect. Four hundred and fifty-three subjects participated in an on-board survey. As a result, the proposed SEM model showed statistical significance as well as a high level of model fitness (GFI = 0.928). According to the results, overall ride comfort was significantly affected by the seat-, fatigue- and interior-related variables, as well as customer satisfaction variables. It is expected that the results of this study could be useful for the enhancement of ride comfort in the next generation of the KTX.

Relavance to industry: This study presents a model of ride comfort for high-speed rail. The developed model can be applicable to evaluate overall comfort as well as to quantify the impacts and scores of each qualitative factor on the overall ride comfort of trains or cars.

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1. Introduction

The concept of ride comfort varies depending on time, country, culture and physical condition of passengers. The patterns of train rides have gradually diversified and studies on ride comfort have been progressing in various aspects. However, studies on ride comfort for high-speed trains are relatively rare due to the fact that only four countries, before South Korea, were operating high-speed railways (France: TGV; Spain: AVE; Japan: Sinkansen; and Germany: ICE) with few customer complaints regarding ride quality. The KTX, which operated in South Korea, is the first high-speed train based on the French platform, the TGV. There were some issues raised from passengers who were not familiar with the European style of the cabin interior and the seat design. After a year of the KTX operation, many issues have been raised, all of which can be largely divided into two categories; (1) problems with the rolling stock seat, and (2) problems with the cabin interior (KRRI, 2004). For the rolling stock seat, the major issue was the reduction of an on-time operation ratio due to the frequent occurrence of problems. As for the cabin interior, several issues have been brought up: (1) the negative effect of ride comfort due to the noise generated by many tunnels (specific geological characteristics of the Korean peninsula), (2) the occurrences of motion sickness related to backward seats, (3) the inconveniences related to seats that did not consider the anthropometry of the Korean population, and (4) the inconstant speed (Korail, 2004).

Many studies on ride comfort and seat convenience produced in the past contributed to the improvement of seat design and convenience (Corlett and Bishop, 1976). Branton's (1969) study on ride comfort suggested that ride comfort was related to the deficiency of passengers' experiences or the low quality of seats. Thus, the ride comfort of the seats was evaluated with various methods. These evaluations focused on assessing the degrees of discomfort. Several other studies tried to evaluate positive seat comfort (Zhao and Tang, 1994). Zhang et al. (1996) studied a model for the perception of comfort and discomfort based on the results of Zhao and Tang's study, as well as their own assumption that discomfort was related to the lack of satisfaction from biomechanical factors such as joint angles, muscle contractions and pressure distribution that generates pain, soreness, numbness, and fatigue. On the other hand, comfort was also surveyed to be related to feelings such as relaxation and physical well-being (Metzger, 1994). Peter (2004) conducted a study focused on testing the posture of passengers for

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Table 1
Survey data for the selection of variables.

Survey type	Gender		Age			Seat position		Journey time (min)			
	Male	Female	20–30s	40–50s	~60s	Forward	Backward	30	60	90	120
Pilot survey[a]	73	106	93	58	28	102	77	–	–	–	–
Main survey[b]	234	219	168	182	103	233	220	130	126	124	73

[a] July 18, 2004–July 20, 2004.
[b] September 8, 2004–October 17, 2004.

cabin design. He evaluated the degree of satisfaction for seat posture with qualitative questionnaires. The results were then implemented in seat designs. Cowings et al. (2001) evaluated the degree to which carsickness affected the performance and emotional state of soldiers during C2V (Command and Control Vehicle) operation. Symptoms that were revealed as hindering factors to ride comfort were drowsiness, headache, nausea, upset stomach, and the effect of the surrounding temperature. In a psychological study related to ride comfort, Looze et al. (2003) analyzed that perceptions of comfort and inconvenience were acquired from the following (including existing information): visual, auditory and olfactory stimuli, current mental status, temperature, moisture, pressure, posture, and movement.

Most of the previous studies demonstrated that ride comfort is a complex emotional state involving various factors such as personal characteristics, hardware design factors, driving environment, etc. It is also important to note that the term 'ride comfort' was used synonymously with 'ride satisfaction,' 'seat comfort,' 'comfort,' 'passenger comfort,' and 'ride quality' (CEN, 1996a, b, 1999; ISO 2631-1, 1997; Johan, 2000). In order to minimize confusion with terminology, ride comfort in this study is operationally defined as the state of 'a pain-free seat environment that is free from physical and visual fatigue to provide a substantial degree of comfort' (Yun et al., 2004).

There have been a number of studies regarding comfort, ride comfort, ride quality and ride satisfaction for vehicles and transportation systems. However, very few studies have been conducted on the aspects of specific methodologies to quantitatively evaluate ride comfort. Also, previous studies have had some limitations on analyzing ride comfort, a complex concept that includes passengers' subjective sensibilities (passenger fatigue, body status, ride satisfaction, etc.) as well as regional characteristics of the place where the train is running.

Based on this background, it is necessary to develop a quantitative evaluation method that investigates the causality of diverse factors (form of seats, design of compartment, tunnel effect, etc.) related to high-speed train rides. This study proposed an approach to modeling the complex concept of ride comfort. For data collection, this study used an on-board questionnaire on ride comfort (excluding the technical problems of the rolling stock seat). The pilot study examined factors related to ride comfort and the main survey examined the degree of relationship among the factors based on Structural Equation Model (SEM). Finally, this study proposed a model that consists of the examined factors (form of seats, design of compartment, tunnel effect, etc.).

Table 2
Variable selection: statistical, technical significance.

Sources	Variables	Variable selection criteria		Variable selection
		Statistical significance[a]	Technical significance[b]	
Related studies	Cabin Ambience	○[c]	○	○
	Personal characteristics	X[d]	X	X
	Train tilting	X	X	X
	Tunneling effect	○	○	○
	Human fatigue: Visual	○	X	○
	Human fatigue: Physical	○	X	○
KTX characteristic variables	Seat (window/aisle)	X	X	X
	Seat with table	X	X	X
	Personal symptoms	○	X	○
	Fare satisfaction	○	X	X
	Seat design	○	○	○

[a] Statistical significance: $p < 0.05$ (pilot test results).
[b] Technical significance: factors considering when KTX was induced into localization (Korail, 2004; KRRI, 2004).
[c] Variable acceptance through statistical or technical significance.
[d] Variable rejection through statistical or technical significance.

2. Method

2.1. Experiment design

One hundred and seventy-nine and 453 passengers participated in the pilot survey and the main survey, respectively. Table 1 shows the pilot survey and main survey data.

The ambient factors and seat factors were identified by point of view of the cabin design engineers (Korail Co.) and by the results obtained from related studies (Zhang et al., 1996; Johan, 2000; Cowings et al., 2001; Looze et al., 2003; Peter, 2004). Two characteristic variables were added: (1) the tunneling effect that often appears during the ride due to the specific features of Korean geological conditions, and (2) the symptoms of individuals (Korail, 2004; KRRI, 2004).

To select variables for the final modeling, both statistical significance and technical significance were evaluated. Statistical significance was evaluated using the results from the pilot survey and technical significance was evaluated using the results from a previous survey conducted by the operating authority, Korail Co. Table 2 shows the variable selection criteria. The variables of visual human fatigue, physical human fatigue, and personal symptoms were not included when the KTX was introduced, but in this study, these were selected as final variables because the pilot survey results were significant. Fare satisfaction, however, was not selected as a final variable. It was an uncontrollable factor in this study because the KTX marketing strategies implement discount rates based on variables such as seat direction (forward or backward), day type (weekday or weekend), etc. (Korail, 2004).

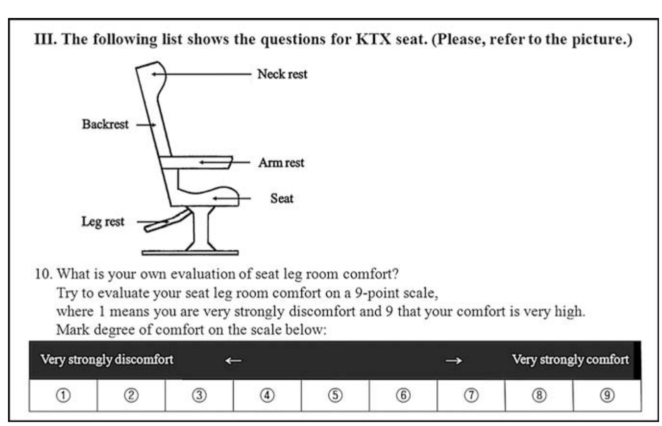

Fig. 1. Example: questionnaires for KTX experiments.

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