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A Study of the Impact of the Use of Real-Time Crowding Information on the Perceived Service Quality of High-Speed Rail by Passengers with Unfixed-Seat Tickets

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Abstract: Unfixed-seat tickets are one of the supplementary forms of tickets used when the transport capacity of high-speed rail is insufficient; however, the needs of passengers with unfixed-seat tickets are often neglected. To understand the influence of unfixed-seat tickets on passengers' perception of the quality of high-speed rail service, including their satisfaction, this study takes the provision of real-time crowding information (RTCI) as the independent variable and the satisfaction of passengers with unfixed-seat tickets with the quality of the high-speed rail service as the dependent variable, and adds social anxiety as a moderating variable, to construct a model. We conducted experiments and gathered data through questionnaires. The results showed that the implementation of RTCI has a significant impact on the satisfaction levels about high-speed railway service quality. In comparison to scenarios without RTCI or with RTCI failure, successful RTCI implementation can significantly enhance user satisfaction. Additionally, the moderating effect of social anxiety is significant. Perceived satisfaction did not significantly differ for individuals with low social anxiety in the absence of RTCI or in cases where RTCI failed; however, for individuals with high social anxiety, perceived satisfaction was significantly lower when RTCI failed compared to the No-RTCI condition. The potential practical implications of these findings are discussed.

Keywords: high-speed rail; real-time crowding information; RTCI; passengers without fixed-seat tickets; service quality

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1. Introduction

High-speed rail (HSR), as a prevalent mode of transportation, plays a pivotal role in both economic development and improving people's livelihood. Since 2008, China has recognized high-speed rail as a significant strategic initiative, extensively constructing high-speed railways and promoting nationwide implementation of online ticketing services. However, due to China's unique cultural and developmental patterns, there is typically an ample supply of seated tickets on ordinary weekdays. Conversely, during peak migration periods such as the Spring Festival holidays, seated tickets are in short supply and passengers are often forced to purchase a limited number of standing or unreserved seat tickets. This results in overcrowding within the carriages, as passengers with unfixed seats stand in public areas, negatively impacting their travel comfort and satisfaction [1–3].

To address the issue of train overcrowding and optimize seat utilization, both "hard" and "soft" approaches are frequently considered [1]. An example of a "hard" approach involves expanding the relevant infrastructure to address the supply–demand mismatch. An example of a "soft" approach is to influence the behavior of passengers by encouraging them to change their time and mode of train travel [4]. The optimal approach is to integrate both the "hard" and "soft" strategies, to address overcrowding effectively and maximize the capacity of the railway system [4]. However, the process of expanding and implementing rolling stock and track capacity entails significant time and financial investments [5]. Therefore, this study primarily focuses on employing soft methodologies. Real-time crowding information (RTCI) is an increasingly viable solution within the realm of soft approaches, as it has the potential to influence passenger choice and behavior by providing RTCI for each carriage of an incoming train through visual displays and loudspeakers [6]. The rationale is that data on historical and current passenger flows in contemporary public transportation systems are collected from diverse sources, including Automated Passenger Counts (APC) and Automated Fare Collection (AFC) systems, load-bearing data, and train occupancy information. These datasets can be processed and transmitted to passengers through RTCI, facilitated by load-data analysis and wireless networks [7].

Previous studies have demonstrated that the implementation of RTCI in public transportation systems, such as subways and trains, not only enhances passengers' efficiency in locating available seats, but also significantly contributes to overall satisfaction levels [6,8–10]. Although numerous studies have confirmed the positive impact of RTCI on passenger satisfaction, a critical concern with existing RTCI systems lies in the reliability of the provided information [10]. Previous researchers have proposed various techniques for estimating passenger counts on trains, such as weight sensors, closed-circuit television, Wi-Fi, and infrared sensors in the doors. However, all these methods are susceptible to distortions that can introduce errors into RTCI systems [11,12]. Drabicki emphasized the risks associated with the accuracy of RTCI which arise from its inherent properties: specifically, the time delay in disseminating crowding information and the influence of passenger reactions induced by information provision on the efficacy of provided RTCI, resulting in disparities between anticipated and actual on-vehicle crowding conditions [10]. Preston hypothesized that participants' pre-existing perceptions regarding the reliability of station information play a crucial role in their decision-making process. Furthermore, if the actual reliability of the information fails to meet these expectations, it is likely to diminish passengers' willingness to modify their behavior [11].

Passenger satisfaction is a topic that has attracted a great deal of interest in academic research as well as in the public and private service sectors, where managers tend to favor customer-centered service satisfaction and continuous performance improvement. In the field of public transportation (PT), several scholars have investigated the factors influencing passengers' transportation satisfaction and how to improve their satisfaction, to attract more passengers. It has been previously suggested that standing in a public area causing crowding inside the compartment can have a serious negative impact on passenger satisfaction [2–4]. Secondly, for unfixed-seat ticket holders who are unable to find a seat to rest for long period, this can also negatively impact ride satisfaction, as Cox concluded that lack of personal space and lack of available seats are common causes of discomfort associated with crowding [5]. This physical proximity to other passengers can exacerbate perceived risks to personal safety, security, and privacy, meaning that passengers may feel stressed, anxious, and fatigued, as well as physically unwell, and these multiple layers of negative feelings can impact the unfixed-seat ticket passengers' satisfaction with the HSR negatively [3,4,12].

RTCI is a promising solution for solving overcrowded carriages and helping passengers without seat tickets to find available seats, which can help HSR improve passenger satisfaction [6,7,9–11]. However, it also brings challenges, such as complexity and uncertainty regarding the HSR service, and these unknown errors may have a negative impact on passenger satisfaction [7]. RTCI can be considered as an e-service provided to passengers, and there have been numerous studies that have concluded that there is a high correlation between high and low quality of service in public transportation and passenger satisfaction, and therefore the quality of service in RTCI also requires further research [13–17].

Service quality is increasingly being recognized as a way for organizations to maintain customer satisfaction, customer patronage, and market share [18–23]. Customer satisfaction with the experience is highly correlated with service quality, as perceived service quality positively affects customer satisfaction [24].

Service encounter failure refers to instances when a service fails to meet the pre-consumption expectations of consumers, resulting in a collapse of the service [25]. Consequently, if the RTCI misjudges congestion information, passengers perceive this as a failure in service provision. Service failure is a prominent research topic in service marketing, and has a negative impact on the relationship between consumers and service providers [26,27]. Moreover, it can be inferred that when a service failure occurs, it significantly affects both the original credibility and overall satisfaction associated with the respective service brand [28]. Previous studies have demonstrated that service reliability is one of the key aspects of passenger satisfaction [24,29,30]. Many scholars have suggested that the unreliability of services in PT negatively affects passenger satisfaction and leads to the abandonment of continued use of the service. According to Martin, when a bus fails to provide its services adequately, passengers opt for alternative transportation options [31]. Soza demonstrated that the reliability of public-transport waiting time and congestion significantly influences users' satisfaction assessment [32]. Regarding the assessment of service quality in Thailand, Jangvechchai found that reliability, assurance, and understanding of the service significantly influenced passenger satisfaction [33]. Therefore, the reliability of RTCI services has a significant impact on passenger satisfaction. Based on these studies, satisfaction with an updated, unreliable service is likely to be lower, compared to satisfaction with the original service.

Therefore, the reliability of RTCI services has a significant impact on passenger satisfaction; successful RTCI services can effectively enhance passenger satisfaction, while failed RTCI services may be counterproductive, and there are relatively few studies in this area.

While numerous existing studies have consistently demonstrated the direct and substantial impact of service failures on user satisfaction, it is important to acknowledge that different demographic groups may exhibit varying levels of satisfaction in response to such failures. In addition, diverse passengers of different genders, ages, incomes, and travel purposes usually have different needs and often have different perceptions of the same service quality [34,35]. By analyzing the heterogeneity of passenger service perceptions, passenger segments can be divided into multiple segments, and the satisfaction- and complaint-formation mechanisms of different passenger segments can be studied, which can help to provide precise recommendations and marketing actions. In a previous study, Zhang demonstrated that consumers exhibit varying degrees of satisfaction in response to service failures by humanoid and non-humanoid robots, with men being more inclined than women to forgive such failures and to revisit the service provider [36]. According to Neira, it has been suggested that the diverse emotions experienced by users have varying impacts on satisfaction when faced with service failures [37]. Therefore, it is evident that varying levels of satisfaction arise, based on a user's distinct conditioning, following a service failure.

HSR is a social scenario in public perception, and, as a public sphere, the carriages are potential social spaces [38,39]. Social anxiety disorder (SAD) is a debilitating psychiatric condition characterized by an intense fear of being evaluated by others and a tendency to avoid situations that involve social evaluation [40–42]. In studies targeting social anxiety, researchers have also incorporated train scenarios as part of their study designs. For instance, Dechant and Reichenberger developed train and waiting-room scenarios within the framework of behavioral testing to assess the efficacy of virtual technology in the psychodiagnosis of social anxiety disorder [43,44].

Previous research has demonstrated that individuals diagnosed with social anxiety disorder exhibit an excessive fear of negative evaluations, which is a prominent symptom of this condition. Moreover, they tend to prefer engaging with robots, and experience reduced levels of tension and stress [45]. Individuals with social anxiety tend to exhibit a preference for interacting with robots rather than humans when anticipating social interactions, in comparison to individuals without social anxiety [46]. In a study by Constantinou, it was established that individuals with high levels of social anxiety incorporate subjective evaluations into their emotional experiences, in contrast to individuals without such conditions. This tendency contributes to an increased apprehension towards engaging in social interactions [47]. In a study by Zalinska, it was found that individuals with high levels of social anxiety tend to prefer self-service and online real-time assistance customer service channels over social media and offline real-time assistance channels [48]. Consequently, it can be inferred that individuals with elevated levels of social anxiety tend to rely heavily on RTCI prompts as a means to circumvent interpersonal interactions with fellow passengers.

However, no research has yet explored whether passenger satisfaction following RTCI failure is influenced by users' personality traits, such as social anxiety; given that high-speed rail travel is a social context, the level of users' social anxiety can impact their interactions with the system and other passengers in the compartment, ultimately affecting user satisfaction with the journey. This study investigates the satisfaction of implementing RTCI in high-speed rail, focusing on a sample of Chinese passengers with varying levels of social anxiety, and explores its relationship with passengers' social anxiety. This study aims to further investigate the potential for optimizing real-time customer information (RTCI) on high-speed rail by incorporating the perspectives and evaluations of passengers with varying levels of social anxiety towards RTCI. The findings provide valuable insights for enhancing service development in high-speed rail, thereby stimulating ridership.

In summary, we used the provision of RTCI as the independent variable, the satisfaction of passengers who had unfixed-seat tickets with the quality of the high-speed rail service as the dependent variable, and the level of passengers' social anxiety as the moderating variable, to construct a model to explore the relationship between RTCI and satisfaction with the quality of high-speed rail service under the moderating effect of social anxiety, as shown in Figure 1.

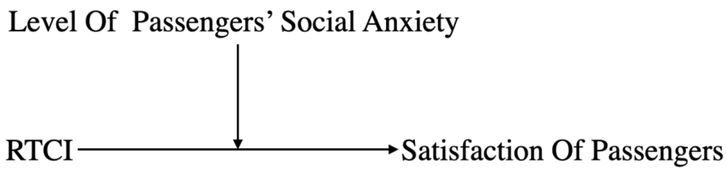


Figure 1. Study model.

2. Experimentation

2.1. Participants

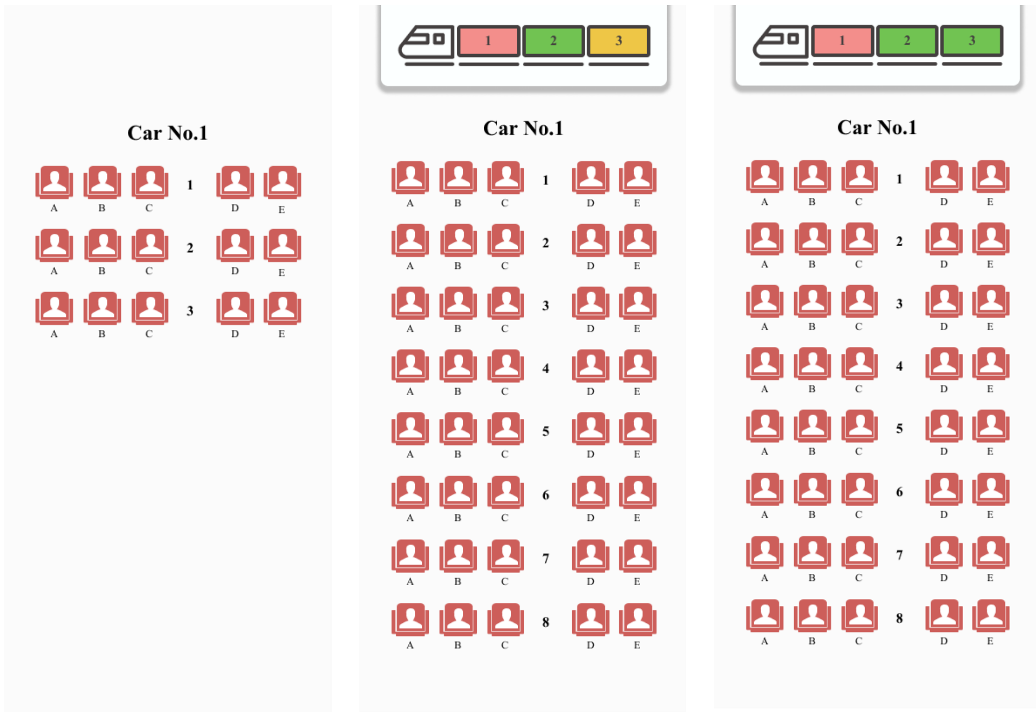
A total of 60 volunteers participated in the present study. The participants were divided into two groups, each consisting of 30 individuals, based on their levels of social anxiety. Social anxiety levels were primarily assessed using the Liebowitz Social Anxiety Scale and the Interaction Anxiousness Scale (IAS) [49].

Participants completed the LSAS to evaluate symptoms of social anxiety. The LSAS encompasses four subscales that capture an individual's apprehension and avoidance in performance-based situations and social interactions. Additionally, a comprehensive score reflecting overall social anxiety was derived by summing the scores from these four subscales. Participants with high social anxiety scores (M = 62.70, SD = 3.87) exhibited a significantly greater likelihood of elevated scores compared to those with low social anxiety (M = 32.17, SD = 6.14), $t(59) = 21.01$, $p < 0.001$.

2.2. Experimental Design and Procedures

In order to evaluate the impact of the real-time crowding information on passenger travel behavior, compartment choice, and other general travel behaviors, we adopted an experimental design similar to that described by Pritchard [50]. Specifically, train-compartment crowding information was visually represented using color-coded boxes: red (indicating full occupancy), yellow (representing higher levels of crowding), and green (suggesting availability of empty seats). Car 1 was set to be full; i.e., there were no seats to choose from. Car 2 was set to have a seat available at the end of the car in row 16; this was seat B, which is a middle seat in a row for three people, and it was marked as an available green-dot position. Car 3 was set to have two available yellow-dot positions. Under the invariant control of determining the seating availability of the above compartments, the experiment took into account three conditions provided by RTCI:

1. The No-RTCI condition replicated the RTCI presentation of the existing high-speed rail system, where visibility is restricted to three rows of seats and it takes ten seconds to switch carriages, as depicted in Figure 2a.
2. The Successful-RTCI condition represents the electronic screen's RTCI presentation mode. Building upon Condition A, the suggestion of cabin congestion degree was incorporated, to accurately reflect the seat's actual usage status, as depicted in Figure 2b.
3. Failed-RTCI condition: based on the Successful-RTCI condition, the congestion status prompt of carriage 3 was changed to green, to demonstrate a scenario of an RTCI prompt error, as shown in Figure 2c.



(**a**) (**b**) (**c**)

Figure 2. Presentation interface under different RTCI conditions. The seat settings in the picture refer to the way seats are presented on existing trains. The top middle position in the picture tells you which car this is. The number represents the row of seats in a carriage, and the letter represents the specific position in the row. (**a**) No RTCI; (**b**) Successful RTCI; (**c**) Failed RTCI.

In this study, a single-factor subject design was employed. The experimental setup consisted of a 3-car train, with each car containing a row of 5 seats, resulting in a total of 18 rows and 90 seats per car. The seating arrangement comprised three seats on one side of the aisle and two seats on the other side. The seat display method adopted the existing high-speed rail approach, utilizing red, yellow, and green indicators to represent the ticket purchase status of each seat. Red indicates that a seat has been purchased and utilized for an extended period, while yellow signifies that it is available for short-term use. Green denotes seats available for long-term usage. In cases where passengers fail to locate their desired position within a carriage, they have the option to switch carriages. The participants utilized a mobile phone provided by the experimenter for conducting the experiment, while a computer was employed to induce interference variables such as situational control environment and mood. Additionally, another mobile phone was used to complete the experimental questionnaire.

Before commencing the experiment, the experimenter provided comprehensive introduction of the experimental background to the participant, and facilitated their informed consent by obtaining their signature on the relevant documentation. Subsequently, they guided the participants through an immersive experience using both visual stimuli presented on a computer screen and accompanying narration. The computer screen depicted "a station platform, where the participant was instructed to envision themselves awaiting the arrival of a high-speed train on a secure and clean platform. In this hypothetical scenario, the participant did not possess a ticket for a seat on the high-speed train and was compelled to purchase a standing ticket instead. They were depicted carrying a backpack weighing approximately 2 kg and pulling a knee-high 22-inch suitcase".

Once the subject had entered the scenario and established their identity, they were provided with an introduction to the experimental background and rules, and subsequently commenced the experiment. Participants sequentially completed the No-RTCI-condition, Successful-RTCI-condition, and Failed-RTCI-condition experiments on mobile phone 1. Subsequently, two questionnaires were administered after the completion of the No-RTCI condition and Successful-RTCI-condition experiments, while a separate questionnaire was filled out upon completion of the Failed-RTCI-condition experiment. Experimenters were interviewed regarding their experience with experiment execution.

2.3. Questionnaire Design

Before commencing the experiment, participants were requested to complete a questionnaire encompassing crucial factors influencing their decision to board a train, including train and platform congestion and entrance and exit locations, as well as availability of luggage racks. The survey also encompassed inquiries regarding passengers' willingness to relocate on the platform to board a less crowded carriage, taking into account occupancy information, as well as their intention to do so while carrying heavy luggage. Additionally, an open-ended question was posed to elicit insights on any supplementary information that could potentially influence the decision to change carriages.

After the completion of the experiment, a questionnaire on user satisfaction needs to be filled out; there are several standardized instruments available to measure satisfaction, the most popular of which is the System Usability Scale (SUS), a widely used standardized questionnaire for assessing perceived usability. This is widely used in assessing user satisfaction, and is favored by experts in human–computer interaction [51–54]. Lewis demonstrated that the SUS exhibits exceptional reliability and validity when compared to other measures of perceived and objective usability, thus affirming its efficacy in assessing usability and user satisfaction [51]. Additionally, Borsci confirmed the suitability of SUS as a rapid tool for evaluating user satisfaction [55].

This scale was chosen for several factors: firstly, its ideal psychometric properties with high reliability and proven validity, and secondly, its relatively short length of 10 items and its low cost and free use [56,57]. In the experiment, participants need to fill out three questionnaires, according to three experimental conditions. Therefore, using a simple scale like SUS as part of the user-experience evaluation prototype can reasonably reduce the evaluation cost and reduce the time and energy for users to fill out questionnaires. Compared with other more complex scales, SUS is easier to understand and use. RTCI technology is a newer technology, and a scale that is easy for participants to understand is more suitable for this experiment.

3. Results

As shown in Table 1, we conducted an analysis of the distribution of participants across demographic variables, with a more comprehensive examination of age, average monthly income, educational level, gender, frequency of traveling on HSR, and length of travel.

Table 1. Distribution of participants on demographic variables.

Eigenvalue	Options	Percent
Age	18–25	51.66%
	26–35	35.00%
	36–45	10.00%
	46–55	3.34%
Average monthly income	Less than CNY 5000	51.31%
	CNY 5000–10,000	28.95%
	More than CNY 10,000	19.74%
Educational level	Middle school	14.48%
	University degree	42.10%
	Postgraduate degree	31.58%
	Doctoral degree and above	11.84%
Gender	Female	63.16%
	Male	36.84%
Frequency of travelling on high-speed rail	1–4 times per month	14.47%
	1–4 times per half year	42.11%
	1–4 times a year	31.58%
	1 time in several years	11.84%
Length of time travelling on high-speed rail	Less than 1 h	23.68%
	1–3 h	43.42%
	3–6 h	27.64%
	More than 6 h	5.26%
Number of past purchases of unfixed-seat tickets	Never before	53.96%
	Infrequent	34.20%
	Frequently	6.58%
	Non-recurrent	5.26%

We calculated the mean and standard deviation of user satisfaction for the different experimental conditions; see Table 2.

Table 2. Mean and standard deviation under different experimental conditions.

	RTCI		
	None	**Success**	**Failure**
Social anxiety (low)	72.75 ± 14.60	86.83 ± 9.56	71.25 ± 13.55
Social anxiety (high)	77.50 ± 12.37	88.67 ± 8.74	67.08 ± 13.23

The repeated-measures ANOVA of 2 (social anxiety: high/low) × 3 (RTCI status: none/success/failure) showed that the main effect of RTCI status was significant: $F(2, 116) = 88.73$, $p < 0.001$. The Successful-RTCI condition significantly improved user satisfaction compared to the No-RTCI and Failed-RTCI conditions, $p < 0.001$, and the user satisfaction under the No-RTCI condition was higher than that under the Failed-TTCI condition, $p < 0.001$. The main effect of social anxiety was not significant: $F(1, 58) = 0.09$, $p = 0.763$. The interaction between RTC and social anxiety was significant: $F(2, 116) = 5.09$, $p = 0.008$, see Figure 3. A simple effects test found that for individuals with low social anxiety there was no significant difference in perceived availability in the No-RTCI (72.75 ± 14.60) or Failed-RTCI conditions: (71.25 ± 13.55), $F(1, 29) = 0.85$, $p = 0.363$; for individuals with high social anxiety, the perceived availability under RTCI failure (67.08 ± 13.23) was significantly lower than that without RTCI: (77.50 ± 12.37), $F(1, 29) = 28.28$, $p < 0.001$. In addition, for the Successful-RTCI condition, there was no difference between the individuals with low or high social anxiety. This indicated that the level of social anxiety modulated the customer experience of the effectiveness of RTCI use.

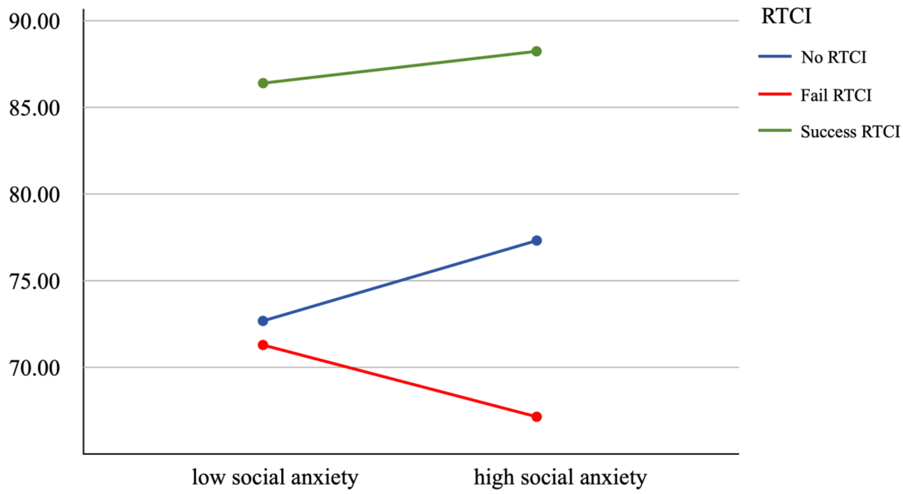


Figure 3. Interaction effects.

4. Discussion

In this study, we constructed a moderated-effects model with social anxiety as a moderating variable to investigate the relationship between the application of RTCI and the satisfaction of high-speed rail passengers with unfixed-seat tickets, and obtained some meaningful results.

The experimental results were consistent with our expectations, and the current study revealed a significant and positive impact of the RTCI cue on service ratings and passenger satisfaction for those holding unfixed-seat tickets for high-speed rail travel. This finding aligns with previous research on RTCI [6,8–10]. Both groups of people with high and low social anxiety in the experiment were more satisfied than those in the No-RTCI-condition experiment when faced with a Successful-RTCI-condition experiment; therefore, it is judged that RTCI is not only applicable to transport such as bus and metro, but also to high-speed rail, and therefore the inclusion of relevant e-services to help passengers on high-speed rail will increase passenger satisfaction. In this era of competitive globalization, providing continuous improvements in service quality and facilities is the only way to ensure passenger loyalty [57].

However, when subjects were confronted with the Failed-RTCI-condition experiment (in which there was a carriage-congestion-message prompt, but the prompt was incorrect), subjects in the low- and high-social-anxiety groups showed very significant differences, starting with a decrease in the scores of both groups of respondents, which can be explained by the fact that facing a service failure can be a worse experience than when the service is successful [25]. This finding aligns with our hypothesis that RTCI satisfaction diminishes in the event of service failures, as reliability, assurance, and comprehension play pivotal roles in shaping passenger contentment with mass-transit-systems' service quality [33,58].

However, the two groups exhibited differential patterns of change: participants in the low-social-anxiety group demonstrated a decrease in scores but still maintained higher scores, compared to the No-RTCI condition. Conversely, individuals in the high-social-anxiety group displayed lower satisfaction scores under the Failed-RTCI condition, as opposed to the No-RTCI-condition experiment. We conducted a comprehensive analysis of the impact of RTCI-prompted seat selection in comparison to traditional seat selection. The majority of the existing literature suggests that passengers' inclination to choose a seat and their satisfaction with the service are significantly enhanced through the utilization of RTCI. A prevailing notion is that the integration of novel and advanced technologies should enhance customers' evaluations of service quality, improve efficiency, and consequently lead to higher levels of satisfaction [6,8–10]. Contrary to commonly held beliefs, our findings demonstrate that RTCI-assisted seat selection does not consistently outperform traditional seat selection. On the contrary, RTCI inaccurately predicts crowding in scenarios where there are excessive passengers present in the carriage [11,13]. In such instances of RTCI service failure, passenger satisfaction is generally diminished [58]. Our study reveals that individuals with varying levels of social anxiety exhibit distinct responses. Respondents with high social anxiety experienced equal or even lower satisfaction in the Failed-RTCI condition compared to the No-RTCI condition. Conversely, respondents with low social anxiety did not experience decreased satisfaction in the Failed-RTCI condition compared to the No-RTCI condition. The specific reasons for this disparity will be further elucidated in subsequent sections.

When faced with a service failure, RTCI was perceived by passengers with high social anxiety as being comparable to or even inferior to traditional seat selection, in terms of trustworthiness and service satisfaction. This situation can be attributed to the fact that individuals with high social anxiety experience heightened apprehension when navigating through physical spaces. Furthermore, according to the current *Diagnostic and Statistical Manual of Mental Disorders: DSM-V. 5th* (*DSM-5*) criteria, high social anxiety is characterized by a persistent fear of social situations and performance occasions where unfamiliar individuals are present or there is a risk of scrutiny from others [59]. Previous research has also indicated that socially anxious individuals exhibit a preference for self-service and online real-time assistance customer-service channels over social media and offline real-time assistance channels [46,48]. In other words, individuals with high levels of social anxiety perceive social interactions as threatening, and consequently avoid them [48]. However, since high-speed rail is a public setting that is commonly used by the general population, the extent of users' social anxiety influences their engagement with the system and fellow passengers, thereby impacting user satisfaction during their journey. From the perspective of passengers with high social anxiety, they endure the discomfort of social interactions while traversing through the compartment in search of their "promised" seat in the RTCI. However, due to a significant disparity between their psychological expectations and actual outcomes, coupled with a perceived lack of commensurate reward for their behavioral efforts, their satisfaction level diminishes below that of individuals who opt for seats within the traditional seat-selection system. It is noteworthy that if passengers with high social anxiety perceive a discrepancy between the reliability of the information and their expectations, their willingness to modify their behavior diminishes [11]. This poses a significant obstacle to the implementation of RTCI on high-speed rail systems, and impedes efforts to enhance HSR user satisfaction.

The satisfaction scores of individuals with low social anxiety in the face of failure were generally comparable between the RTCI-condition experiment and the No-RTCI condition. Based on these findings, it is anticipated that individuals with lower levels of social anxiety will exhibit minimal cognitive burden during social interactions and will demonstrate a greater propensity for interpersonal communication, thereby reducing their reliance on system services without significantly compromising their satisfaction.

However, this finding does not imply that RTCI lacks utility or potential as an effective tool for assisting seat selection in the high-speed rail environment. Additionally, we observed that the provision of RTCI enhanced the inclination of passengers with higher levels of social anxiety to choose a seat, consequently leading to heightened perception and improved experience regarding HSR service quality. In comparison to traditional seat selection, the RTCI system can effectively encourage passengers with unassigned seat tickets to actively search for available seats, thereby enhancing their perception of the quality of high-speed rail service and increasing overall user satisfaction. On the contrary, individuals with higher levels of social anxiety and who are unfixed-seat-ticket passengers tend to exhibit resentment towards the implementation of RTCI services, resulting in reduced trust and perception of the overall experience. Consequently, they may even prefer to adhere to traditional seat-selection methods as a means of conserving cognitive effort.

This study is helpful to the related field, firstly by presenting a different perspective on the development of RTCI technology itself. In the relevant literature in the past, most of the literature focuses on the benefits of RTCI's intervention in PT, with little mention of the technical limitations of RTCI itself. Peftitsi examines the possibilities and benefits of RTCI's application to subways, and concludes by suggesting that the crowding information provided by RTCI to commuters is based on predictions; these can be incorrect, due to the uncertainty and variability of supply and demand [60]. This study goes on to analyze again the impact of RTCI intervention in PT from the perspective of RTCI's unavoidable failures, adding a certain perspective and direction of thinking about RTCI research.

Secondly, we have included in our study an analysis of the requirements of public transportation for different population types. For HSR and other public transportation operators, this study provides insights on how to improve services and how to segment the population to provide targeted services to improve overall passenger satisfaction. Kim researched the possibility of applying RTCI to buses, looking at the type of information people need more at different times of the day, and summarizing it with respect to what people in different occupations are concerned about [61]. In this study, it is proposed that passengers with high social anxiety require higher reliability from RTCI technology, which significantly improves satisfaction in successful RTCI conditions, but significantly decreases it in failed conditions. This finding is consistent with the results of other studies of socially anxious populations; Pozharliev found that anxious attachment increased satisfaction with a service robot [62].

Finally, although this study is based on high-speed rail for the research analysis of the application of RTCI, the research summary of RTCI in this study is still applicable in the practical application to other public transportation. Many existing metros and buses have been installed with RTCI prompts, such as Zhang's study on the impact of RTCI for the Stockholm metro pilot [6]. The results of this study can still help other public transportation to update RTCI services, to improve passenger satisfaction.

In this study, we used the provision of RTCI as the independent variable, the satisfaction of passengers who had unfixed-seat tickets with the quality of the high-speed rail service as the dependent variable, and the level of passengers' social anxiety as the moderating variable, to construct a model to explore the relationship between RTCI and satisfaction with the quality of high-speed rail service under the moderating effect of social anxiety. The results of the study are summarized as follows: firstly, the expected development and application results of RTCI technology in high-speed rail are affirmed, as the conclusions reached by other researchers are consistent with the fact that RTCI implementation in high-speed rail can help passengers with unfixed-seat tickets to avoid crowded compartments and find available seats, and significantly improve passenger satisfaction; this is a positive result for both operators and passengers, but, in the face of the failure of the RTCI, passengers with different social anxieties will react very differently. The innovation of this study is its focus on situations where RTCI experiences service failures and the introduction of different groups of passengers to explore user-satisfaction outcomes following RTCI failures.

In addition to this, there are some limitations in this study, such as the fact that the sample size of the experiment was relatively small. However, this study still found some useful patterns, and it is hoped that it can be improved on in the future.

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Informed Consent Statement: Written informed consent has been obtained from the participants, to publish this paper.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

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