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Optimised Human-Computer Interaction for Intelligent Business Seats in High-Speed Trains

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ABSTRACT

The purpose of this paper is to explore the enhancement of the level of high-speed train business cockpit intelligence and intelligent functions of the user human-computer interaction satisfaction, on the basis of existing research, the use of questionnaire method and interview method on the business seat of the target population demand research analysis summary, and further use of the hierarchical analysis method to construct the cockpit intelligent functions applicable to different business travel scenarios of the comfort evaluation model, and then on the relevant intelligent functions for the assignment of the weight of the calculation, so as to obtain the priority ranking of the relevant intelligent functions to provide the experimental basis for the subsequent business seat intelligent cockpit research design.

Keywords: User experience research, Business seat cockpit, Comfort evaluation system

INTRODUCTION

In the document "Design Code for High-Speed Railway", the State Railway Administration of China (SARA) defines high-speed railway as a passenger dedicated railway using standard gauge and running at a speed of 250km to 350km per hour. As the level of China's socio-economic development and the quality of life of the residents continue to improve, the public has put forward higher requirements for the optimisation of the service quality of high-speed railways as an important intercity transport carrier, especially in terms of meeting the diversified travel needs of the passengers, which has shown significant demands. Among them, business seats, as a high-end product of railway passenger service, aim to provide a more comfortable and private travelling experience to meet the needs of passengers pursuing high-quality travel services. Preference heterogeneity plays a critical role in shaping high-speed rail passengers' choice behavior (Chen et al., 2024).

As a kind of differentiated service, business seat attracts passengers who pay attention to travelling experience, but nowadays there are only some differences between business seat and first/second class seat in terms of crew service and seat comfort (Jou, Chien & Wu, 2011).The design and service optimisation of business seats play an important role in improving passengers' satisfaction and selection tendency. With the advancement of

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high-speed train technology and the improvement of the intelligence level of contemporary technology, business seats should also integrate the emerging technology, keep up with the technological development of the times, improve the level of intelligence, and provide personalised services, thus improving the core competitiveness of business seats.

Research Target

The purpose of this paper is to explore the enhancement of the level of high-speed train business cockpit intelligence as well as the user human-computer interaction satisfaction of intelligent functions, with reference to the development status of automotive intelligent cockpit, and the collection of existing cockpit intelligent functions.

This study firstly collates and summarises the current development status of business seat cockpits at home and abroad, as well as the R&D direction of automotive intelligent cockpits in adjacent fields and the advantages and disadvantages of existing designs, and points out the limitations of the existing intelligent functions in the context of high-speed trains. On the basis of the existing research, the questionnaire method and interview method are used to analyse the demand of the target group of business seats, and the hierarchical analysis method is used to construct a comfort evaluation model of the intelligent functions of the cockpit applicable to different business travel scenarios, and then the weights of the relevant intelligent functions are assigned to calculate the weights, so as to get the priority ranking of the relevant intelligent functions, and to provide the basis for the experimental design of subsequent research and development of the intelligent cockpits in the business seats.

Research Methodology

Interview method refers to a research method in which the researcher collects information in the form of oral questions and answers through face-to-face conversations with the research subjects. The researcher interacts with the interviewees according to the research purpose and the preset question framework, guiding the interviewees to express their opinions, attitudes, experiences, behaviours, and other information on the relevant topics or phenomena, so as to gain an in-depth understanding of the inner thoughts of the research subjects and the reasons behind their behaviours.

The researchers selected a total of 15 people, aged between 23 and 60 (10 men and 5 women), all of whom had multiple high-speed train business class travelling experiences, with the aim of exploring passengers' perceptions of various aspects of the existing business class feature design and their potential need for future business class intelligence, and to derive a preliminary collection of business class intelligence features as shown in the figure below.

Table 1: Business cockpit intelligent function collection.

Functional Properties	Comfortableness	Convenience	Safety	Personalised	Entertainment
	Intelligent temperature Control	Voice assistant	Fatigue monitoring	Seat memory	Entertainment system
	Seat Adjustment	Wireless charging	Privacy mode	APP linkage	Audiovisual system
	Lighting Adjustment	Sleep mode	One-button alarm	Volume control	Film mode
	Seat ventilation	Getting on the bus	Burst detection	Operating mode	Game mode
	Seat Heating	Arrival announcement	Luggage position	Preference	Screen sharing

A questionnaire is an empirical research method that systematically obtains information about the attitudes, behaviours, opinions or backgrounds of research subjects through a standardised and structured data collection tool.

Interviews were conducted with users, and the questionnaire included the collection of demand for travelling in business seats, and the summary of scenario analysis of travelling by high-speed rail. According to the questionnaire, the smart features that users need the most when travelling in the business seat include wireless charging, entertainment, temperature and light adaption, and adjustable privacy space. The questionnaire is shown in the figure below. Combined with the function ensemble derived from the previous interview method, the resulting intelligent function ensemble of the business cockpit is preliminarily filtered and sorted by function priority.

Evaluation Modelling

Comprehensive evaluation model of business seat cockpit comfort is established by combining the research data derived from three research methods: interview method and questionnaire method. The sitting comfort prediction model developed by Bian et al. (2022) (89.5% accuracy) significantly improves the scenario adaptability of seat adaptive adjustment algorithms and provides a cross-modal data validation framework for quantifying smart function weights in business-class cabins through the Analytic Hierarchy Process (AHP) in this study. The interview method provides feedback on users' expectations of the cockpit functions from the perspective of the intelligent functions of the cockpit and classifies them according to the different functional attributes. The questionnaire method explores the user's experience in business seat travelling from different angles, and argues and screens the intelligent cockpit collection derived from the interview method.

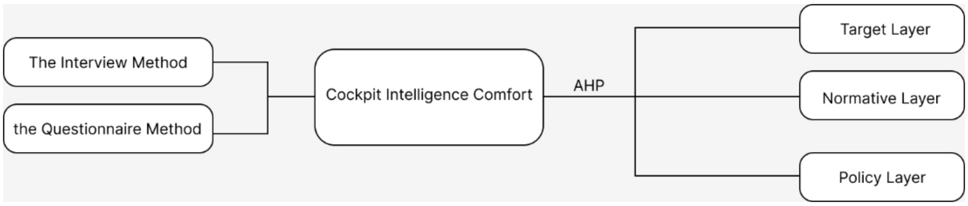

Figure 1: Guideline layer two-by-two comparison matrix.

ESTABLISHMENT OF BUSINESS INTELLIGENT COCKPIT COMFORT EVALUATION

Indicator System

The Analytic Hierarchy Process (AHP) is a classic multi-criteria decision-making tool that helps decision-makers balance complex factors by quantifying subjective judgments (Podvezko, 2009). Using the hierarchical analysis method, the user research smart cockpit functions obtained in the previous section were classified as: comfort, convenience, safety, personalisation, and entertainment. According to the functional classification, the objectives are decomposed into the objective layer, criterion layer, and programme layer. The target layer is the weighting analysis of the intelligent functions of the business seat; the criterion layer is the five functional categories; and the programme layer is the specific functions (e.g., intelligent temperature control, seat memory, etc.).

Constructing a Judgement Matrix

Based on the data derived from the 1–9 scale method, a two-by-two comparison matrix for the guideline layer was constructed as follows:

Table 2: Guideline layer two-by-two comparison matrix.

Normative Layer	Comfortableness	Convenience	Safety	Personalised	Entertainment
Comfortableness	1	5	4	7	8
Convenience	1/5	1	1/2	3	4
Safety	1/4	2	1	4	5
Personalised	1/7	1/3	1/4	1	2
Entertainment	1/8	1/4	1/5	1/2	1

Consistency Indicator (CI) and Consistency Ratio (CR) were calculated, requiring CR < 0.1.

The formula:

CR=CI/RI.

CI=λmax-n/n-1

CI ----- Consistency Indicators

CR----- Consistency ratio

RI ----- Stochastic consistency index, n is the matrix order.

Calculation of Guideline Layer Weights

Weights were calculated using the eigenvector method and passed the consistency test (CR < 0.1).

Table 3: Hierarchical analysis result.

Term	Eigenvector	Weighting	Maximum Eigenvalue	CI Value
Comfortableness	2.689	53.771 per cent	5.174	0.043
Convenience	0.711	14.210 per cent		
Safety	1.055	21.093 per cent		
Personalised	0.329	6.571 per cent		
Entertainment	0.218	4.355 per cent		

Consistency Indicator Testing

In this study, a 5th order judgement matrix was constructed, corresponding to the above table can be queried to obtain the random consistency RI value of 1.120, RI value for the following consistency test calculation use.

Table 4: Summary of consistency test results.

Maximum Characteristic Root	CI Value	RI Value	CR Value	Consistency Test Results
5.174	0.043	1.120	0.039	pass (a bill or inspection etc)

Normally, the smaller the CR value is, the better the consistency of the judgement matrix is, if the CR value is less than 0.1, the judgement matrix satisfies the consistency test; if the CR value is greater than 0.1, it means that there is no consistency, and it should be adjusted appropriately after the judgement matrix is analysed again. This time, the CI value is 0.043 for the 5th order judgement matrix, and the RI value is 1.120, so the CR value is 0.039<0.1, which means that the judgement matrix satisfies the consistency test, and the weights obtained from the calculation are consistent.

Calculation of Programme Layer Weights

Repeat steps for two-by-two comparisons of programme layer functions under each criterion layer. Weights were calculated using the eigenvector method and passed the consistency test ($CR < 0.1$)

Global Weighting

Global weight = criterion level weight × programme level weight Global weight = criterion level weight × programme level weight

Based on the Analytical Hierarchy Process (AHP) model, combining the guideline level weights with the programme level weights, the following results were obtained by global weighting:

Table 5: Summary of consistency test results.

Rankings	Functionality	Normative Layer	Guideline Layer Weights	Programme Level Weights	Global Weight
1	Intelligent temperature control	Comfortableness	53.77 per cent	52.1%	28.02 per cent
2	Health monitoring	Safety	21.09 per cent	54.2 per cent	11.42 per cent
3	Seat Adjustment	Comfortableness	53.77 per cent	21.6 per cent	11.62 per cent
4	Voice assistant	Convenience	14.21 per cent	44.8 per cent	6.37 per cent
5	Privacy Mode	Safety	21.09 per cent	23.1%	4.87 per cent
6	Wireless charging	Convenience	14.21 per cent	27.3 per cent	3.88 per cent
7	Lighting Adjustment	Comfortableness	53.77 per cent	11.7 per cent	6.29 per cent
8	Seat memory	Personalised	6.57 per cent	48.3 per cent	3.17 per cent
9	One-button alarm	Safety	21.09 per cent	10.8 per cent	2.28 per cent
10	APP Linkage	Personalised	6.57 per cent	25.6 per cent	1.68 per cent

Data Validation and Sensitivity Analysis

Consistency test: all judgement matrices with CR values < 0.1 pass the test.

User feedback: actual satisfaction with the high-weighted features was consistent with the weighting ordering as tested by 10 users (Pearson correlation coefficient $r = 0.82$, $r= 0.82$, $p<0.05$, $p< 0.05$).

CONCLUSION

This study aims to provide a scientific basis for the design optimization of high-speed rail business-class cabins through priority analysis of their intelligent functions. The main conclusions are summarized as follows:

In the priority analysis of intelligent functions for business-class cabins, the comfort dimension holds the highest weight, significantly surpassing other functional categories. This result fully demonstrates users' strong reliance on dynamic physical environment adjustment capabilities during travel.

However, during the optimization process, lightweight interaction design should be explored to avoid user experience degradation caused by feature redundancy. A/B testing reduces experimentation costs and supports data-driven refinement of interface variables. Studies show its adoption correlates with significant efficiency gains in iterative design processes (Koning, Hasan & Chatterji, 2022), offering a scalable framework for adaptive human-machine interaction optimization. User acceptance can be validated through A/B testing to ensure rational resource allocation.

The prioritized intelligent functions and collected core user data can guide subsequent optimization designs for business-class cabins. This approach will enhance satisfaction among target users and strengthen the core competitiveness of high-speed rail business-class services.

Theoretical Contribution: Quantify the priority of intelligent functions in high-speed trains through AHP model, and provide methodological support for the mapping of "user requirements-engineering design". It reveals the correlation mechanism between intelligent functions and user experience, which complements the research at the intersection of traffic engineering and human factors engineering.

Practical value: Guide the allocation of R&D resources to avoid cost wastage due to over-design. Provide priority reference for train manufacturers to optimise cockpit design, and reduce R&D trial and error costs. The results of the study provide theoretical support systematisation for future intelligent cockpit optimisation, and have important academic value and application prospects.

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